Final Feasibility Study for Remedial Action at Agra, Kansas
Final Feasibility Study for Remedial Action at Agra, Kansas

Environmental Research Division
Argonne National Laboratory

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<td>AMSL</td>
<td>above mean sea level</td>
</tr>
<tr>
<td>AWWA</td>
<td>American Water Works Association</td>
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<tr>
<td>BGL</td>
<td>below ground level</td>
</tr>
<tr>
<td>CCC</td>
<td>Commodity Credit Corporation</td>
</tr>
<tr>
<td>CERCLA</td>
<td>Comprehensive Environmental Response, Compensation, and Liability Act</td>
</tr>
<tr>
<td>CFR</td>
<td>Code of Federal Regulations</td>
</tr>
<tr>
<td>d</td>
<td>day</td>
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<tr>
<td>DHHS</td>
<td>U.S. Department of Health and Human Services</td>
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<td>DOE</td>
<td>U.S. Department of Energy</td>
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<tr>
<td>ECPT</td>
<td>electronic cone penetrometer</td>
</tr>
<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
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<td>ESC</td>
<td>Expedited Site Characterization</td>
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<tr>
<td>ft</td>
<td>foot (feet)</td>
</tr>
<tr>
<td>gpm</td>
<td>gallons per minute</td>
</tr>
<tr>
<td>in.</td>
<td>inch</td>
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<td>IRIS</td>
<td>Integrated Risk Information System</td>
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<tr>
<td>h</td>
<td>hour</td>
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<tr>
<td>K</td>
<td>hydraulic conductivity ($K_h$, horizontal; $K_v$, vertical)</td>
</tr>
<tr>
<td>µg/L</td>
<td>micrograms per liter</td>
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<tr>
<td>MCL</td>
<td>maximum contaminant level</td>
</tr>
<tr>
<td>mi</td>
<td>mile</td>
</tr>
<tr>
<td>min</td>
<td>minute</td>
</tr>
<tr>
<td>PVC</td>
<td>polyvinyl chloride</td>
</tr>
<tr>
<td>S</td>
<td>storativity</td>
</tr>
<tr>
<td>S_y</td>
<td>specific yield</td>
</tr>
<tr>
<td>T</td>
<td>transmissivity</td>
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<tr>
<td>USDA</td>
<td>U.S. Department of Agriculture</td>
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<td>USGS</td>
<td>U.S. Geological Survey</td>
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<tr>
<td>VOC</td>
<td>volatile organic compound</td>
</tr>
<tr>
<td>yr</td>
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Final Feasibility Study for Remedial Action at Agra, Kansas

1 Introduction

The former grain storage facility of the Commodity Credit Corporation (CCC) of the U.S. Department of Agriculture (USDA) at Agra, Kansas, has been identified as a source of carbon tetrachloride contamination in local groundwater. The CCC/USDA has entered into an interagency agreement with the U.S. Department of Energy (DOE) under which Argonne National Laboratory provides technical assistance to the CCC/USDA for site characterization and remedial feasibility investigations at former CCC/USDA facilities in Kansas and Nebraska. These investigations are carried out by using the Expedited Site Characterization (ESC) methodology developed by Argonne.

Field investigations for the initial portions of the ESC program at Agra (equivalent to a remedial investigation) were conducted during June, August-September, and November of 1995. The results of these studies (Argonne 1995a, 1996) demonstrated the presence of a single, unconfined aquifer system developed within a complex suite of unconsolidated, interbedded sands and silts. The vertical and lateral distribution of the aquifer lithologies is strongly controlled by the underlying, relatively impermeable bedrock topography. A groundwater carbon tetrachloride plume was identified within the aquifer system, extending approximately 2,100 ft southeastward from the former CCC/USDA grain storage site. The plume terminates near two former municipal water supply wells, one of which remains in use for seasonal irrigation of the town’s high school football field. Surface and subsurface soil investigations revealed no residual contamination by volatile organic compounds (VOCs) in soils at the former CCC/USDA facility. Possible residual contamination at the site of a commercial building formerly located southwest of the CCC/USDA facility and believed to have been used for storage of carbon tetrachloride was postulated on the basis of the observed presence of carbon tetrachloride in groundwater beneath the building site.

This report documents feasibility analyses conducted under the ESC program to evaluate the potential need for remediation of the aquifer system at Agra under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Section 2 summarizes field investigations carried out for the feasibility study. Section 3 provides an overview of the nature and extent of contamination identified at the Agra site. Sections 4 and 5 discuss the development and testing of conceptual and mathematical models for the groundwater flow system.
at Agra, within the context of geologic, hydrogeologic, and geochemical constraints drawn from the ESC field studies.

Section 6 presents the no-action scenario for the aquifer system at Agra. Section 7 summarizes the results of risk assessments for the no-action alternative. Remediation scenarios for the aquifer system were not examined, because analysis of all data indicated that the no-action alternative is appropriate for the protection of human health and the environment at Agra.

There is no known link between the commercial fumigant storage building, previously located at Main Street and Railroad Avenue, and the former CCC/USDA activities at Agra. Contaminant migration scenarios and risks that might result from the inferred presence of a residual carbon tetrachloride source at the site of the storage building are briefly presented in Section 8, however, to assist the town’s government officials and regulatory agencies in evaluating potential future groundwater contamination concerns.
Final Feasibility Study for Remedial Action at Agra, Kansas

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June 1997

Work sponsored by Commodity Credit Corporation, United States Department of Agriculture
2 Investigation Methods

A limited program of field activities was carried out during the ESC feasibility study work for Agra. Detailed descriptions of the field procedures employed were presented in the Master Work Plan (Argonne 1994). The locations investigated are shown in Figure 2.1, together with the locations of the Phase I and Phase II ESC studies.

2.1 Drilling Program

One soil boring, SB36 (see Figure 2.1), was drilled during the feasibility study. Drilling was performed by the Layne-Western Company of Omaha, Nebraska. An Acker Soilmax hollow-stem auger was used.

Boring SB36 was installed to serve as a temporary pumping well for use in determining the hydraulic properties (in pump testing) of the uppermost, relatively continuous sand zone within the middle silt/sand package (Argonne 1996), in accordance with procedures described in the Master Work Plan (Argonne 1994). Boring SB36 was drilled through the upper silt and middle silt/sand units to a total depth of 65 ft BGL (below ground level). Well cuttings were examined as drilling progressed, to identify sedimentary variations within the upper silt and the upper portion of the middle silt/sand package. The soil boring was completed by using 4-in.-diameter polyvinyl chloride (PVC) casing with a 0.020-in. slotted screen set at 42.7-62.7 ft BGL (1,794.78-1,774.78 ft above mean sea level [AMSL]). A lithologic log and a construction diagram for this well are presented in Appendix A. After completion, the well was developed by multiple cycles of alternate surging and bailing until the bailing water was free of fines. A submersible pump was then used to purge the well until the water ran clear and the basic physical properties of the discharge (temperature, pH, and conductivity) stabilized.

2.2 Piezometer Installation

Argonne’s 40-ton electronic cone penetrometer (ECPT) truck was used to install three additional piezometers (SB37, SB38s, and SB38; see Figure 2.1) at the Agra site as part of the feasibility study activities. The ECPT operations were conducted by Applied Research Associates, Inc.
FIGURE 2.1 Map Showing Locations Investigated during Phase I, Phase II, and the Feasibility Study Portions of the ESC Activities at Agra.
The well points were installed in the upper sand zone (SB37, SB38s) and the basal sand zone (SB38) by using a direct-push technique in which 1-in.-diameter PVC casing and screen were attached to a sacrificial cone penetrometer tip and advanced to the desired depth inside the cone penetrometer rods. The rods were then withdrawn, leaving the tip, screen, and casing in place. The annular space above the screen was backfilled with bentonite pellets.

The piezometers were installed as monitoring points for use in pump testing of the upper and basal sand zones of the aquifer system. Upper-sand piezometers SB37 and SB38s were installed at distances of 96 ft and 197 ft, respectively, northeast of 4-in. well SB36. Piezometers SB37 and SB38s were screened over the interval 57-63 ft BGL. Basal-sand piezometer SB38 was installed adjacent to SB38s and was screened over the interval 95-101 ft BGL.

2.3 Water Level Monitoring

Water levels in temporary well SB36 and piezometers SB36, SB37, SB38s, and SB38, as well as changes in barometric pressure at the site, were monitored over the 13-day period from June 27 to July 9, 1996, by using pressure transducers connected to automatic data loggers. The measurements were carried out to identify possible "background" water level fluctuations and to estimate the barometric efficiencies of these borings prior to pump testing of the upper and basal sand zones. The results of the monitoring exercise are presented in Section 4.1.2; barometric efficiencies are discussed in Appendix B.

During July and September 1996, static water levels in a total of 12 temporary wells and piezometers within the upper and basal sand units were measured by hand with an electronic water level meter, to the nearest 0.01 ft from a surveyed mark on the casing riser. The results of these measurements are presented in Section 4.1.2.

2.4 Aquifer Pump Testing

Constant-discharge aquifer pumping tests were conducted to determine the basic hydraulic properties (transmissivity \([T]\) or horizontal hydraulic conductivity \([K_h]\), vertical hydraulic conductivity \([K_v]\), and storativity \([S]\)) of the upper and basal sand zones and the intervening middle silt/sand package.
Testing of the upper sand zone was accomplished by pumping temporary well SB36 and monitoring the drawdowns induced at well points SB16, SB23s, SB28s, SB37, and SB38s. Testing of the complete aquifer complex was carried out by pumping former municipal well PW04. Water level changes within the aquifer system resulting from this pumping were recorded in the above well points and also in temporary wells SB15 and SB36 and in piezometers SB23, SB28, and SB38. The full details of these tests and an analysis of the test results are presented in Appendix B.
3 Extent of Contamination

This section summarizes information on the distribution of contaminants in the soil and groundwater at Agra, obtained during the ESC investigations of the site. The detailed results of these studies are in the Agra Phase I and Phase II ESC reports (Argonne 1995a, 1996).

3.1 Soil Contamination

Vadose zone soil samples were collected at 15 discrete depth intervals ranging from 2.0 to 47.2 ft BGL in soil boring SBO1, located near the center of the former CCC/USDA grain storage site (see Figure 2.1). Surface (< 1.5 ft BGL) and near-surface (1.5-4 ft BGL) soil samples were also collected at 45 locations throughout the former site (see Figure 2.4 of the ESC Phase II report [Argonne 1996]) during the course of the ESC investigations at Agra. None of the soil samples analyzed contained carbon tetrachloride or chloroform at concentrations above the quantitation limit (see Appendix H of the ESC Phase II report [Argonne 1996]), suggesting that a residual soil source of carbon tetrachloride does not exist beneath the former CCC/USDA facility.

Six surface (< 1.5 ft) soil samples were also collected at the former site of a commercial building believed to have been used for the storage of grain fumigants, located approximately 280 ft southwest of the former CCC/USDA facility (see Figure 2.4 and Appendix H of the ESC Phase II report [Argonne 1996]). No carbon tetrachloride or chloroform was detected in any of these samples, but elevated carbon tetrachloride levels found in groundwater samples collected beneath the former building site (see Section 3.2) suggest that a residual soil source of contamination might be present at this location. No further sampling was conducted at this site as part of the Argonne investigations, because there is no known relationship between possible fumigant storage at this location and former CCC/USDA activities in Agra.

3.2 Groundwater Contamination

To identify the areal distribution of VOC contamination within the Agra aquifer system, groundwater samples were collected and analyzed from numerous domestic wells, public water supply wells, temporary monitoring wells, and ECPT soil borings in the vicinity of Agra. In addition, detailed profile sampling was carried out with the ECPT at nine locations to determine the vertical distribution of contaminants within the aquifer complex. The results of these analyses are summarized in Figures 3.1 and 3.2.
FIGURE 3.1 Map of Agra Showing the Distribution of Carbon Tetrachloride within the Aquifer (Carbon tetrachloride concentrations are shown in µg/L. Location of cross section B-B', presented in Figure 3.2, is shown in orange.)
FIGURE 3.2 Geologic Section Showing the Vertical Distribution of Carbon Tetrachloride in Wells Lying along the Approximate Central Axis of the Contaminant Plume (See Figure 3.1 for locations of wells and of cross section B-B'. Carbon tetrachloride concentrations are shown in µg/L.)
The plan view (Figure 3.1) shows an elongated, somewhat lobate groundwater carbon tetrachloride plume identified within the aquifer, extending approximately 2,100 ft southeastward from the former CCC/USDA grain storage site, in the predominant direction of groundwater flow. The plume terminates near two former municipal water supply wells, one of which (PW04) remains in use for seasonal irrigation of the town’s high school football field. On the basis of this observation, Argonne (1996) proposed that long-term use of municipal wells PW03 and PW04 probably prevented or significantly limited further contaminant migration downgradient from these wells. Carbon tetrachloride concentrations within the plume are highly variable, ranging from 5 µg/L at SB35 to a maximum measured value of 180 µg/L at MW01, near the western, upgradient margin of the plume. Figure 3.1 shows that the upgradient limit of the groundwater plume is irregular and appears to have separated already from the presumed source area at the former CCC/USDA site, supporting the conclusion that a residual soil source does not exist at the grain storage site. In contrast, the high observed carbon tetrachloride concentration at monitoring well MW01 appears inconsistent with groundwater flow pathways originating near the former CCC/USDA site but coincides with the location of the former fumigant storage building discussed in Section 3.1.

Figure 3.2 illustrates the vertical distribution of carbon tetrachloride within the aquifer, in a cross section oriented along the approximate axis of the groundwater plume. The northern portion of the plume is located in the saturated, uppermost sand and silty intervals of the middle sand/silt package, which directly overlie bedrock upgradient from the prominent bedrock valley penetrated at borings SB15, SB11, and SB23. Carbon tetrachloride contamination extends downward into the deeper portions of the middle sand/silt package and the basal sand unit near the upgradient margin of the bedrock valley. However, contamination was not detected in the basal sand at SB11, indicating that downgradient migration of carbon tetrachloride is more limited in the basal sand than in the overlying silt/sand horizons.

No chloroform was identified at concentrations above the quantitation limit in any of the groundwater samples analyzed.
4 Development of the Conceptual Hydrogeologic Model

Phase I and Phase II of the ESC studies documented the local geology, characteristics of groundwater flow, groundwater geochemistry, and contaminant distribution within the unconfined aquifer at Agra. The results suggest that the patterns of groundwater flow and contaminant migration at the town are determined predominantly by (1) the distribution of the aquifer sediments in relation to the underlying complex bedrock topography and (2) the probable impact of past and continuing groundwater withdrawal from the aquifer at former municipal wells PW03 and PW04.

Key aspects of the geologic, physiographic, and hydrologic conditions at the site have been integrated to develop working conceptual and numerical hydrogeologic models of the Agra aquifer complex. These models provide the basis for the evaluation of possible remediation requirements at Agra presented in Section 6.

4.1 Constraints Imposed on the Hydrogeologic Model

4.1.1 Geologic Constraints

The following geologic constraints can be imposed on the models of the aquifer system at Agra:

- The unconsolidated Quaternary geologic section identified at Agra consists of three basic units: the upper silt, the middle silt/sand package, and the basal sand. The distribution and thicknesses of these units vary significantly across the area of investigation and are strongly controlled by the underlying Cretaceous bedrock topography. The relationships of these units to bedrock topography were depicted in a series of seven geologic cross sections, presented as Figures 3.4-3.10 of the Phase II ESC report (Argonne 1996).

- Lithologic and geophysical data obtained from borings and ECPT soundings were used to construct an elevation map of the bedrock surface in the immediate vicinity of Agra, as shown in Figure 4.1. The map depicts the presence of two prominent depressions, interpreted as incised paleovalleys, that are separated by
FIGURE 4.1 Elevation Map (in feet AMSL) Depicting Relief on Bedrock Surface in the Immediate Vicinity of Agra
a paleoupland area trending roughly east-west beneath the central portion of the town. The larger, southern bedrock depression is inferred to represent the possible “headwaters” area of a southeastward-trending paleovalley, roughly paralleling the present surface drainage pattern of major tributary channels to the North Fork Solomon River. The northern bedrock depression lies immediately east of the former CCC/USDA site and has an apparent east-west orientation, suggesting a possible origin as a tributary to a larger, southeastward-trending channel inferred to lie east of the area covered by the ESC investigations.

Lithologic data of limited quality that are available for municipal wells PW01 and PW02, southwest of the former CCC/USDA site (see Figure 2.1), suggest the possible presence of a third bedrock depression that is separated from both the northern and southern paleovalleys by a bedrock ridge trending north-south and underlying Main Street.

- The upper silt unit is continuous across the entire area of investigation. The unit ranges in thickness from approximately 30 ft at the southern limit of the study area to 50 ft within the northern paleovalley, generally increasing in thickness to the north. The upper silt consists predominantly of silts, silty clays, and sandy silts deposited as loess. A noncalcareous, relatively porous sandy silt horizon encountered within the upper silt at a depth of approximately 20-30 ft BGL has been interpreted as a paleosol.

- The middle silt/sand package ranges in total thickness from 0 ft along the north-south-trending bedrock high to a maximum of 75 ft within the southern bedrock valley. The uppermost, silty portion of the middle silt/sand package is laterally continuous across most of the study area, generally ranging from 7 to 25 ft in thickness, and is capped by a prominent paleosol complex. The uppermost silt of the middle silt/sand package is absent only on the bedrock high identified at the southern end of Main Street.

- A prominent, relatively continuous complex of fluvial sands, henceforth referred to as the “upper sand” for convenience, underlies the uppermost silty portion of the middle silt/sand package over much of the study area. The upper sand, which is absent on the bedrock high identified at the southern end of Main Street, thins appreciably (from a maximum penetrated thickness of 25 ft within the southern paleovalley) over the inferred northern extension of the bedrock
The upper sand is also missing within the northern paleovalley, where it is inferred to have been removed by erosion and later replaced by clayey silts. These observations are summarized in Figures 4.2 and 4.3, which depict elevation maps representing the interpreted upper and basal surfaces of the upper sand.

- A second, deeper sandy interval of more limited extent lies within the middle silt/sand package at elevations of 1,750-1,770 ft AMSL. These deeper sands are restricted to the southern paleovalley, ranging from 15 to 20 ft in thickness along the northeastern valley wall. The sands thin toward the center of the valley and are absent along its inferred southeastward-trending axis south of wells PW03 and PW04 (see Figure 4.1).

- The basal sand unit has been identified only within the southern and northern paleovalleys, where it directly overlies the Cretaceous bedrock. The unit consists of fine- to medium-grained silty sands that range in thickness from 15 ft to a maximum of 35 ft within the southern paleovalley. An elevation map depicting the upper surface of the basal sand within the southern paleovalley is in Figure 4.4.

4.1.2 Hydrologic Constraints

The following hydrologic constraints can be imposed on the models of the aquifer system at Agra:

- Long-term (46-yr) precipitation data (see Figure 4.5) obtained for Smith Center, Kansas, approximately 17 mi east of Agra, indicate an average annual precipitation rate of approximately 25 in./yr for this area. Figure 4.5 shows that 1994 and 1995 precipitation levels were near this long-term average, following rainfalls significantly above average during 1992 and 1993.

- Figure 4.6 presents monthly precipitation levels for 1994 and 1995. The figure shows that most of the rainfall received at Smith Center occurs during April/May-August. The monthly data for 1995 indicate that the summer months of June and July were particularly dry, following very high rainfalls in May.
FIGURE 4.2 Elevation Map (in feet AMSL) Depicting Relief on the Upper Surface of the Upper Sand Interval
FIGURE 4.3 Elevation Map (in feet AMSL) Depicting Relief on the Lower Surface of the Upper Sand Interval
FIGURE 4.4 Elevation Map (in feet AMSL) Depicting Relief on the Upper Surface of the Basal Sand Interval
Departure from Average Annual Precipitation, Smith Center, KS

Average Annual Precipitation, 1949-1995: 25.17 inches

FIGURE 4.5 Annual Precipitation Levels for the Period 1949-1995, Recorded at Smith Center, Kansas, Approximately 17 mi East of Agra
1994-5 Monthly Precipitation Data for Smith Center, KS

FIGURE 4.6 Monthly Precipitation Levels for the Period 1994-1995, Recorded at Smith Center, Kansas, Approximately 17 mi East of Agra
- Site-specific data on potential recharge rates at Agra are unavailable; however, extrapolation of long-term (30-yr) regional average trends for this area (Dugan and Peckenpaugh 1985) suggested a possible mean annual range of only 1-2 in./yr, or roughly 4-8% of mean annual precipitation.

- Water level data presented in the Agra Phase II ESC report (Argonne 1996), in conjunction with groundwater geochemical and isotopic relationships identified in Phase I (Argonne 1995a), strongly suggest that the saturated lithologies of the upper silt, middle silt/sand, and basal sand units at Agra behave as a single, unconfined aquifer.

- Water level data variously obtained at 17 upper- and basal-sand monitoring points during the course of the Agra ESC investigations are summarized in Figure 4.7. The available data indicate that water levels within the upper and basal sand intervals have been very stable over the period of record. This observation is qualitatively consistent with the absence of large-scale agricultural irrigation activities in the Agra area and with only limited use of wells PW03 and PW04 within the town.

- Groundwater within the upper sand northwest of SB16 flows toward the south-southeast under an approximate hydraulic gradient of 0.007 (see Figure 4.8). Flow within the upper sand becomes more southeasterly, under a reduced hydraulic gradient, within the mapped limits of the southern bedrock valley. Groundwater flow within the basal sand also parallels the bedrock valley, under a low hydraulic gradient (0.002) similar to that in the overlying upper sand.

- A persistent vertical (downward) hydraulic gradient between the upper and basal sands decreases in magnitude with horizontal distance downgradient from paired monitoring points SB16 and SB15. Water levels in the upper and basal sands at paired monitoring points SB23s and SB23 are effectively identical.

- Continuous groundwater monitoring data obtained during Phase II of the ESC (Argonne 1996) revealed a pattern of regular, sharp drawdown spikes in the water level record from basal sand well SB15, which is approximately 230 ft upgradient from wells PW03 and PW04. The drawdown spikes occurred
FIGURE 4.7 Summary of Water Level Variations in the Aquifer at Agra, June 8, 1995, to September 20, 1996
FIGURE 4.8 Composite Map Showing Average Potentiometric Head Levels in the Upper and Basal Sand Units and Their Relationships to Bedrock Topography (Upper-sand contours are shown in blue, basal sand contours in red, and bedrock contours in gray. All contours show elevation in ft AMSL.)
approximately every 24 hr. No drawdown response was observed in the record from any other nearby basal- or upper-sand piezometer monitored at that time. Field observations made during the feasibility study suggest that these drawdowns probably reflect short-term pumping of well PW03, which is used sporadically to fill portable livestock watering tanks and agricultural spraying tanks. Visually estimated flow rates from well PW03 during one such operation were on the order of 50 gpm (gallons per minute).

- The water level and geochemical data previously obtained from the upper and basal sand intervals at Agra suggest that the interbedded, fine-grained sediments that vertically separate the upper and basal sands do not form an effective hydraulic barrier to vertical groundwater flow within the aquifer under the essentially steady-state conditions represented by the measurements.

- In contrast, continuous groundwater monitoring data collected during the feasibility investigation demonstrate the response of the upper and basal sand intervals to transient stress caused by cyclic pumping of well PW04 for watering of the high school football field. Groundwater level variations for piezometers SB36, SB37, and SB38s in the upper sand and SB38 in the basal sand are shown in Figure 4.9. These piezometers are all located within 175 ft of well PW04 (see Figure 2.1). Flow measurements made at the site indicate a pumping rate of approximately 44 gpm from well PW04 under the normal operating conditions for the football field sprinkler system. A significant cone of depression is developed within both the basal and upper sand intervals as a result of pumping of PW04. Daily pumping of the well for 8-13 hr during the period July 1-4, 1996, indicated that water levels did not recover to prepumping levels in either the basal or upper sand interval during the intervening nonpumping periods (11-16 hr); however, recovery was more rapid in the basal sand portion of the aquifer. Water levels within the upper sand continued to decrease slightly, for up to 1-2 hr after levels within the basal sand began to rebound. The recorded aquifer responses to pumping are consistent with the earlier proposal that the finer-grained sediments of the middle silt/sand unit do not prevent hydraulic communication between the upper and basal sands. The monitoring data suggest, however, that reduced vertical permeability within the middle silt/sand package limits the rate of groundwater exchange that is possible between the upper and basal sands under stressed conditions.
Agra Water Level Monitoring Results

FIGURE 4.9 Continuous Water Level Monitoring Traces Recorded for Selected Wells and Piezometers in the Vicinity of Former Municipal Well PW04, June 27 to July 9, 1996
• Construction information available for well PW03 is incomplete; data obtained from the preconstruction permit application for the well suggest that PW03 is screened or gravel packed across both the deeper sand within the middle silt/sand package and the basal sand unit. Permit application specifications for well PW04 indicate that it was to be screened within the basal sand only; however, subsequent well registration data suggest that PW04 might also have been partially screened or gravel packed across the sands of the middle silt/sand package and the basal sand (Argonne 1995b) and subsequently grouted across the upper sand interval.

• The available control data suggest that little or no vertical or lateral groundwater flow occurs from the upper sand into the thick, predominantly clayey silt fill of the northern bedrock valley near the former CCC/USDA facility.

• The town of Agra currently receives drinking water supplies from three operational municipal wells. Wells PW01 and PW02 are located west of the bedrock high that forms the western margin of the northern and southern bedrock valleys (see Figure 4.1) and show no evidence of carbon tetrachloride contamination. Municipal well PW05 is located approximately 1 mi east of the town and is believed to penetrate an adjacent, hydraulically separate bedrock valley similar to those identified at Agra. Recorded water levels demonstrate that the pumping of wells PW01, PW02, and PW05 has no detectable influence on groundwater flow in the area of Argonne’s investigations downgradient from the former CCC/USDA grain storage facilities.

• Detailed historic water use records for the Agra municipal water supply system could not be obtained for the current study; however, available information indicates that well PW03 was in regular use as a drinking water supply well from 1954 to 1985. Well PW04 was installed in 1982 and was also in regular use for drinking water supply until 1985. PW04 has been used seasonally by the high school from 1991 until the present. The water level monitoring data presented in Figure 4.9 suggest that long-term cyclic pumping of these wells would have strongly influenced groundwater flow patterns, and therefore contaminant migration patterns, throughout the Agra aquifer during their operational lifetimes.
4.1.3 Constraints on the Distribution of Carbon Tetrachloride

The following constraints can be imposed on the distribution of carbon tetrachloride at Agra:

- The groundwater carbon tetrachloride plume identified within the Agra aquifer extends approximately 2,100 ft southeastward from the former CCC/USDA grain storage site (see Figure 3.1), to the approximate location of former municipal wells PW03 and PW04. No carbon tetrachloride contamination has been detected downgradient from these wells.

- Carbon tetrachloride contamination is present in the upper sand over the mapped extent of the plume shown in Figure 3.1. In the area upgradient of wells PW03 and PW04, contamination is also present in the deeper portions of the middle silt/sand unit and the basal sand.

- The upgradient limit of the groundwater plume is irregular and appears to have separated from the presumed source area at the former CCC/USDA site, supporting the conclusion that a residual soil source does not exist at the grain storage site. In contrast, the high observed carbon tetrachloride concentration at monitoring well MW01 appears inconsistent with an origin from the CCC/USDA facility, suggesting the possible existence of a residual soil source at the site of the fumigant storage building formerly located near MW01.

4.2 Description of the Conceptual Hydrogeologic Model

The above observations form the basis for the conceptual model of groundwater flow and contaminant transport proposed here. Our hypothesis is that shallow groundwater flow southeastward across the Agra area originates primarily as underflow from topographically higher areas to the northwest of the town, with supplemental flow derived from limited local recharge. Groundwater flow is restricted to the relatively thin, saturated portion of the upper sand and silts in areas where these deposits lie directly over bedrock or relatively impermeable valley fills, such as the area northwest of the southern bedrock valley. Within the southern bedrock valley, expansion of this shallow flow into the thicker, composite upper and basal sand and silt units present in the valley results in a natural downward flow of groundwater near the upgradient margin of the valley.
and a reduction in flow velocity within the bedrock-controlled aquifer. Downward movement of groundwater from the upper sand to the deeper basal sand might, in part, occur preferentially at the upgradient valley margin because of the localized presence of the intermediate sand zone within the middle silt/sand package in this area. The downward component of flow decreases downgradient as groundwater movement again becomes predominantly horizontal, parallel to the orientation of the bedrock valley. We further propose that groundwater flow within the limits of the southern bedrock valley is locally hydraulically isolated from groundwater flow that might occur in similar bedrock channels outside the area of Argonne's investigation.

The downgradient orientation and the continuity of the southern bedrock valley south of the Agra ESC study area are problematic, because regional geologic data indicate that the Cretaceous bedrock lithologies underlying Agra exhibit a complex, badlands-style topography in exposures along the modern North Fork Solomon River Valley (Johnson 1993). Regional mapping of the buried Cretaceous bedrock surface in western Phillips County and western Kansas (Merriam 1988), however, indicates that a broad paleovalley underlies the present trend of the North Fork Solomon River, suggesting that paleodrainage trends in the Agra area may have generally mirrored the present southeastward surface drainage patterns. Under this assumption, we hypothesize that groundwater within the southern bedrock valley might ultimately be discharged to the surface at bedrock exposures within several ephemeral stream beds that are tributary to Deer Creek, approximately 2.5 mi south-southeast of Agra and 3 mi north-northeast of the town of Kirwin.

The above conceptual model is in qualitative agreement with the observed distribution of carbon tetrachloride contamination within the Agra aquifer. The model suggests that contaminant migration into the deeper portions of the aquifer within the southern bedrock valley occurred as a result of the natural patterns of vertical and horizontal groundwater flow. We hypothesize that historic pumping of wells PW03 and PW04 reinforced these natural patterns and might have significantly reduced or prevented the further migration of carbon tetrachloride downgradient.
5 Numerical Models

The working conceptual hydrogeologic model on which the numerical aquifer models were based is relatively simple; however, detailed representation of the complex three-dimensional geometry of the aquifer sediments and the resulting groundwater flow was not straightforward. It would be difficult, if not impossible, to both determine and fully represent the geologic characteristics and transient hydraulic history of the actual three-dimensional aquifer and groundwater flow system within workable numerical models. In addition, our ability to calibrate such models would limit the potential benefits of their construction. In light of this tradeoff, we adopted a simplified approach to representing the flow system that incorporates the most significant features of the conceptual model, and we used sensitivity analyses to evaluate the effects of uncertainties on the results of the numerical simulations.

The characteristics and spatial geometry of the aquifer sediments at Agra were estimated from measured field data for the portion of the modeled domain characterized during the Agra ESC investigations. Extrapolation of sediment types and thicknesses into the more marginal portions of the modeled domain was carried out under the following four key assumptions, which were drawn from the geologic and hydrogeologic constraints outlined in Section 4:

1. The southern bedrock valley is laterally continuous and trends south-southeastward, paralleling the observed groundwater flow directions depicted in Figure 4.8.

2. The width and depth of the valley remain relatively constant downgradient, within the limits of the modeled domain.

3. The relative thicknesses and character of the sediments within the stratified valley fill remain similar to those penetrated in the upgradient portion of the valley.

4. Sediments of the deeper middle silt/sand package and the basal sand that are confined within the bedrock valley are hydraulically isolated from saturated materials that might exist at equivalent elevations outside the bedrock highs defining the valley.
5.1 Groundwater Flow Model

Groundwater flow modeling was carried out by using the U.S. Geological Survey (USGS) modular, three-dimensional, finite-difference groundwater modeling package commonly referred to as MODFLOW (McDonald and Harbaugh 1988). Assumed hydraulic conductivity distributions used in the flow simulations, as well as the resulting calculated potentiometric surface data, were used as input to the particle-tracking code GWPAT (Shafer 1992) in order to predict groundwater flow and contaminant migration pathways in selected model cases.

A rectangular grid approximately centered on the town of Agra, measuring 5,625 ft by 7,500 ft, was constructed with uniform 75-ft by 75-ft grid spacing to yield 100 rows and 75 columns. The orientation of the gridded domain relative to the site, shown in Figure 5.1, was chosen to be roughly orthogonal to the apparent predominant direction of groundwater flow within the upper sand unit of the aquifer. The dimensions of the domain were chosen to minimize influences of the model boundary in the central area of the grid, highlighted in Figure 5.1, in response to simulated pumping of former municipal wells PW03 and PW04, located near the southeastern corner of the town. For these studies, a three-layer model was created representing (1) the upper sand unit of the middle silt/sand package, as well as the overlying and laterally adjacent, somewhat permeable portions of the middle and upper silts that lie within the zone of groundwater saturation; (2) the remaining, deeper portions of the middle silt/sand package; and (3) the basal sand.

Model layer 1, representing the upper sand and the laterally and vertically adjacent silts, was modeled as an unconfined zone by using the simplified distribution of aquifer materials shown in Figures 5.2 and 5.3. Field data presented in Figures 4.2 and 4.3 were used to delimit the distribution and thickness of the upper sand unit. Materials outside the inferred extent of the sand were modeled as moderately permeable silts. A uniform base elevation was assumed for these sediments. A uniform horizontal hydraulic conductivity \(K_h\) for the sand facies of 3-6 ft/d (feet per day) and vertical hydraulic conductivity \(K_v\) values of 1-4 ft/d were considered during model development and sensitivity testing, effectively bracketing the range of values determined from pump testing of this unit. During model calibration and testing, \(K_h\) values of 0.1-2 ft/d were imposed for the silt facies.

Measured elevation data presented in Figure 4.4 were used to define the basal surface of the middle silt/sand package (model layer 2) within the southern bedrock valley. The modeled
FIGURE 5.1 Map of the Agra Area, Showing the Location and Orientation of the Domain Simulated in the Groundwater and Contaminant Transport Modeling Studies (Outer rectangle shows the limits of the modeled domain. Dimensions of the domain are 5,625 ft by 7,500 ft. Inner rectangular outline highlights the focus area for calibration of the flow model. Dimensions of the focus area are 2,250 ft by 4,350 ft.)
FIGURE 5.2 Grid Distribution of Sediment Zones for Model Layer 1 (upper sand and adjacent silts) (Values shown indicate both $K_h$ and $K_v$, in ft/d.)
FIGURE 5.3 Model Grid Representation of Elevations (ft AMSL) on the Lower Surface of Model Layer 1 (upper sand and silts), Based on Extrapolation of Data Shown in Figure 4.3
representation of this surface is shown in Figure 5.4. Uniform, low values of $K_h$ and $K_v$ were assumed for the predominantly silty sediments in the central and southern portions of the modeled unit. Higher $K_h$ and $K_v$ values (see Figures 5.5 and 5.6) were imposed in a limited area near the northeastern margin of the bedrock valley, reflecting the observed presence of relatively thick interbedded sands within the middle silt/sand package in this area. The remainder of the model layer lying outside the margin of the bedrock channel was simulated by using the MODFLOW "inactive" cell option. During calibration and testing of the groundwater flow model, $K_h$ and $K_v$ values of 0.03-4 ft/d and 0.03-1 ft/d, respectively, were used for the middle silt/sand package.

The possible existence of dual screens and/or vertically continuous gravel packs in wells PW03 and PW04 was simulated during development of the groundwater flow model by empirically imposing higher $K_v$ values within the middle silt/sand package (model layer 2) at the grid squares representing the locations of these wells (see Figure 5.6).

The sediment distribution within the basal sand, simulated as the third layer of the numerical model, is illustrated in Figure 5.7. Figure 5.8 shows the simplified model representation of the base of this sand, extrapolated from the bedrock contours presented in Figure 4.1. During development of the flow model, $K_h$ and $K_v$ values of 4-30 ft/d were considered for the basal sand.

Fixed-head boundary conditions were imposed at the northwestern and southeastern margins of model layer 1, on the basis of the observation that water levels and hydraulic gradients within the upper sand have been very consistent throughout Argonne’s investigations. No-flow boundaries were imposed along the remaining edges of layer 1, because these edges are approximately parallel to inferred streamlines within the upper sand and adjacent silts. Upgradient and lateral groundwater flow boundaries within model layers 2 and 3 were imposed by the bedrock walls that define the southern paleovalley. The presence of bedrock was represented in these layers by MODFLOW “inactive” cells. The southern, downgradient model boundaries of the active areas in layers 2 and 3 were simulated by using fixed-head values set equal to the corresponding cells in model layer 1, in keeping with the field observation that hydraulic heads in the upper and basal sands have remained approximately equal to each other at paired monitoring points SB23s and SB23, located 1,100 ft downgradient from the northern margin of the southern bedrock valley.
FIGURE 5.4 Model Grid Representation of Elevations (ft AMSL) on the Lower Surface of Model Layer 2 (middle silt/sand unit), Based on Extrapolation of Data Shown in Figure 4.4
FIGURE 5.5 Grid Distribution of Sediment Zones and $K_h$ Values for Model Layer 2 (middle silt/sand unit) ($K_h$ values are shown in ft/d.)
FIGURE 5.6 Grid Distribution of Sediment Zones and $K_v$ Values for Model Layer 2 (middle silt/sand unit) ($K_v$ values are shown in ft/d. Small gray squares show modeled grid locations of wells PW03 and PW04.)
Figure 5.7 Grid Distribution of Sediment Zones for Model Layer 3 (basal sand unit) (Values shown indicate both $K_h$ and $K_v$, in ft/d.)
FIGURE 5.8 Model Grid Representation of Elevations (ft AMSL) on the Lower Surface of Model Layer 3 (basal sand unit), Based on Extrapolation of Data Shown in Figure 4.3
5.2 Contaminant Transport Model

The migration of carbon tetrachloride in the vicinity of Agra was simulated for selected groundwater flow and contaminant transport scenarios by using the numerical transport code MT3D (Zheng 1992) coupled to the three-dimensional groundwater flow model described in Section 5.1.

Data on the specific transport characteristics of the aquifer materials (dispersivity, adsorption characteristics) and contaminated groundwater (contaminant decay rate, adsorption characteristics) encountered at Agra were unavailable for this investigation. Estimates of these parameters derived from published information (Pickens and Grisak 1981; Yeh 1981) and calibrated values determined for the Utica contamination site (retardation < 1.5, decay rate < 2%/yr [Argonne 1995c]) were therefore employed in the present study.

Longitudinal and horizontal transverse dispersivities of 30 ft and 3 ft, respectively, were assumed for all model layers. A retardation factor of 1.3 and a maximum natural decay rate of 1%/yr for carbon tetrachloride were imposed as conservative parameters for the model. Simulations were generally carried out for migration periods of 60 yr under the various scenarios considered.

Model representations of the carbon tetrachloride plume concentrations in the upper and basal sands used as starting conditions for the transport simulations (model layers 1 and 3) are shown in Figure 5.9. Initial concentrations imposed for the middle sand/silt package (model layer 2) were similar to those shown for the basal sand. These representations are very conservative, because they assume complete vertical saturation within each aquifer interval at the concentrations depicted in Figure 5.9.

5.3 Model Calibration and Testing

5.3.1 Calibration Approach

The observations about groundwater flow outlined in Section 4.1.2 illustrate that the hydraulic regime of the aquifer at Agra has remained quite stable throughout Argonne's
FIGURE 5.9 Model Grid Representation of Carbon Tetrachloride Concentrations in Model Layer 1 (upper sand interval) and Model Layer 3 (basal sand unit), Used as Starting Conditions for the Contaminant Transport Simulation (Starting concentrations for model layer 2 [middle silt/sand unit], not shown, were similar to those for layer 3. Concentrations are shown in µg/L.)
investigations. This present stability has been perturbed only locally, by the periodic, short-term operation of former municipal wells PW03 and PW04. Pumping of municipal water supply wells PW01, PW02, and PW05 has no detectable effect on groundwater flow patterns in the area of Argonne’s investigations downgradient from the former CCC/USDA grain storage facilities. The field data obtained on the transient response of the aquifer to the pumping of wells PW03 and PW04 is significant, however, because historic groundwater flow conditions at the site that governed contaminant migration and the subsequent formation of the existing carbon tetrachloride plume might have been substantially influenced by the former regular operation of PW03 and PW04 as municipal water supply wells.

In light of the above considerations, we have addressed development and testing of the Agra groundwater flow and contaminant transport models by attempting to “history match” the response of the models to that of the actual flow system in terms of three distinct criteria. First, steady-state simulations were carried out to develop a basic calibration for the models reflecting the stable groundwater flow patterns recently observed. Second, the steady-state model parameters were refined under transient conditions by attempting to recreate the water level variations observed during aquifer pump testing conducted as part of this feasibility investigation. Finally, advective (particle tracking) and advective-dispersive transport simulations were carried out to determine the ability of the conceptual and numerical models to recreate the distribution of carbon tetrachloride within the aquifer observed in the actual groundwater plume. History matching of the flow model under each of these scenarios focused on the quantitative matching of measured and simulated water levels and flow directions in the upper and basal sands, in an area surrounding the former CCC/USDA site and the existing contaminant plume near the center of the modeled domain, as highlighted in Figure 5.1. Simulation results near the boundaries of the modeled domain were only qualitatively evaluated.

An iterative, trial-and-adjust procedure was used to modify model input parameters during each stage of the history-matching process. Intrinsic parameters of the model hydrogeologic setting, such as aquifer hydraulic conductivities and layer thicknesses, were adjusted to develop a representation of the physical aquifer that is consistent with available geologic controls. Within this physical model, we then adjusted boundary conditions to approximate the historically observed distribution of hydraulic heads in each portion of the aquifer under both quasi-steady-state and transient groundwater flow conditions. The “goodness of fit” values of simulated and measured heads for each modeled history-matching scenario were evaluated, and the process of parameter and boundary condition adjustment was repeated until a suite of model parameters yielding an acceptable match to the calibration targets was achieved.
5.3.2 Quasi-Steady-State History Matching

The “best fit” simulated potentiometric surfaces developed for the upper and basal sands under quasi-steady-state conditions are shown in Figures 5.10 and 5.11. Agreement between measured and simulated heads were generally within ±0.5 ft.

A difference between measured and modeled heads exceeding ±0.5 ft was observed only at monitoring points SB28s and SB28, near the northwestern, upgradient margin of the southern paleovalley. The poorer correspondence in head values observed at this location might in part reflect the inability of the simplified model geometry to represent the detailed three-dimensional pattern of groundwater flow near the steeply inclined wall of the bedrock valley. The modeled hydraulic gradients for the upper sand interval northwest of the bedrock valley, and for both the upper and basal sands within the bedrock valley, are consistent with those determined from the field data.

Potentiometric surfaces were generated for steady-state conditions under two alternative assumptions: (1) that wells PW03 and PW04 are gravel packed and screened within the basal sand only and (2) that the wells might also be at least partially screened or gravel packed across the sands of the middle silt/sand unit. The results obtained under these two scenarios were virtually identical, suggesting that possible vertical groundwater flow at the former municipal well boreholes is unlikely to contribute significantly to the observed equilibration of hydraulic heads within the upper and basal sands, downgradient within the southern bedrock valley.

5.3.3 Transient History Matching

Calibration of the groundwater flow model under transient conditions was carried out by modeling aquifer drawdowns recorded at the Agra site during two constant-discharge pumping tests. Full details of these tests are presented in Section 2.4 and Appendix B.

---

1 Simulated head values in these diagrams and in all subsequent text and appendix figures are shown relative to an arbitrary reference elevation of 1.700 ft AMSL. Measured water level elevations posted in all diagrams are shown as actual values in ft AMSL.
FIGURE 5.10 Simulated Upper-Sand Potentiometric Surface for the Calibrated Steady-State Groundwater Flow Model (Posted values shown are measured water levels [ft AMSL] for November 6, 1995. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE 5.11 Simulated Basal-Sand Potentiometric Surface for the Calibrated Steady-State Groundwater Flow Model (Posted values are measured water levels [ft AMSL] for November 6, 1995. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
5.3.3.1 Well PW04 Pumping Test

The PW04 well test was simulated by modeling pumping at the grid cell representing the well location for a period of 25 hr and a flow rate of 26.7 gpm. The steady-state hydraulic head distributions for the upper and basal sands shown in Figures 5.10 and 5.11 were used as starting conditions for the transient simulations.

Predicted potentiometric surfaces at the end of the 25-hr pumping period were again generated under the two alternative well construction scenarios for wells PW03 and PW04 described in Section 5.3.2. In each case, removal of water from the boreholes was simulated to occur in the lower model layer (layer 3).

The “best fit” potentiometric surfaces produced for the upper and basal sands under both alternatives were only subtly different; results for the case incorporating vertical leakage are presented in Figures 5.12 and 5.13. This simulation was empirically achieved by imposing a $K_v$ value of 10 ft/d at the grid cells representing both wells. Calculated drawdowns for both modeled scenarios are compared in Table 5.1 to measured drawdowns obtained from the actual pumping test. As Table 5.1 shows, a marginally better agreement between predicted and observed values was obtained at most monitoring locations for the leakage simulation (modeled scenario 2), suggesting that some vertical hydraulic communication between the upper and basal aquifer sands might occur via both the PW03 and PW04 boreholes under pumping conditions. Whether the inferred hydraulic pathway at these locations is the result of continuous gravel packing, multiple well screens, poor or failed grouting of the boreholes, or other possible mechanisms could not be determined from the information available for this study.

5.3.3.2 Well SB36 Pumping Test

The SB36 pumping test was simulated by modeling pumping at the grid cell representing the well location for a period of 760 min and a flow rate of 3.9 gpm. The steady-state hydraulic head distributions for the upper and basal sands shown in Figures 5.9 and 5.10 were again used as starting conditions for the transient simulations.

Well SB36 is screened in the upper sand interval only. Actual pump testing of the well had no detectable effect on hydraulic heads within the basal sand or at nearby upper-sand monitoring
FIGURE 5.12 Predicted Upper-Sand Potentiometric Surface Resulting from Transient Simulation of the Well PW04 Pumping Test (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE 5.13 Predicted Basal-Sand Potentiometric Surface Resulting from Transient Simulation of the Well PW04 Pumping Test (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
TABLE 5.1 Comparison of Modeled and Actual Drawdown Responses

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<th>Source</th>
<th>SB36</th>
<th>SB37</th>
<th>SB38s</th>
<th>SB38d</th>
<th>SB15</th>
<th>SB16</th>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>1.3</td>
<td>1.7</td>
<td>1.5</td>
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</tr>
<tr>
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<td>1.8</td>
<td>1.2</td>
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<td>Well SB36 Pump Test</td>
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<td></td>
<td></td>
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<td></td>
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<td>0.4</td>
<td>0.1</td>
<td>-</td>
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</tr>
</tbody>
</table>

*a* No response.

*b* Value corrected for resolution of model grid per Anderson and Woessner (1992).

points SB37 and SB38s (see Figure 2.1). Simulation of the SB36 test also resulted in no measurable drawdown in the deeper portions of the aquifer. The "best fit" model potentiometric surface (see Figure 5.14) achieved for the upper sand, however, depicts small amounts of drawdown at these piezometers. Calculated drawdowns from the model are compared to measured values from the well test in Table 5.1. The discrepancy between measured and predicted heads is believed to be an artifact of small-scale lithologic heterogeneities within the upper sand interval, which are not discretely represented by the simplified $K_h$ distribution used for the model.

5.3.4 Model Generation of the Observed Contaminant Plume

A series of particle tracking and advective-dispersive contaminant transport simulations was conducted to evaluate whether the conceptual and numerical groundwater flow models described in the preceding sections can account for the observed vertical and horizontal distribution of carbon tetrachloride contamination within the Agra aquifer.

On the basis of available information about the history of grain fumigant usage and the discovery of contaminated groundwater at the site, a period of approximately 20 yr was
FIGURE 5.14 Predicted Upper-Sand Potentiometric Surface Resulting from Transient Simulation of the Well SB36 Pumping Test (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
considered reasonable for formation of the presently observed carbon tetrachloride plume. Within this time frame, two potential contaminant transport scenarios were considered: (1) that former intermittent pumping of municipal wells PW03 and PW04 was insufficient in duration to have exerted any significant influence on groundwater flow patterns within the aquifer and (2) that historic pumping of PW03 in particular might have influenced groundwater flow and contaminant migration.

The steady-state potentiometric surfaces for the upper and basal sand shown in Figures 5.10 and 5.11 were used to represent ambient groundwater flow conditions that might have existed during the formation of the carbon tetrachloride plume. The historic pumping scenario was simulated by assuming a long-term “average” continuous pumping rate of 10 gpm for municipal well PW03 during plume formation, or 4 hr of operation per day at the well’s design capacity of approximately 60 gpm (Argonne 1995b). Well PW04 would not have been present for most of the period of plume formation; therefore, enhanced vertical leakage at the PW04 grid location was not modeled in these simulations.

To test the plume formation hypothesis, two-dimensional forward particle tracking analyses were carried out to identify expected contaminant migration pathways and travel times for carbon tetrachloride within the upper sand interval. Both the former CCC/USDA facility and the suspected former fumigant storage building located southwest of the CCC/USDA site were considered as potential contaminant source areas during these analyses.

“Best fit” particle tracking pathways generated under the above two scenarios for plume formation are compared in Figures 5.15 and 5.16. In each figure, a 20-yr period of contaminant migration from the former CCC/USDA site is depicted. As shown, long-term pumping of municipal well PW03 under the modeled conditions has relatively little influence on the predicted pattern or timing of contaminant movement within the upper sand portion of the aquifer in the area northwest of the southern bedrock valley. The assumed pumping of well PW03 (Figure 5.16) does, however, result in predicted capture of all of the flow paths originating from the former grain storage site within approximately 20 yr, in agreement with the restricted downgradient extent of the actual plume. (The apparent termination of flow paths at PW04 in Figure 5.16 is coincidental; these pathways continue to extend toward well PW03 at longer simulation times.)

A simulated contaminant migration period of only 5 yr is shown in both Figures 5.15 and 5.16 for particle tracks originating at the site of the former fumigant storage building. The
FIGURE 5.15 Forward Particle Tracking Analysis Showing Predicted Upper-Sand Migration Pathways (in red) for Contaminants Originating at the Former CCC/USDA Site and the Former Fumigant Storage Building Site (Pathways originating at the former CCC/USDA site reflect simulated 20-yr migration. Pathways originating at the former storage building site reflect 5-yr migration. The mapped outline of the existing plume is shown in blue. The upper-sand potentiometric surface is as shown in Figure 5.10. Contour interval = 1 ft.)
FIGURE 5.16 Forward Particle Tracking Analysis Showing Predicted Upper-Sand Migration Pathways (in red), Assuming Pumping of Well PW03, for Contaminants Originating at the Former CCC/USDA Site and the Former Fumigant Storage Building Site (Pathways originating at the former CCC/USDA site reflect simulated 20-yr migration. Pathways originating at the former storage building site reflect 5-yr migration. The mapped outline of the existing plume is shown in blue. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
observed similarity of the predicted migration pathways and the actual contaminant distribution in this region of the plume, in conjunction with the high carbon tetrachloride concentration (180 µg/L) identified in groundwater at the former building site, empirically suggests that carbon tetrachloride leaching from an inferred residual soil source in this area might postdate the onset of formation of the main body of the existing groundwater plume at Agra.

The two-dimensional particle tracking algorithm could not be used to evaluate the downward flow of groundwater into the deeper portions of the southern bedrock valley proposed in the conceptual model. To investigate the three-dimensional aspects of contaminant migration within the modeled aquifer system, a simulated “tracer” test was performed by using the three-dimensional, advective-dispersive transport model MT3d (Zheng 1992). The objective of these simulations was to predict the extent and geometry of contamination expected within the aquifer; no attempt was made to simulate in detail the concentrations observed in the actual plume. For simplicity, the experiment was performed by imposing a fixed groundwater contaminant concentration of 180 µg/L at the grid cells representing both the former CCC/USDA and storage building sites, assuming that no other contaminant was present initially, and by forward modeling the development of a plume downgradient over 20 yr. The results of these experiments for the ambient and PW03-pumping scenarios are presented in Figures 5.17-5.20.

The results of the simulations show that, under either groundwater flow scenario, contaminant migration into the deeper portions of the aquifer within the southern bedrock valley is predicted by the numerical models. Both simulations predict a modeled plume in the upper sand that is wider along its western margin than the actual plume; this is a result of the assumed continuous leaching of carbon tetrachloride at the former storage building site. Predicted and actual plumes within the upper sand are quite similar for either migration scenario, but the distribution of carbon tetrachloride at the downgradient toe of the model plume under the PW03 pumping scenario (Figures 5.19 and 5.20) more closely matches the actual plume in the upper and basal sand intervals. This result is in qualitative agreement with the presumed use of PW03 for drinking water supply from 1954 until 1985 and suggests that operation of PW03, and subsequently PW04, has in fact prevented further downgradient migration of carbon tetrachloride within both the upper and basal sand intervals.
FIGURE 5.17  Transport Analysis Showing Simulated 20-Year Development of an Upper-Sand Contaminant Plume Originating at the Former CCC/USDA Site and the Former Fumigant Storage Building Site (Predicted concentrations are shown in red; contour interval = 40 µg/L. The mapped outline of the existing plume is shown in blue. The upper-sand potentiometric surface is as shown in Figure 5.10; contour interval = 1 ft.)
FIGURE 5.18 Transport Analysis Showing Simulated 20-Year Development of a Basal-Sand Contaminant Plume Originating at the Former CCC/USDA Site and the Former Fumigant Storage Building Site (Predicted concentrations are shown in red; contour interval = 20 µg/L. The mapped outline of the existing plume is shown in blue. The basal-sand potentiometric surface is as shown in Figure 5.11; contour interval = 1.0 ft.)
FIGURE 5.19 Transport Analysis Showing Simulated 20-Year Development of an Upper-Sand Contaminant Plume, Assuming Pumping of Well PW03, Originating at the Former CCC/USDA Site and the Former Fumigant Storage Building Site (Predicted concentrations are shown in red; contour interval = 40 µg/L. The mapped outline of the existing plume is shown in blue. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL; contour interval = 1 ft.)
FIGURE 5.20 Transport Analysis Showing Simulated 20-Year Development of a Basal-Sand Contaminant Plume, Assuming Pumping of Well PW03, Originating at the Former CCC/USDA Site and the Former Fumigant Storage Building Site (Predicted concentrations are shown in red; contour interval = 20 µg/L. The mapped outline of the existing plume is shown in blue. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL; contour interval = 0.5 ft.)
5.4 Sensitivity Analyses

Sensitivity analyses were carried out by systematically varying individual model input parameters, under steady-state conditions, with the parameters listed in Table 5.2 and the potentiometric surfaces shown in Figures 5.10 and 5.11 as base conditions. The experimental conditions of these analyses are summarized in Table 5.3. The results of the analyses are presented in Appendix C and summarized in Table 5.4 and Figures 5.21 and 5.22.

The results of the sensitivity runs indicate that, by far, the simulated water levels in both the upper sand/silt unit and the basal sand (model layers 1 and 3) are most strongly influenced by the assumed hydraulic conductivities selected for these layers. Changes in the $K_h$ of the upper sand facies of model layer 1 directly influenced the resulting predicted heads at monitoring points upgradient of the southern bedrock valley margin but had only a minor effect on predicted heads within the limits of the bedrock valley because of the greater net transmissivity of the thicker sedimentary section within the valley. In contrast, decreases in the imposed $K_h$ of the model layer 1 silt facies had a very significant influence on estimated heads throughout the modeled domain, because this parameter largely determines the hydraulic gradients and therefore the volume of available groundwater flow entering the entire model domain at the northwestern (upgradient) boundary of layer 1.

5.5 Summary

The results of the simulations presented in Section 5.3 demonstrate that the conceptual and calibrated numerical models of groundwater flow and contaminant transport developed for this study yielded predicted hydraulic heads, groundwater flow directions, and three-dimensional contaminant migration patterns that are qualitatively and/or quantitatively in agreement with the values measured for the actual Agra aquifer. On this basis, we concluded that the calibrated models are suitable for use in investigating possible remedial alternatives for Agra.
### TABLE 5.2 Summary of Parameters Used in the Calibrated Groundwater Flow Model

<table>
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<th>Parameter</th>
<th>Value Used</th>
<th>Model Layer 1</th>
<th>Model Layer 2</th>
<th>Model Layer 3</th>
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<td>Figure 5.2</td>
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<td></td>
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<tr>
<td>Vertical hydraulic conductivity (ft/d)</td>
<td>Figure 5.2</td>
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<td>Effective porosity (%)</td>
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<td>40.0</td>
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<td>Specific storage (1/ft)</td>
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TABLE 5.3 Sensitivity Analysis Run Conditions

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<td>Model layer 1, sand facies $K_h$ decreased by 50% to 2 ft/d</td>
</tr>
<tr>
<td>S2</td>
<td>Model layer 1, sand facies $K_h$ increased by 50% to 6 ft/d</td>
</tr>
<tr>
<td>S3</td>
<td>Model layer 1, silt facies $K_h$ decreased by 75% to 0.5 ft/d</td>
</tr>
<tr>
<td>S4</td>
<td>Model layer 1, silt facies $K_h$ decreased by 50% to 1 ft/d</td>
</tr>
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<td>Model layer 1, sand facies $K_v$ decreased by 50% to 2 ft/d</td>
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<tr>
<td>S6</td>
<td>Model layer 1, sand facies $K_v$ decreased by 75% to 1 ft/d</td>
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<td>S7</td>
<td>Model layer 2, sandy zone $K_h$ increased by 82% to 4 ft/d</td>
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### TABLE 5.4 Results of Sensitivity Analysis Runs

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<td>-0.7</td>
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Results shown in Figure 5.22

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</tbody>
</table>

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**Notes:**

- **a** Values are shown as deviation from measured head (ft) at the monitoring point, calculated as (modeled minus measured).
- **b** Root mean square error.
FIGURE 5.21 Results of Sensitivity Analyses for the Calibrated Groundwater Flow Model for Runs Yielding Absolute Deviations of < 1.5 ft from Measured Values at All Calibration Points (Conditions of simulation runs are in Table 5.3.)
FIGURE 5.22 Results of Sensitivity Analyses for the Calibrated Groundwater Flow Model for Runs Yielding Absolute Deviations of > 1.5 ft from Measured Values (Conditions of simulation runs are in Table 5.3.)
6 Evaluation of Aquifer Restoration Requirements

Groundwater restoration scenarios for Agra were evaluated on the basis of the calibrated models of groundwater flow and contaminant transport described in Section 5. No evidence has been found for a residual soil source of contaminants in surface or subsurface soils examined from the former CCC/USDA site. The results indicate that the northwestern (upgradient) margin of the existing groundwater contaminant plume has already migrated downgradient from the inferred former source area. Therefore, the simulations presented in this section focus on the prediction of migration patterns for the present contaminant plume only. The no-action alternative was modeled first to determine the risk associated with allowing attenuation of the carbon tetrachloride plume to occur by natural processes. In each case, continued use of municipal water supply wells PW01, PW02, and PW05 was assumed to have no effect on groundwater flow and contaminant migration patterns in the vicinity of the carbon tetrachloride plume.

As noted in Section 3.1, however, available contaminant data suggest that a residual soil source of contamination might exist at the site of the former fumigant storage building located southwest of the former CCC/USDA site. No subsurface sampling was conducted at this site as part of the Argonne ESC investigations, because there is no known relationship between possible fumigant storage at this location and former CCC/USDA activities in the town. Possible scenarios that might result in continued groundwater contamination from the hypothesized soil source are addressed briefly in Section 8, however, to assist the town government and/or regulatory agencies in evaluating potential future groundwater concerns at Agra.

6.1 No-Action Alternative

Two plausible groundwater use scenarios for the town were considered under the no-action alternative. First, groundwater flow and contaminant transport were modeled under the assumption that all future use of both wells PW03 and PW04 would be prohibited, resulting in migration of the plume under the natural, ambient hydraulic gradient. An alternative (possibly more likely) scenario was also considered under the assumption that seasonal use of well PW04 for watering of the high school football field, as currently practiced by the town, would continue.

6.1.1 No Further Use of Well PW04

Simulations were carried out under the assumption that no natural decay of carbon tetrachloride and no future use of either well PW03 or PW04 will occur over at least a 60-yr
period. The results are presented in Figures 6.1-6.6. Results representing expected plume configurations in the upper and basal sands after 20 yr of migration are shown in Figures 6.1 and 6.2. A significant decrease in carbon tetrachloride concentrations within the upper sand interval, as well as a reduction in the extent of groundwater contamination, is predicted within 20 yr under this scenario, although relatively little further movement of the downgradient toe of the plume is indicated. The predicted decreases in carbon tetrachloride contamination in the upper sand would be largely compensated by the growth of a more areally extensive plume within the basal sand unit, indicating that significant downward migration of carbon tetrachloride would be expected in response to the natural vertical gradient at the northwestern margin of the southern bedrock valley. Plume configurations predicted after 40 yr and 60 yr of migration, shown in Figures 6.3-6.6, depict more rapid downgradient migration and a decrease of concentrations in the basal sand portion of the aquifer relative to the upper sand, because of the higher hydraulic conductivity and greater groundwater (dilution) volume of the basal sand unit.

In the absence of natural decay, residual carbon tetrachloride concentrations on the order of 10-15 µg/L would be expected to remain within the aquifer after 60 yr. Modeling of the no-action scenario under the assumption of a nominal 1%/yr natural decay rate, shown in Appendix D, Figures D.1-D.5, results in predicted carbon tetrachloride concentrations of 5-10 µg/L at the end of the same 60-yr time interval. These residual concentrations will continue to be attenuated by dispersion, mixing, and decay with further migration downgradient. Prediction of the long-term migration pathway of the residual plume is problematic because of the very strong control of bedrock topography on the presence and lithologic characteristics of aquifer sediments. Regional mapping of the buried Cretaceous bedrock surface in western Phillips County and western Kansas (Merriam 1988) suggests that groundwater within the southern bedrock valley might ultimately be discharged to the surface at bedrock exposures within several ephemeral stream beds that are tributary to Deer Creek, approximately 2.5 mi south-southeast of Agra and 3 mi north-northeast of the town of Kirwin. Results of the risk analyses presented in Section 7 demonstrate, however, that groundwater contaminant levels in the absence of pumping of well PW04 are unlikely to pose an unacceptable health risk to any existing or potential residents outside the present boundaries of the town.
FIGURE 6.1 Simulated Upper-Sand Carbon Tetrachloride Plume Resulting from 20-Year Migration under the No-Action Scenario (The upper-sand potentiometric surface is as shown in Figure 5.10; water level contour interval = 1 ft. Maximum predicted concentration = 24 µg/L. Contour interval = 10 µg/L. Labeled points 1-3 show the locations of hypothetical residences considered in the assessment of health risks; see Section 7.1.)
FIGURE 6.2 Simulated Basal-Sand Carbon Tetrachloride Plume Resulting from 20-Year Migration under the No-Action Scenario (The basal-sand potentiometric surface is as shown in Figure 5.11; water level contour interval = 1 ft. Maximum predicted concentration = 33 µg/L. Contour interval = 10 µg/L. Labeled points 1-3 show the locations of hypothetical residences considered in the assessment of health risks; see Section 7.1.)
FIGURE 6.3 Simulated Upper-Sand Carbon Tetrachloride Plume Resulting from 40-Year Migration under the No-Action Scenario (The upper-sand potentiometric surface is as shown in Figure 5.10; water level contour interval = 1 ft. Maximum predicted concentration = 16 µg/L. Contour interval = 10 µg/L. Labeled points 1-3 show the locations of hypothetical residences considered in the assessment of health risks; see Section 7.1.)
FIGURE 6.4 Simulated Basal-Sand Carbon Tetrachloride Plume Resulting from 40-Year Migration under the No-Action Scenario (The basal-sand potentiometric surface is as shown in Figure 5.11; water level contour interval = 1 ft. Maximum predicted concentration = 20 µg/L. Contour interval = 10 µg/L. Labeled points 1-3 show the locations of hypothetical residences considered in the assessment of health risks; see Section 7.1.)
FIGURE 6.5 Simulated Upper-Sand Carbon Tetrachloride Plume Resulting from 60-Year Migration under the No-Action Scenario (The upper-sand potentiometric surface is as shown in Figure 5.10; water level contour interval = 1 ft. Maximum predicted concentration = 11 µg/L. Contour interval = 5 µg/L. Labeled points 1-3 show the locations of hypothetical residences considered in the assessment of health risks; see Section 7.1.)
FIGURE 6.6 Simulated Basal-Sand Carbon Tetrachloride Plume Resulting from 60-Year Migration under the No-Action Scenario (The basal-sand potentiometric surface is as shown in Figure 5.11; water level contour interval = 1 ft. Maximum predicted concentration = 7 µg/L. Contour interval = 5 µg/L. Labeled points 1-3 show the locations of hypothetical residences considered in the assessment of health risks; see Section 7.1.)
6.1.2 Continued Seasonal Use of Well PW04 for Irrigation

Ownership of former municipal well PW04 was transferred to the high school in Agra in 1991, at which time the well was disconnected from the town’s water distribution system. Since that time, well PW04 has been used for seasonal watering of the high school football field.

Groundwater level monitoring data presented in Section 4.1.2 demonstrate that a local cone of depression develops within both the upper and basal sand units of the aquifer at Agra during the operation of well PW04 for irrigation and that drawdowns generated by the well do not fully recover to prepumping water levels when pumping occurs periodically.

To illustrate this effect, a series of model potentiometric surfaces for the upper sand and basal sand units was generated for a hypothetical seven-day pumping period, during which PW04 was operated for 12 hr each day, followed by 12 hr of water level recovery. A model pumping rate of 44 gpm was used, on the basis of field-estimated flow rates for the high school sprinkler system under typical operating conditions. The results of these analyses are presented in Appendix D, Figures D.6-D.20.

Reverse particle tracking path lines representing an arbitrary length of time have been superimposed in Figure 6.7 on the upper-sand potentiometric surface resulting after 12 hr of pumping of PW04, to emphasize the groundwater flow regime developed after only one day of irrigation. Figures D.6-D.13 in Appendix D show that the cone of depression developed around well PW04 will persist during the intervening nonpumping cycles because of the slow recovery rate of heads within the upper sand (Figure 4.9). The path lines demonstrate that cyclic pumping of well PW04 will result in containment and partial capture of the upgradient portion of the carbon tetrachloride plume within the upper sand while the well is being used. Particle tracking could not be used to delineate flow paths for the corresponding basal-sand potentiometric surfaces because of numerical interferences caused by the proximity of well PW04 to the modeled boundary of the bedrock valley. The hydraulic head contour relationships for the basal-sand simulations presented in Figures D.14-D.20 suggest, however, that capture of the upgradient portion of the plume within the basal sand might also be expected during irrigation pumping.
FIGURE 6.7 Simulated Upper-Sand Potentiometric Surface Resulting from Pumping of Well PW04 for 12 Hours at a Rate of 44 gpm (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft. Green dashed lines show groundwater flow pathways of arbitrary length within the sand at the end of pumping. Blue outline shows extent of the present carbon tetrachloride plume.)
6.2 Summary of Aquifer Restoration Evaluation

The results of these analyses indicate that pumping of well PW04 for watering of the high school football field would be expected to reduce further the extent and downgradient migration of carbon tetrachloride contamination within the Agra aquifer, relative to the nonpumping scenario outlined in Section 6.1.1. In light of this observation, the risk calculations presented in Section 7 for the nonpumping scenario are considered to be conservative estimates.
7 Risk Assessment for the No-Action Alternative

Field measurements documenting the present distribution of carbon tetrachloride in groundwater at the Agra site, together with the results of modeling the future migration of the observed contaminant plume, were used to update the baseline assessment of risks to human health and the environment resulting from exposure to carbon tetrachloride. This risk assessment presents an analysis of risks associated with current and potential future water use conditions in the vicinity of the site.

The risk assessment presented here was calculated on the basis of the U.S. Environmental Protection Agency's (EPA's) Risk Assessment Guidance for Superfund (EPA 1989). Calculations were carried out initially for the contaminant migration scenarios presented under the no-action alternative, to provide the basis for decisions about the possible need for an alternative groundwater remedial action at Agra.

7.1 Water Use and Contaminant Exposure Scenarios

Exposure of the Agra population to water containing carbon tetrachloride for domestic use is prevented because residents receive their supply of water via a municipal distribution system. Water is presently obtained for this system from wells PW01 and PW02, located in the northwestern portion of the town, and from well PW05, located approximately 1 mi east of Agra. Testing of these wells has shown them to be free of carbon tetrachloride contamination. The plume development scenarios discussed in Section 6 indicate that continued migration of the existing plume will pose no threat of future contamination of the groundwater supplied to the public water distribution system from these wells. Because continued operation of the public water system is assumed, no risk from exposure to carbon tetrachloride is anticipated for current or potential future residents living within the service area of this system.

The transport simulations presented for the no-action alternative suggest, however, that continued downgradient migration of the carbon tetrachloride plume might result in movement of the contaminant southeastward, beyond the limits of the area currently served by the public water supply. Carbon tetrachloride concentrations downgradient within the aquifer are expected to be highest if the use of well PW04 for irrigation is completely discontinued. Field reconnaissance indicates that land downgradient of the town, within the projected migration pathway, is used entirely for agricultural purposes and is very sparsely populated.
As a potential worst-case scenario, we have considered the unlikely situation in which
(1) new residences are built within the expected migration pathway on private lands (currently
cultivated fields) lying just outside the present service limits of the distribution system and (2) the
residents have to obtain their entire domestic water supply from new private wells drilled in the
contaminated aquifer. Three hypothetical locations for new residences were considered for the
potential assessment of risk; these sites are shown as Locations 1-3 in Figures 6.1-6.6 and
Appendix D, Figures D.1-D.5. Results of the transport modeling indicate that the highest
predicted contaminant levels under the no-action alternative (with no pumping of PW04) will be
encountered at Location 2, immediately south of State Route 35 at the southern edge of town.

7.2 Contaminant Concentrations

Future carbon tetrachloride concentrations at Location 2 were determined from the results
of groundwater flow and transport modeling described in Section 6.1. From these results, the
30-yr periods having the highest cumulative concentrations were selected for risk analysis, 30 y
representing the 95th percentile for duration of residency by an individual (EPA 1989).

If any new wells were screened only within the more productive basal sand unit,
contaminant concentrations exceeding the maximum contaminant level (MCL) of 5 µg/L would
first reach Location 2 in the year 2009. The 30-yr residency period producing the maximum
exposure for residents would begin in the year 2010. Groundwater carbon tetrachloride
concentrations would reach a maximum of 23.4 µg/L in 2016, if no natural decay occurred, and
would again be below the MCL of 5 µg/L by 2045.

As a second alternative, pumping from both the upper and basal sands was considered.
This alternative would produce a mixture of waters, combined in proportion to the relative
transmissivities of the sand units. The result would be slightly reduced carbon tetrachloride
concentrations in the produced water, with the maximum concentration (if no decay occurred) just
under 22 µg/L.

Risk calculations were performed on the basis of these water use scenarios under the
assumption of no natural decay of carbon tetrachloride, as well as for the case of natural decay at
the minimal rate of 1%/yr. All calculations assumed that no future pumping of wells PW03 or
PW04 would occur.
7.3 Dynamic Risk Assessment

A dynamic risk assessment method was used to calculate health risks for carbon tetrachloride exposures incurred each year over the lifetime of a resident using groundwater at Location 2. Standard assumptions regarding exposure pathways and contaminant intakes were used (see Appendix E, Tables E.1-E.8), but exposure was calculated year by year, on the basis of the relevant projected plume concentration. Carcinogenic risks were then integrated over the period of residency to arrive at cumulative risk values.

All parameters, assumptions, and calculations used in the risk assessment are presented in the tables and figures of Appendix E. Certain tables of results in Appendix E make reference to chloroform, a common by-product of carbon tetrachloride, although no chloroform has been found in any groundwater samples taken at Agra. The results of the assessment are summarized in Table 7.1.

TABLE 7.1 Summary of Risks under the No-Action Alternative

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<th>Chronic Noncarcinogenic</th>
<th>Subchronic Noncarcinogenic</th>
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<td></td>
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* Calculated for maximum exposure occurring in 2016.
7.3.1 Carcinogenic Risk Assessment

Carcinogenic risk is a function of cumulative exposure to a contaminant over a lifetime or over the duration of residency at a contaminated site. For the 30-yr maximum exposure period, the maximum total carcinogenic health risk from exposure to the migrating carbon tetrachloride plume, if no natural decay occurred and water use was exclusively from the basal sand, would be 3.88E-05 for adults and 5.81E-05 for children. Both of these values are within the acceptable range of 1E-06 to 1E-04 defined in 40 CFR 300.430. These values decrease to 2.97E-05 and 4.55E-05, respectively, if the effects of natural decay at a rate of 1%/yr are invoked.

7.3.2 Noncarcinogenic Risk Assessment

Two calculations of noncarcinogenic risk were made. The maximum computed chronic noncarcinogenic hazard index, representing the ratio of actual intake of contaminant to acceptable dose, is 0.86 for adults and 1.22 for children. Only the hazard index for a child born at the worst possible time exceeds the acceptable risk level of 1.0. This index is decreased to 0.96 for a child if a 1% decay rate for carbon tetrachloride is taken into account.

Calculations were also made of the subchronic noncarcinogenic hazard index, which is based on the highest exposure over a period of less than 7 yr. The subchronic hazard index, computed for the year of highest contaminant concentration, is 0.10 for adults and 0.36 for children. These values are well within the acceptable limit for this parameter.

7.4 Uncertainties

This risk assessment was prepared by using assumptions recommended by the EPA (1989). As such, the assessment incorporates uncertainties delineated in that guidance. Other uncertainties specifically related to this case consist primarily of the following:

- The presence of human receptors at the locations considered is not simply uncertain but a hypothetical worst-case assumption, as is the necessity for such residents to use contaminated wells for their only supply of water. The water use scenarios presented do not consider the likelihood that the city would extend its public water supply to new residences established near the city limits.
• The risk values presented were generated under the assumption that no further use of well PW03 or PW04 would occur throughout the 30-yr period of the risk assessment. As noted in Section 6.1.2, continued operation of well PW04 for irrigation may reasonably be expected. Such operation would reduce long-term contaminant levels reaching locations downgradient from the current plume site.

• No inhalation reference concentration for carbon tetrachloride is listed in the EPA IRIS (Integrated Risk Information System) database or in the Health Effects Assessment Summary Tables (HEAST). As a result, this factor would be omitted in some risk assessment models. The risk assessment presented here uses a provisional reference concentration based on an unofficial EPA memo. Until sufficient evidence has been accumulated by the EPA on the health effects of carbon tetrachloride inhalation, the noncarcinogenic hazard index will contain uncertainty in risks calculated for inhalation pathways. This factor is significant, in that vapor inhalation accounts for about one-fourth of the adult hazard index and one-third of the child hazard index.

• A situation similar to that at Agra occurs at Bruno, Nebraska, which was the subject of a public health assessment conducted by the U.S. Department of Health and Human Services in 1994 (DHHS 1994). A conclusion of this assessment was that chronic exposure to carbon tetrachloride in groundwater at a level of 40 µg/L poses no threat of adverse cancer or noncancer health effects. The worst case in the no-action scenario at Agra produces a maximum annual groundwater concentration of about 24 µg/L. The experience at Bruno suggests ambiguity in the current interpretation of laboratory studies of the health effects of carbon tetrachloride exposure and adds uncertainty to calculations based on these interpretations.

7.5 Conclusions

The principal exposure pathways contributing to both carcinogenic and noncarcinogenic risks associated with carbon tetrachloride in the groundwater at Agra are the ingestion of drinking water and the inhalation of vapors during showering or bathing. Noncarcinogenic risk from carbon tetrachloride inhalation was included in Argonne’s risk assessment, although it is not currently recognized in EPA databases.
The calculated carcinogenic risks from residential exposure to carbon tetrachloride in groundwater are within acceptable limits established by the *Code of Federal Regulations*. The only risk exceeding standards is the chronic noncancerous risk to a child born at the worst possible time and remaining at the residence for 28 yr, under the assumption of no natural decay of carbon tetrachloride. In this case the hazard index reaches 1.2, compared with a standard of 1.0. Exclusion of the questionable vapor inhalation pathways or inclusion of a conservative decay rate for carbon tetrachloride of 1%/yr would decrease the child hazard index to well within acceptable limits. The peak concentrations anticipated in the worst-case scenario described in Section 7.3 (no decay, water withdrawal from the basal sand only) are lower than those documented elsewhere by the U.S. Department of Health and Human Services to be harmless to exposed humans. Plume concentrations in all cases analyzed will fall below those used for the risk assessment calculations if the current practice of seasonal pumping of well PW04 continues.

Argonne therefore concludes that future migration of the existing carbon tetrachloride plume at Agra will pose no unacceptable health risks to current or possible future residents in the vicinity of Agra.
8 Evaluation of Possible Contaminant Migration from the Former Commercial Storage Building Site

No link is known between the commercial fumigant storage building, previously located at Main Street and Railroad Avenue, and the former CCC/USDA activities at Agra. Contaminant migration scenarios and risks that might result from the inferred presence of a residual carbon tetrachloride source at the storage building site are briefly presented in this section, however, to assist the town’s government officials and regulatory agencies in evaluating potential future concerns about groundwater contamination at Agra.

8.1 Possible Migration Scenarios

Two hypothetical contaminant migration scenarios were modeled on the basis of the available groundwater contaminant data to investigate the possible effect on groundwater of a residual carbon tetrachloride source within soils at the former storage building site. A carbon tetrachloride concentration of 180 µg/L was measured in groundwater at the building site (see Figure 3.1) during the Argonne Phase I ESC study (Argonne 1995a). Both scenarios were modeled under the conservative assumption that no future pumping of either well PW03 or PW04 would occur.

Contaminant migration was simulated initially under the hypothesis that natural recharge water infiltrating the vadose zone at the former building site would acquire a fixed carbon tetrachloride concentration of 180 µg/L during passage through the contaminated soils. A long-term average recharge rate of 2 in./yr was assumed, on the basis of published estimates for the region (Dugan and Peckenpaugh 1985). The results of the transport simulation are shown in Figure 8.1 for 20 yr of migration. Comparison of Figure 8.1 to results for the no-action alternative depicted in Figure 6.1 suggests that the added contribution of carbon tetrachloride from the soil source under this scenario would have little impact on contaminant concentrations or risks associated with migration of the preexisting plume. At longer simulation times, the narrow plume of low concentration extending downgradient from the source area, shown in Figure 8.1, assumes a steady-state condition and does not increase in size or concentration.

A second, more severe, scenario was modeled under the assumption that carbon tetrachloride would be leached from the source area in amounts sufficient to maintain a long-term
FIGURE 8.1 Simulated Upper-Sand Carbon Tetrachloride Plume Resulting from 20-Year Migration under Hypothetical Soil Source Scenario 1, Described in Section 8.1 (The upper-sand potentiometric surface is as shown in Figure 5.10; water level contour interval = 1 ft. Maximum predicted concentration = 24 µg/L. Contour interval = 10 µg/L.)
concentration of 180 µg/L in the saturated zone directly beneath the site. To achieve this condition, the leachate reaching the water table would have to have a concentration considerably higher than 180 µg/L in order to compensate for the effects of natural dilution within the saturated zone. Predicted contaminant migration patterns under this scenario are summarized in Figures 8.2-8.7. The simulation results suggest that a new carbon tetrachloride plume, comparable in areal extent to the existing plume, could develop downgradient of the former building site within 20 yr under the assumed source conditions. Prolonged migration under this model, depicted in Figures 8.4-8.7, would result in further downgradient extension of the plume beyond the municipal limits of Agra.

The plume migration patterns presented in Figures 8.1-8.7 indicate that the hypothesized presence of a residual soil source of carbon tetrachloride at the former storage building site poses no threat of future contamination of groundwater supplied to the public water distribution system from presently operational municipal wells PW01, PW02, and PW05.

Although the models described above are hypothetical, they do suggest that a residual soil source at the former fumigant storage building site might affect health risks arising from the downgradient migration of contaminated groundwater in the vicinity of Agra. We have therefore performed a risk estimate based on the second, more extreme source model depicted in Figures 8.2-8.7.

8.2 Estimation of Potential Risks

A risk calculation, identical to that described in Section 7, was conducted for the second, more severe scenario, in which contaminated soil at the former fumigant storage building is assumed to result in a fixed carbon tetrachloride concentration of 180 µg/L in groundwater beneath the site. In keeping with the approach outlined in Section 7, risk values were calculated with the assumption of (1) no natural decay of carbon tetrachloride and (2) a minimal decay rate for carbon tetrachloride of 1%/yr. Plume diagrams for the latter scenario are not shown, because the predicted migration pathways are identical in both cases; only the resulting concentrations are affected. Results of these calculations are included in Appendix E, Tables E.18-E.23 and Figures E.13 and E.14, and are summarized in Table 8.1.

The addition of a continuous soil source as described in Section 8.1 results in minor changes to the predicted location of maximum exposure, the exposure levels, and the estimated risks to hypothetical future residents within the potential plume migration pathway.
FIGURE 8.3 Simulated Basal-Sand Carbon Tetrachloride Plume Resulting from 20-Year Migration under Hypothetical Soil Source Scenario 2, Described in Section 8.1 (The basal-sand potentiometric surface is as shown in Figure 5.11; water level contour interval = 1 ft. Maximum predicted concentration = 32 µg/L; contour interval = 20 µg/L.)
FIGURE 8.4 Simulated Upper-Sand Carbon Tetrachloride Plume Resulting from 40-Year Migration under Hypothetical Soil Source Scenario 2, Described in Section 8.1 (The upper-sand potentiometric surface is as shown in Figure 5.10; water level contour interval = 1 ft. Maximum predicted concentration = 180 µg/L; contour interval = 20 or 40 µg/L.)
FIGURE 8.5 Simulated Basal-Sand Carbon Tetrachloride Plume Resulting from 40-Year Migration under Hypothetical Soil Source Scenario 2, Described in Section 8.1 (The basal-sand potentiometric surface is as shown in Figure 5.11; water level contour interval = 1 ft. Maximum predicted concentration = 60 µg/L; contour interval = 20 µg/L.)
FIGURE 8.2 Simulated Upper-Sand Carbon Tetrachloride Plume Resulting from 20-Year Migration under Hypothetical Soil Source Scenario 2, Described in Section 8.1 (The upper-sand potentiometric surface is as shown in Figure 5.10; water level contour interval = 1 ft. Maximum predicted concentration = 180 µg/L; contour interval = 20 or 40 µg/L.)
FIGURE 8.6 Simulated Upper-Sand Carbon Tetrachloride Plume Resulting from 60-Year Migration under Hypothetical Soil Source Scenario 2, Described in Section 8.1 (The upper-sand potentiometric surface is as shown in Figure 5.10; water level contour interval = 1 ft. Maximum predicted concentration = 180 µg/L; contour interval = 20 or 40 µg/L.)
FIGURE 8.7 Simulated Basal-Sand Carbon Tetrachloride Plume Resulting from 60-Year Migration under Hypothetical Soil Source Scenario 2, Described in Section 8.1 (The basal-sand potentiometric surface is as shown in Figure 5.11; water level contour interval = 1 ft. Maximum predicted concentration = 69 µg/L; contour interval = 20 µg/L.)
TABLE 8.1 Summary of Estimated Risks with a Continuous Soil Source

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Carcinogenic Risk</th>
<th>Chronic Noncarcinogenic</th>
<th>Subchronic Noncarcinogenic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adult</td>
<td>Child</td>
<td>Adult</td>
</tr>
<tr>
<td>No Decay of Carbon Tetrachloride</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumping from basal and upper sands</td>
<td>5.32E-05</td>
<td>6.69E-05</td>
<td>1.18</td>
</tr>
<tr>
<td>Natural Decay of 1% per Year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumping from basal and upper sands</td>
<td>3.3E-05</td>
<td>4.20E-05</td>
<td>0.73</td>
</tr>
</tbody>
</table>

* Calculated for maximum exposure occurring in 2055.

8.2.1 Exposures

Figures 8.2-8.7 indicate that the zone of highest concentration within the plume generated under the continuous-soil-source model is expected to follow a pathway lying slightly to the west of that expected for the present groundwater plume. The level of highest exposure under this scenario would not be reached until 2053, when carbon tetrachloride concentrations are projected to be over 31 µg/L at hypothetical residence Location 1 shown in these figures. If natural decay of carbon tetrachloride at a rate of 1%/yr is taken into account, this level is reduced to 18.4 µg/liter. The 30-yr period of residence with the highest exposure during the 60 yr included in the plume model begins in 2026, and the period of highest exposure for a child occurs if the child is born in 2034.

8.2.2 Risks

The estimated carcinogenic risk for an adult resident at Location 1 if no natural contaminant decay occurs was calculated to be 5.32E-05, while the carcinogenic risk for a child born in the worst-case year would be 6.69E-05. These risk levels are within the 40 CFR 300 limit of 1E-04.
The noncarcinogenic hazard index for an adult if no natural decay occurs is 1.18, and that for a child is 1.42. Both these indexes exceed the acceptable limit of 1.0. When 1% decay is considered, the hazard index for an adult is reduced to 0.73, and that for a child is 0.89.

8.3 Summary

The hypothetical scenarios outlined demonstrate that the possible existence of a residual soil source of carbon tetrachloride at the site of the former grain fumigant storage building poses no threat of future contamination of groundwater supplied to the public water distribution system from wells PW01, PW02, and PW05. A persistent, concentrated soil source would be required to generate groundwater contaminant levels that would pose an unacceptable health risk to possible future residents downgradient of the town who were not served by the Agra public water supply system. Whether carbon tetrachloride is actually present in soils at the former building site and at what concentration is, however, unknown.
9 Conclusions and Recommendations

9.1 Conclusions

The major conclusions from the Agra feasibility investigations are as follows:

- Simulation of the no-action alternative under a range of plausible groundwater flow and contaminant migration scenarios indicated that the present carbon tetrachloride plume will continue to move downgradient to the southeast, under the control of the ambient hydraulic gradients within the aquifer. Growth of the plume within the basal sand portion of the aquifer, as well as depletion of concentrations and reduction in the areal extent of contamination in the upper sand interval, are predicted because of downward migration of contaminated water from the upper sand at the upgradient margin of the southern bedrock valley. Natural restoration of groundwater within the municipal limits of the town is expected within 40-60 yr, as a result of downgradient migration, mixing, dispersion, and possible natural decay of the residual contaminant plume.

- The predicted reduction of contaminant levels within the aquifer might be enhanced if the current seasonal pumping of former municipal well PW04 for irrigation use only continues.

- The plume development scenarios discussed in Section 6 indicate that continued migration of the existing plume will pose no threat of contamination to the environment or to groundwater supplied to the public water distribution system from presently operational municipal wells PW01 and PW02, located in the northwestern portion of the town, and from well PW05, located approximately 1 mi east of Agra.

- Dynamic risk assessment calculations for the no-action alternative at Agra indicate that this alternative generates risks well within the acceptable limits. The calculated carcinogenic risks from residential exposure to carbon tetrachloride in groundwater are within acceptable risk limits established by the Code of Federal Regulations. The only risk exceeding standards is the chronic
noncarcinogenic risk to a child born at the worst possible time, who remains at the residence for 28 yr, if no natural decay of carbon tetrachloride occurs. In this case the hazard index reaches 1.2, compared with a standard of 1.0. Exclusion of the questionable vapor inhalation pathways or inclusion of a conservative decay rate of 1%/yr for carbon tetrachloride would reduce the child hazard index to a value well within acceptable limits. The peak concentrations anticipated in the worst-case scenario described in Section 7.3 (no decay, water withdrawal only from the basal sand) are below those documented elsewhere by the U.S. Department of Health and Human Services (DHHS 1994) to be harmless to exposed humans. Plume concentrations under the no-action alternative would be further reduced, to levels below those used for the risk assessment calculations, if the current practice of seasonal pumping of well PW04 continues.

- No link is known between the commercial fumigant storage building previously located at Main Street and Railroad Avenue and the former CCC/USDA activities at Agra. The possibility that a subsurface soil source of carbon tetrachloride remains at this location has been postulated on the basis of available groundwater contaminant data from the site. Hypothetical modeling indicates that a persistent, concentrated soil source would be required to generate groundwater contaminant levels that would pose an unacceptable health risk to possible future residents downgradient of the town who were not served by the Agra public water supply system. The actual presence or concentration of carbon tetrachloride in soils at the former storage building site has not, however, been determined.

9.2 Recommendations

The no-action alternative under CERCLA should be accepted for the Agra aquifer, because the risks posed by this alternative are within EPA-established acceptable limits, and no potential negative environmental impacts would be expected. This option assumes that all drinking water within the town of Agra will continue to come from wells PW01, PW02, and PW05 and that any future wells that might be installed by the town for water supply will be located outside the potential range of contamination.
Further investigation by the appropriate regulatory agencies or the potentially responsible parties is recommended to determine whether a residual source of carbon tetrachloride is present in subsurface soils at the site of the commercial grain fumigant storage building formerly located at Main Street and Railroad Avenue.
10 References


Appendix A:

Drilling Log for Temporary Well SB36
**Argonne National Laboratory**

**Project:** AGRA  
**Ground Elevation:** 1837.48 ft  
**Total Depth:** 65 ft

**Soil Boring ID:** SB36  
**Log Type:** Soil Boring

**Driller:** John Gornick  
**Company:** Layne Western

**Plot Date:** 10/09/96

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**LITHOLOGY**

- **0 ft:** Organics: clays and silts, dark brown, moist, with pebbles; disturbed by cultivation
- **5 ft:** Clay: slightly silty, med. brown to tan, few pebbles, moist
- **10 ft:** Silty clay: slightly sandy, medium brown to tan, slightly moist
- **15 ft:** Silty clay: tan, slightly moist, few pebbles
- **20 ft:** Silty clay: tan, dense, hard, slightly moist
- **25 ft:** Clay: medium to dark brown, dense, with FeOx staining, moist to slightly moist, slightly sandy, v. fine gr.
- **30 ft:** Sand: tan-orange to tan, v. fine, with minor to moderate clay, carbonate pebbles
- **35 ft:** Clayey silt: trace sand, orange to orange-tan
- **40 ft:** Clay: slightly silty, tan, with few sand grains, carbonate grains, moist
- **45 ft:** Silt: clayey, few sand grains, moist to wet, MnOx?
- **50 ft:** Silt: trace sand, clayey, tan, wet
- **55 ft:** Sand/silt/clay: tan, sand v. fine to fine, probably a sandy silt with clay, hole making water; W.L. 45.0' BGL @ 2.55 p.m.-6/20/96
- **60 ft:** Silt: trace sand with clay
- **65 ft:** Silty sand: sand content minor; gravel from 63 - 64' with sand and silt

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**Well Construction**

- **4" sch. 40 PVC from 0 - 64.7'**
- **0.20 slot screen from 42.7 - 62.7'**
- **Seal**
- **Sand pack from 40 - 65'**
Appendix B:

Analysis of Aquifer Pumping Test Results
Appendix B:

Analysis of Aquifer Pumping Test Results

B.1 Introduction

Two constant-discharge-rate pumping tests were conducted at Agra, Kansas, between July 11 and July 16, 1996. The tests were performed (1) to estimate the groundwater flow properties (i.e., transmissivity, hydraulic conductivity, storativity, and specific yield) of the upper sand interval and the basal sand interval and (2) to assess the hydraulic interaction between the upper sand interval and the basal sand interval. The first test involved the pumping of former municipal well PW04 for 25 hr (1,500 min) on July 11 and July 12, 1996. The second test was conducted on July 15, 1996, by pumping shallow well SB36 for 12 hr and 45 min.

The software packages AQTESOLV for Windows® (HydroSOLVE 1996) and PMPTST® (Hall and Chen 1996) were used for analysis of the Agra pumping test results. In all cases, type curves were visually fitted to the data to preferentially weight the time-versus-drawdown data, as necessary.

B.2 Well SB36 Test Results

The following sections describe the background to the SB36 pumping test; the pretest design, data collection, and corrections; pumping test analyses; and conclusions from the test pertaining to the hydraulic properties of the upper sand interval.

B.2.1 Test Background and Design

Well SB36 was installed and screened as a pumping well within the upper sand interval to permit constant-discharge pump testing of this unit. Observation points for the SB36 pumping test were SB23, SB23s, SB28, SB28s, SB37, SB38, and SB38s. The installation of well SB36 and piezometers SB37, SB38, and SB38s is discussed in Sections 2.1 and 2.2. The locations of these borings are shown in Figure 2.1. Table B.1 contains the surveyed coordinates of the monitoring points and their distances from the pumping well, SB36.
TABLE B.1 Survey Locations of Monitoring Points Used for the SB36 Pumping Test at Agra, Kansas

<table>
<thead>
<tr>
<th>Well</th>
<th>North a (ft)</th>
<th>East a (ft)</th>
<th>Distance from SB36 (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB36</td>
<td>520756.54</td>
<td>1686875.80</td>
<td>0</td>
</tr>
<tr>
<td>SB23</td>
<td>520255.14</td>
<td>1687250.14</td>
<td>626</td>
</tr>
<tr>
<td>SB23s</td>
<td>520256.24</td>
<td>1687247.45</td>
<td>623</td>
</tr>
<tr>
<td>SB28</td>
<td>520626.18</td>
<td>1686276.83</td>
<td>613</td>
</tr>
<tr>
<td>SB28s</td>
<td>520631.42</td>
<td>1686276.11</td>
<td>613</td>
</tr>
<tr>
<td>SB37</td>
<td>520832.33</td>
<td>1686934.85</td>
<td>96</td>
</tr>
<tr>
<td>SB38</td>
<td>520912.96</td>
<td>1686987.81</td>
<td>192</td>
</tr>
<tr>
<td>SB38s</td>
<td>520917.71</td>
<td>1686989.77</td>
<td>197</td>
</tr>
</tbody>
</table>

a North and east locations are Kansas State Plane Coordinates shown in feet. Horizontal datum is converted North American Datum (NAD) 27.

B.2.2 Conditions of the SB36 Pumping Test

Well SB36 was pumped for 765 min, from 10:15 until 23:00 on July 15, 1996. A target pumping rate of approximately 10 gpm was originally expected for the SB36 test, but preliminary flow testing indicated that continuous pumping rates above 5 gpm could not be sustained by the well. The SB36 test was performed at a target flow rate of 4.0 gpm, which was held nearly constant throughout the test with only minor fluctuations. No drawdown related to the pumping of SB36 was observed at any of the designated observation points. Therefore, for purposes of analysis, the SB36 pumping test was treated as a single-well test with constant discharge.

B.2.2.1 Data Corrections

The upper sand interval is unconfined. Water levels in wells screened in unconfined aquifers are typically assumed not to be influenced by fluctuations in barometric pressure, but the static water level in SB36 appeared to respond to changes in barometric pressure. Barometric efficiencies are typically estimated for aquifer test wells prior to pump testing, so that a correction can be applied to water level variations observed in the test wells for changes in barometric pressure during the pumping period. A barometric efficiency for SB36 was estimated from data for
Feasibility Study for Agra, Kansas
Version 00, 11/05/96

air pressure versus water level over two time periods at the end of June 1996 (Figure B.1), when water levels in several wells showed little or no influence from the pumping of PW04 for football field watering. The barometric pressure during the same period is shown in Figure B.2. A barometric efficiency of 65% was computed for well SB36 from the relationship shown in Figure B.3.

Although a barometric efficiency of 65% appears unusual for a well screened in an unconfined aquifer, McWhorter and Sunada (1977) pointed out that a barometric response might be observed in unconfined aquifers, if interchange of the air above the water table is restricted by overlying sediments. The upper sand interval is overlain by 30-50 ft of silts and clays, which could account for the barometric efficiency observed.

Water levels during the test were recorded by using pressure transducers and automatic data logging equipment with a logarithmically decreasing sampling frequency. Barometric pressure was also recorded at the site (Figure B.4) throughout the testing period. Figure B.5 shows the raw drawdown data for the SB36 test well, along with the drawdown data corrected for barometric pressure effects during the test, for a barometric efficiency of 65%. Because of the substantial uncorrected drawdown (about 12 ft) in SB36, the barometric correction is negligible.

Under water table conditions, drawdown is associated with a corresponding decrease in saturated thickness and, therefore, transmissivity. According to Walton (1987), analytical models for aquifer test analysis are based on the assumption that drawdown is negligible in comparison to the initial saturated thickness of the aquifer. Consequently, when drawdown is significant, as is the case for the SB36 test, it must be adjusted to compensate for the effects of aquifer dewatering before the test data are analyzed further. The Jacob correction (Jacob 1944) was used for the water table drawdown adjustment, for an assumed average upper-sand thickness of 17 ft in the vicinity of the well. The raw drawdown in SB36 resulting from the pumping test and the drawdown adjusted by the Jacob correction are shown in Figure B.6.

B.2.2.2 Analysis of the SB36 Pumping Test

Aquifer test analyses based on drawdown in the production well are subject to uncertainty because of incomplete knowledge about the effective radius and the pumping efficiency of the well. Several different methods of aquifer test analysis were used to address these uncertainties, and the
FIGURE B.1 Pretest Hydrographs for Temporary Well SB36 and Piezometers SB37, SB38s, and SB38, Showing the Time Intervals Selected for the Estimation of Barometric Efficiencies
Agra, KS Pre-Pumping Test Barometric Pressure

FIGURE B.2 Pretest Barometric Pressure Record
FIGURE B.3  Plot Showing the Barometric Efficiency of Well SB36

SB36 Barometric Efficiency = 65%
FIGURE B.4 Barometric Pressure Record for the Period of Aquifer Testing at Agra
Comparison of SB36 Test Drawdowns

FIGURE B.5 Comparison of Raw Drawdown Recorded in SB36 during Pump Testing with Drawdown Corrected for Barometric Pressure Effects
FIGURE B.6 Comparison of Raw Drawdown Recorded in SB36 during Pump Testing with Drawdown Corrected for Aquifer Dewatering Effects (Jacob correction)
SB-36 TEST NO. 1

Data Set: C:\PROJECTS\ANL\AGRA\SB36PMP1\SB-36C1.AQT
Date: 08/10/96        Time: 21:10:21

AQUIFER DATA

Saturated Thickness: 17. ft

FIGURE B.7 Log-Log Plot of Time versus Corrected Drawdown for SB36
results were evaluated in terms of convergence toward a reasonable solution for transmissivity (and thus hydraulic conductivity) and storativity values for the upper sand. The analyses of Jacob-corrected drawdown in SB36 were performed by assuming that the upper sand interval is unconfined.

The Neuman (1974) solution for pumping tests in unconfined aquifers was first applied to the SB36 test data. Neuman’s method is strictly valid only for drawdown in observation wells screened in unconfined aquifers. This method assumes 100% well efficiency (i.e., that drawdown in the well, after Jacob’s correction is applied, is equivalent to drawdown in the aquifer adjacent to the well).

The shape of the log-log plot of time versus drawdown for SB36 (Figure B.7) suggests a delayed gravity response to drawdown, which is typical for unconfined aquifers. The SB36 drawdown curve might also, however, show a response to thinning or a change in lithology of the aquifer at some distance from the pumping well. Both possibilities were initially considered.

Figure B.8 shows the optimal visual fit of Jacob-corrected drawdown data from SB36 with the Neuman type curve for $\beta = 0.03$. The Neuman method was the only approach used that provides an estimate of specific yield ($S_y$); however, in the absence of knowledge about the effective radius of the well, the computed $S_y$ of 0.6857 is considered unreliable and unrealistically high.

Figures B.9 and B.10, respectively, show the curve fits resulting from application of the Theis (1935) type curve matching and Cooper-Jacob (1946) straight-line analysis techniques to time-versus-drawdown data from the SB36 test, for an assumed well efficiency of 100%. A very close match with the Theis type curve was achieved for the Jacob-corrected time-drawdown data up to about 320 min, when drawdown began to exceed that predicted by the type curve (Figure B.9). The Cooper-Jacob straight-line analysis (Figure B.10) confirmed the closeness of the Theis type curve matching.

Similarly, Figures B.11 and B.12 show the curve-fitting results for the Theis type curve and the Cooper-Jacob straight-line analyses for an assumed well efficiency of 80%. Figures B.13 and B.14 are the same analyses for an assumed well efficiency of 60%.
SB-36 TEST NO. 1
Data Set: C:\PROJECTS\ANL\AGRA\SB36PMP1\SB-36C1.AQT
Date: 08/10/96  Time: 14:44:50

SOLUTION
Aquifer Model: Unconfined
Solution Method: Neuman
T = 38.23 ft²/day
S = 0.06929
Sy = 0.6857
β = 0.03

AQUIFER DATA
Saturated Thickness: 17 ft

WELL DATA
<table>
<thead>
<tr>
<th>Pumping Wells</th>
<th>Observation Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Name</td>
<td>X (ft)</td>
</tr>
<tr>
<td>SB-36</td>
<td>1.687E+06</td>
</tr>
</tbody>
</table>

FIGURE B.8 Neuman Analysis for SB36
SB-36 TEST NO. 1
Data Set: C:\PROJECTS\ANL\AGRA\SB36PMP\SB-36C1.AQT
Date: 08/10/96  Time: 14:16.07

Aquifer Model: Unconfined
Solution Method: Theis
T = 72.48 ft²/day
S = 0.05598

AQUIFER DATA
Saturated Thickness: 17. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

<table>
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<tr>
<th>Well Name</th>
<th>X (ft)</th>
<th>Y (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB-36</td>
<td>1.687E+006</td>
<td>5.208E+005</td>
</tr>
</tbody>
</table>

Observation Wells

<table>
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<tr>
<th>Well Name</th>
<th>X (ft)</th>
<th>Y (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB-36</td>
<td>1.687E+006</td>
<td>5.208E+005</td>
</tr>
</tbody>
</table>

FIGURE B.9  Theis Analysis for SB36, Assuming 100% Well Efficiency
FIGURE B.10 Cooper-Jacob Analysis for SB36, Assuming 100% Well Efficiency
SB-36 TEST NO. 1

Data Set: C:\PROJECTS\ANL\AGRA\SB36PMP1\SB-36C1.AQT
Date: 08/10/96 Time: 13:58:57

SOLUTION

Aquifer Model: Unconfined
Solution Method: Theis

\[ T = 84.39 \text{ ft}^2/\text{day} \]
\[ S = 0.07796 \]

AQUIFER DATA

Saturated Thickness: 17 ft
Anisotropy Ratio (Kz/Kr): 1

WELL DATA

<table>
<thead>
<tr>
<th>Pumping Wells</th>
<th>Observation Wells</th>
</tr>
</thead>
<tbody>
<tr>
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<td>X (ft)</td>
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<td>SB-36</td>
<td>1.687E+006</td>
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</tbody>
</table>

FIGURE B.11  Theis Analysis for SB36, Assuming 80% Well Efficiency
SB-36 TEST NO. 1
Data Set: C:\PROJECTS\ANL\AGRA\SB36PMP1\SB-36C1.AQT
Date: 08/10/96 Time: 13:57:29

SOLUTION
Aquifer Model: Unconfined
Solution Method: Cooper-Jacob
T = 84.39 ft²/day
S = 0.07796

AQUIFER DATA
Saturated Thickness: 17. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA
<table>
<thead>
<tr>
<th>Well Name</th>
<th>X (ft)</th>
<th>Y (ft)</th>
<th>Observation Wells</th>
</tr>
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<tbody>
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<td>SB-36</td>
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<td>5.208E+005</td>
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<tr>
<td>SB-36</td>
<td>1.687E+006</td>
<td>5.208E+005</td>
<td></td>
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</tbody>
</table>

FIGURE B.12 Cooper-Jacob Analysis for SB36, Assuming 80% Well Efficiency
SB-36 TEST NO. 1
Data Set: C:\PROJECTS\ANL\AGRA\SB36PMP1\SB-36C1.AQT
Date: 08/10/96  Time: 13:28:06

Aquifer Model: Unconfined
Solution Method: Theis
T = 102. ft^2/day
S = 0.1239

AQUIFER DATA
Saturated Thickness: 17. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

<table>
<thead>
<tr>
<th>Pumping Wells</th>
<th>Observation Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Name</td>
<td>X (ft)</td>
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<td>SB-36</td>
<td>1.687E+006</td>
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<td>SB-36</td>
<td>1.687E+006</td>
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</tbody>
</table>

FIGURE B.13 Theis Analysis for SB36, Assuming 60% Well Efficiency
SB-36 TEST NO. 1

Data Set: C:\PROJECTS\ANL\AGRA\SB36PMP1\SB-36C1.AQT
Date: 08/10/96  Time: 13:28:40

SOLUTION

Aquifer Model: Unconfined
Solution Method: Cooper-Jacob
T = 102 ft²/day
S = 0.1239

AQUIFER DATA

Saturated Thickness: 17 ft
Anisotropy Ratio (Kz/Kr): 1

WELL DATA

<table>
<thead>
<tr>
<th>Pumping Wells</th>
<th>Observation Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Name</td>
<td>X (ft)</td>
</tr>
<tr>
<td>SB-36</td>
<td>1.687E+06</td>
</tr>
</tbody>
</table>

FIGURE B.14 Cooper-Jacob Analysis for SB36, Assuming 60% Well Efficiency
For comparison only, the upper sand was also assumed to be confined during the SB36 pumping test. This assumption allowed the application of the pumping test analysis method of Papadopulos and Cooper (1967), which was specifically developed for analyzing drawdown in the production well. The Papadopulos and Cooper method was applied to the SB36 drawdown data corrected only for barometric pressure responses. The results of type curve matching with this method are shown in Figure B.15.

### B.2.2.3 Conclusions from the SB36 Pumping Test

The upper-sand pumping test performed at SB36 was valid. Although the pumping rate was low (4 gpm) and the observed drawdown was limited to the production well, meaningful test results were obtained from the analysis of time-drawdown data from the production well.

Table B.2 shows the results of the various test analyses performed on the SB36 time-drawdown data. The estimates for transmissivity ($T$) and storativity ($S$) from the Theis and Cooper-Jacob analyses, for the 100% well efficiency and the Jacob-corrected data, closely match the results of the Papadopulos and Cooper analysis, which assumed confined conditions with 100% well efficiency and corrected only for barometric effects. The estimate of transmissivity from Neuman analysis was roughly one-half those from the Theis and Cooper-Jacob analyses for an assumed well efficiency of 100%. Except for the Neuman analysis, the calculated estimates of hydraulic conductivity range from approximately 4 to 6 ft/d, depending on the assumed well efficiency.

Figure B.16 is a graph of transmissivity versus well efficiency for the Theis results presented in Table B.2. If the efficiency of SB36 is about 90%, a reasonable estimate of the transmissivity of the sands of the upper sand interval in the vicinity of SB36 is 75-80 ft$^2$/d. This value translates to an estimate of hydraulic conductivity of 4.5 ft/d. According to the American Water Works Association (AWWA 1989), a hydraulic conductivity of 4-5 ft/d is within the range of $K_h$ expected for silty sand and is, therefore, consistent with the lithology of the upper sand interval penetrated at Agra.

All of the storativity estimates from the different test analyses performed on the SB36 time-drawdown data are in close agreement, including the Neuman estimate. A reasonable value for $S$ for the sands of the upper sand interval is 0.08. The single estimate of specific yield, $S_y$, is
Pumping well : SB-36
Pumping rate \( Q \) = 4,0000 USG/Min
Radius of casing \( r_c \) = 0.1700 FT
Radius of well bore \( r_w \) = 0.3300 FT
\( \alpha = 0.30000 \)

Transmissivity \( T = \) 529.981 USGPD/FT
Storativity \( S = \) 0.08203285
Stor. \[ \alpha r_c^2 / r_w^2 \] \( S_2 = \) 0.07961433

MATCH POINT:
\( 1 / uw = 22.03 \)
\( F( uw, \alpha ) = 1.1561111 \)
Time = 1.00 0.0453949 Min
Drawdown = 1.00 0.8649688 FT

**FIGURE B.15** Papadopulos and Cooper Analysis for SB36
TABLE B.2 Results of the SB36 Pumping Test Analyses

<table>
<thead>
<tr>
<th>Analysis Method</th>
<th>Aquifer Condition</th>
<th>Barometric Efficiency (%)</th>
<th>Discharge (gpm)</th>
<th>Assumed Well Efficiency (%)</th>
<th>Transmissivity (ft²/d)</th>
<th>Specific Yield, $S_y$</th>
<th>Storativity, $S$</th>
<th>Assumed Saturated Thickness (ft)</th>
<th>Hydraulic Conductivity, $K$ (ft/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neuman</td>
<td>Unconfined</td>
<td>65</td>
<td>4</td>
<td>100</td>
<td>38</td>
<td>0.68</td>
<td>0.09</td>
<td>17</td>
<td>2.2</td>
</tr>
<tr>
<td>Theis</td>
<td>Unconfined</td>
<td>65</td>
<td>4</td>
<td>100</td>
<td>72</td>
<td>NA</td>
<td>0.06</td>
<td>17</td>
<td>4.2</td>
</tr>
<tr>
<td>Cooper-Jacob</td>
<td>Unconfined</td>
<td>65</td>
<td>4</td>
<td>100</td>
<td>72</td>
<td>NA</td>
<td>0.06</td>
<td>17</td>
<td>4.2</td>
</tr>
<tr>
<td>Theis</td>
<td>Unconfined</td>
<td>65</td>
<td>4</td>
<td>80</td>
<td>84</td>
<td>NA</td>
<td>0.08</td>
<td>17</td>
<td>4.9</td>
</tr>
<tr>
<td>Cooper-Jacob</td>
<td>Unconfined</td>
<td>65</td>
<td>4</td>
<td>80</td>
<td>84</td>
<td>NA</td>
<td>0.08</td>
<td>17</td>
<td>4.9</td>
</tr>
<tr>
<td>Theis</td>
<td>Unconfined</td>
<td>65</td>
<td>4</td>
<td>60</td>
<td>102</td>
<td>NA</td>
<td>0.12</td>
<td>17</td>
<td>6.0</td>
</tr>
<tr>
<td>Cooper-Jacob</td>
<td>Unconfined</td>
<td>65</td>
<td>4</td>
<td>60</td>
<td>102</td>
<td>NA</td>
<td>0.12</td>
<td>17</td>
<td>6.0</td>
</tr>
<tr>
<td>Papadopulos and</td>
<td>Confined</td>
<td>65</td>
<td>4</td>
<td>100</td>
<td>71</td>
<td>NA</td>
<td>0.08</td>
<td>17</td>
<td>4.2</td>
</tr>
<tr>
<td>Cooper</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*NA, not applicable.*
Results of SB36 Pump Test Analyses

![Graph showing calculated upper sand transmissivity (ft²/day) versus assumed well efficiency (%)](image)

FIGURE B.16 Well Efficiency versus Calculated Transmissivity for SB36
problematic. The $S_v$ estimate resulting from the Neuman analysis (i.e., 0.68) is unrealistically high. In most unconfined aquifers, the specific yield is comparable to the effective porosity, typically ranging from about 0.1 to 0.3 (AWWA 1989).

The rather sudden increase in the rate of drawdown in SB36 about 320 min into the pumping test might indicate a reduction in transmissivity at some distance from SB36, caused by a decrease in permeable thickness in the upper sand interval, a change in lithology, or both. Decreasing thickness of the upper sand on the bedrock highs that define the margins of the southern bedrock valley was documented during Phase II of the Agra ESC investigations, but the cone of depression generated during the pumping test apparently did not extend far enough from SB36 to detect these margins. The unexplained increase in the rate of drawdown in SB36 might be the result of a decrease in well efficiency during the test, caused by partial clogging of the well screen.

### B.3 Well PW04 Pumping Test

The following sections describe the background to the PW04 pumping test; the pretest design, data collection, and corrections; the pumping test analyses; and the conclusions of the test pertaining to the hydraulic properties of the basal sand and the middle silt/sand interval.

#### B.3.1 Test Background and Design

The PW04 pumping test was carried out to investigate (1) the hydraulic properties of the basal sand portion of the aquifer and (2) the degree of hydraulic interconnection between the upper and basal sands across the middle sand/silt package.

Well PW04 was drilled to shale bedrock at a depth of 128 ft BGL. The available documentation regarding the construction of this well (Argonne 1995b) is, however, ambiguous. According to data accompanying the original permit application for this well, PW04 was to be completed with a 39-ft screen installed immediately above the bedrock surface. A later well registration document filed for PW04 indicates that the well was perforated over two discrete intervals: at 48-74 ft BGL, corresponding to the upper sand and silts of the middle sand/silt package, and at 100-126 ft BGL, within the basal sand. The registration document further states that the well was grouted from 5 ft to 60 ft BGL, across the portion of the shallower screen.
within the upper sand. For the analysis of the PW04 pumping test, well PW04 was assumed to be effectively screened only in the basal sand. The possible effects of dual screening or continuous gravel packing of this well on the expected patterns of groundwater flow and contaminant migration in the Agra aquifer were discussed in Section 5.3.

Well PW04 fully penetrates the basal sand interval, which is 30-35 ft thick in the vicinity of PW04. The basal sand interval is thought to be unconfined and hydraulically communicative with the overlying upper sand interval. Alternatively, the basal sand might exhibit behavior more representative of leaky confined conditions.

Ten wells completed in both the upper and basal sands were initially designated as observation points for the PW04 pumping test. These wells are SB15, SB16, SB23, SB23s, SB28, SB28s, SB36, SB37, SB38, and SB38s. The locations of the wells and piezometers are shown in Figure 2.1. Table B.3 contains the surveyed coordinates of PW04 and the observation points, along with the distance of each observation point from PW04.

<table>
<thead>
<tr>
<th>Well</th>
<th>North (ft)</th>
<th>East (ft)</th>
<th>Distance from PW04 (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PW04</td>
<td>520931.94</td>
<td>1686875.63</td>
<td>0</td>
</tr>
<tr>
<td>SB15</td>
<td>521161.72</td>
<td>1686835.81</td>
<td>233</td>
</tr>
<tr>
<td>SB16</td>
<td>521173.73</td>
<td>1686826.01</td>
<td>247</td>
</tr>
<tr>
<td>SB23</td>
<td>520255.14</td>
<td>1687250.14</td>
<td>774</td>
</tr>
<tr>
<td>SB23s</td>
<td>520256.24</td>
<td>1687247.45</td>
<td>771</td>
</tr>
<tr>
<td>SB28</td>
<td>520626.18</td>
<td>1686276.83</td>
<td>672</td>
</tr>
<tr>
<td>SB28s</td>
<td>520631.42</td>
<td>1686276.11</td>
<td>671</td>
</tr>
<tr>
<td>SB36</td>
<td>520756.54</td>
<td>1686875.80</td>
<td>175</td>
</tr>
<tr>
<td>SB37</td>
<td>520832.33</td>
<td>1686934.85</td>
<td>116</td>
</tr>
<tr>
<td>SB38</td>
<td>520912.96</td>
<td>1686987.81</td>
<td>114</td>
</tr>
<tr>
<td>SB38s</td>
<td>520917.71</td>
<td>1686989.77</td>
<td>115</td>
</tr>
</tbody>
</table>

a North and east locations are Kansas State Plane Coordinates shown in feet. Horizontal datum is converted North American Datum (NAD) 27.
B.3.2 Conditions of the PW04 Pumping Test

The PW04 pumping test started at 13:30 on July 11, 1996, and continued for 25 hr, until 14:30 on July 12, 1996. The design discharge rate for the test was 35 gpm, but approximately 15 min after pumping began, the discharge rate was reduced to 26.7 gpm to avoid exceeding the pressure limit of the carbon filtration system connected to the pump discharge line. The discharge rate was held steady at 26.7 gpm for the remainder of the test. Figure B.17 presents a graph of discharge rate versus time for the test.

Water levels in the pumping and observation wells were recorded by using pressure transducers and automatic data logging equipment and a logarithmically decreasing sampling frequency. Barometric pressure recorded at the site during the PW04 test was used to correct the drawdowns in the observation wells before the time-drawdown data were analyzed. Drawdown in PW04 was not monitored during the test because of a lack of access to the riser pipe under the pump mount. Water levels were monitored in each of the borings throughout the PW04 pumping test. Negligible or no response to the pumping of PW04 was observed at the most distant piezometers (SB16, SB23, SB23s, SB28, and SB28s).

B.3.2.1 Data Corrections

Barometric efficiencies for SB36, SB37, SB38, and SB38s were computed from water level data collected during the period in late June 1996 shown in Figure B.1 and the corresponding barometric pressure measurements shown in Figure B.2. The computed barometric efficiencies of these piezometers are shown in Figure B.3 and Figures B.18-B.20. (Note that a “d” was added to the name of SB38 in the figures to more readily differentiate it from the shallow observation well, SB38s.) The barometric efficiency of SB15 could not be computed and was, consequently, assumed to be 40%. The barometric efficiencies for all PW04 observation points that exhibited drawdown are listed in Table B.4, which summarizes the results of the PW04 pumping test.

Corrections were made as appropriate for the effects of partial penetration, on the basis of the configuration of each well or piezometer and the analysis approach being used. None of the observation borings fully penetrated the total unconfined thickness of the combined upper sand, middle silt/sand package, and basal sand intervals. Well PW04 is assumed to fully penetrate the basal sand interval, but the observation wells penetrate the upper sand and basal sand only
FIGURE B.17 Summary of PW04 Pumping Rate Variations

AGRA, KS PWS 04 AQUIFER TEST

Data Set: C:\PROJECTS\ANL\AGRA\PW4_TESTS\SB37\S\AQT
Date: 08/18/96  Time: 12:19:42

AQUIFER DATA

Saturated Thickness: 81. ft

Anisotropy Ratio (Kz/Kr): 1.
FIGURE B.18  Plot Showing the Barometric Efficiency of Well SB37

SB37 Barometric Efficiency = 62%
FIGURE B.19  Plot Showing the Barometric Efficiency of Well SB38
FIGURE B.20 Plot Showing the Barometric Efficiency of Well SB38s

SB38s Barometric Efficiency = 52%
### TABLE B.4 Results of the PW04 Pumping Test Analyses

<table>
<thead>
<tr>
<th>Well</th>
<th>Aquifer Condition</th>
<th>Barometric Efficiency (%)</th>
<th>Analysis Method</th>
<th>Transmissivity, $T$ (ft²/d)</th>
<th>Assumed Aquifer Thickness (ft)</th>
<th>Horizontal Hydraulic Conductivity, $K_h$ (ft/day)</th>
<th>Storativity, $S$</th>
<th>Specific Yield, $S_y$</th>
<th>Vertical Hydraulic Conductivity, $K_v$ (ft/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB15</td>
<td>Unconfined</td>
<td>40 b</td>
<td>Neuman</td>
<td>1033</td>
<td>81</td>
<td>12.7</td>
<td>0.001</td>
<td>0.5</td>
<td>0.11 c</td>
</tr>
<tr>
<td>SB15</td>
<td>Leaky</td>
<td>40 b</td>
<td>Hantush-Jacob</td>
<td>588</td>
<td>45</td>
<td>13.1</td>
<td>0.0007</td>
<td>NA d</td>
<td>0.04 e</td>
</tr>
<tr>
<td>SB36</td>
<td>Unconfined</td>
<td>65</td>
<td>Theis</td>
<td>1603</td>
<td>81</td>
<td>19.8</td>
<td>0.02</td>
<td>NA</td>
<td>- f</td>
</tr>
<tr>
<td>SB37</td>
<td>Unconfined</td>
<td>62</td>
<td>Theis</td>
<td>1155</td>
<td>81</td>
<td>14.3</td>
<td>0.02</td>
<td>NA</td>
<td>-</td>
</tr>
<tr>
<td>SB38</td>
<td>Unconfined</td>
<td>51</td>
<td>Neuman</td>
<td>1684</td>
<td>81</td>
<td>20.8</td>
<td>0.02</td>
<td>0.29</td>
<td>0.07 c</td>
</tr>
<tr>
<td>SB38s</td>
<td>Leaky</td>
<td>51</td>
<td>Hantush-Jacob</td>
<td>1037</td>
<td>45</td>
<td>23.0</td>
<td>0.001</td>
<td>NA</td>
<td>0.03 e</td>
</tr>
<tr>
<td>SB38s</td>
<td>Unconfined</td>
<td>52</td>
<td>Neuman</td>
<td>1103</td>
<td>81</td>
<td>13.6</td>
<td>0.0004</td>
<td>0.002</td>
<td>-</td>
</tr>
</tbody>
</table>

* All analyses assumed partial penetration of the aquifer.

* Estimated.

* $K_v$ estimated for the full thickness of the aquifer.

* NA, not applicable.

* $K_v$ estimated only for the materials above the basal sand.

* Not calculated.
partially. The aquifer test analysis approaches of Neuman (for unconfined aquifers [1974]) and Hantush-Jacob (for leaky aquifers [1955]) incorporate partially penetrating well geometries in their solutions.

**B.3.2.2 Analysis of the PW04 Pumping Test**

Water levels in several of the designated observation wells for the PW04 test showed no response to pumping of the well. Drawdown data recorded in piezometer SB28 showed a slight response to PW04 pumping, but after correction for barometric effects, the total drawdown in SB28 was negligible and was not suitable for meaningful pumping test analysis. Figure B.21 shows the raw drawdown observed in SB28, along with the corrected drawdown of less than 0.2 ft.

The upper sand interval and the basal sand interval are thought to be unconfined, although hydraulic heads in the upper sand tend to be persistently slightly higher than those in the basal sand near the northern margin of the southern bedrock valley. It is Argonne's opinion that the intervening middle silt/sand package might impede groundwater flow to the deeper portion of the aquifer, at least in this area, without confining the basal sand. For the pumping test analyses, the system was assumed to be unconfined, with a total initial saturated thickness of 81 ft. For comparison, time-drawdown data from basal-sand monitoring points SB15 and SB38 were also used to perform analyses under the alternative assumption that the basal sand might behave as a leaky confined unit in response to pumping of limited duration.

Well SB15 is screened in the basal sand interval. Data from this well were first analyzed for assumed unconfined conditions by using Neuman's method, which accounts for partial penetration and delayed gravity response. Figure B.22 shows the visual fit of the corrected time-drawdown data for SB15 to the Neuman type curves for $\beta = 0.07$. Both the Neuman Type A and Type B curves provided a close fit to the corrected data. The decrease in the rate of drawdown observed at later times in the test could suggest a delayed gravity response, which is typical for drawdown in unconfined aquifers. The shape of the log-log curve of time versus drawdown for SB15 is also similar, however, to the shape of drawdown curves representing leakage into a leaky confined aquifer. The time-drawdown data for SB15 were also analyzed for assumed leaky-aquifer conditions and partial penetration of the observation well. As Figure B.23 shows, an equally close fit was achieved for the corrected SB15 drawdown data by using the Hantush-Jacob analysis for
SB28 Drawdown During PW04 Pumping Test

FIGURE B.21 Drawdown Recorded at SB28 during the PW04 Pumping Test
AGRA, KS PWS 04 AQUIFER TEST

Data Set: C:\PROJECTS\ANLVAGRA\PW4_TEST\SB15.C.AQT
Date: 08/17/96  Time: 22:50:27

SOLUTION
Aquifer Model: Unconfined
Solution Method: Quick Neuman
T = 1032.9 ft²/day
S = 0.001267
Sy = 0.5
B = 0.07079

AQUIFER DATA
Saturated Thickness: 81. ft

WELL DATA

<table>
<thead>
<tr>
<th>Pumping Wells</th>
<th>Observation Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Name</td>
<td>X (ft)</td>
</tr>
<tr>
<td>PWS 04</td>
<td>1.687E+006</td>
</tr>
</tbody>
</table>

FIGURE B.22 Neuman Analysis for SB15 during the PW04 Pumping Test.
AGRA, KS PWS 04 AQUIFER TEST

Data Set: A\SB15\C_AQT
Date: 10/07/96 Time: 09:48:36

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush-Jacob

T = 588.3 ft^2/day
S = 0.0006828
r/B = 0.4286

AQUIFER DATA

Saturated Thickness: 35 ft
Anisotropy Ratio (Kz/Kr): 1

WELL DATA

<table>
<thead>
<tr>
<th>Well Name</th>
<th>X (ft)</th>
<th>Y (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWS 04</td>
<td>1.687E+06</td>
<td>5.209E+05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Well Name</th>
<th>X (ft)</th>
<th>Y (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB15</td>
<td>1.687E+06</td>
<td>5.212E+05</td>
</tr>
</tbody>
</table>

FIGURE B.23 Hantush-Jacob Analysis for SB15 during the PW04 Pumping Test
leaky aquifers, with the type curve for $r/B = 0.4$. The hydraulic conductivities estimated from both analyses of the SB15 drawdown data are in close agreement. The transmissivity calculated from the SB15 Neuman analysis is 1.033 ft$^2$/d, which, divided by the unconfined-aquifer thickness of 81 ft, results in a hydraulic conductivity estimate of approximately 13 ft/d. Dividing the Hantush-Jacob calculated transmissivity of 588 ft$^2$/d (for leaky confined conditions) by the thickness (35 ft) of the basal sand interval yields a calculated $K_h$ of 16.8 ft/d. The Neuman calculated specific yield for SB15 is 0.5. This $S_y$ is higher than would normally be expected for the types of sediments penetrated at Agra.

Well SB36 responded to the pumping of PW04 during the test. SB36 is screened in the upper sand. As Figure B.24 shows, a very close fit of the SB36 corrected time-drawdown data to the Theis type curve was achieved. No other analytical approach provided a reasonable solution. The transmissivity calculated from the analysis of SB36 drawdown is 1,603 ft$^2$/d. This value is in marked contrast to the transmissivity calculated from the SB36 test for the upper sand interval (i.e., 72 ft$^2$/d), suggesting that the bulk of the transmissivity controlling drawdown at this location is associated with the basal sand interval, with little contribution from the upper sand.

Well SB37, which is screened in the upper sand interval, responded similarly to SB36 to pumping of PW04. Well SB37 has a 6-ft screen, however, versus the 20-ft screen in SB36. The Theis type curve also fitted the SB37 log-log time-versus-drawdown data well (Figure B.25). The abrupt change in drawdown observed about 15 min into the test is believed to be a result of decreasing the pumping rate at this time, from 35 gpm to 26.7 gpm. The transmissivity calculated from the Theis analysis of corrected drawdown in SB37 is 1,155 ft$^2$/d, which is less than the value calculated at nearby SB36. Well SB37 has a much shorter screen than SB36 and is more than 50 ft closer to PW04, however, suggesting that partial-penetration effects (which are not accounted for in the Theis analysis) might have affected the results.

The Theis data analysis method was developed for the interpretation of drawdown responses in confined aquifers, in apparent conflict with the unconfined nature of the aquifer observed at Agra. Review of the Neuman type curve analysis technique for unconfined aquifers (Neuman 1974) indicates, however, that unconfined aquifers will respond to pumping at any point within the aquifer in accord with the theoretical Theis curve during both the earliest phases of drawdown and the late stages of drawdown. During these pumping phases, the effects of delayed gravity response (vertical drainage of initially saturated porosity in response to lowering of the
Saturated Thickness: 81. ft

Aquifer Model: Unconfined
Solution Method: Theis

\[ T = 1603.4 \text{ ft}^2/\text{day} \]
\[ S = 0.01857 \]

AQUIFER DATA

Anisotropy Ratio \((K_z/K_r)\): 1

WELL DATA

<table>
<thead>
<tr>
<th>Well Name</th>
<th>X (ft)</th>
<th>Y (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWS 04</td>
<td>1.687E+06</td>
<td>5.209E+05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Well Name</th>
<th>X (ft)</th>
<th>Y (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB36</td>
<td>1.687E+06</td>
<td>5.208E+05</td>
</tr>
</tbody>
</table>

FIGURE B.24 Theis Analysis for SB36 during the PW04 Pumping Test
Aquifer Model: Unconfined
Solution Method: Theis

\[ T = 1154.6 \, \text{ft}^2/\text{day} \]
\[ S = 0.01783 \]

AQUIFER DATA
Saturated Thickness: 81 ft
Anisotropy Ratio (Kz/Kr): 1

WELL DATA

<table>
<thead>
<tr>
<th>Pumping Wells</th>
<th>Observation Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Name</td>
<td>X (ft)</td>
</tr>
<tr>
<td>PWS 04</td>
<td>1.687E+06</td>
</tr>
</tbody>
</table>

FIGURE B.25 Theis Analysis for SB37 during the PW04 Pumping Test
water table) within the unconfined aquifer are not apparent. We hypothesize that the drawdown behavior observed in piezometers SB36 and SB37 reflects only the early stages of drawdown at these locations.

The closest piezometers to PW04 (SB38s and SB38) should arguably provide the most reliable pumping test analyses. The SB38s data trend (Figure B.26) shows what might be a slightly delayed gravity response, 10-20 min after the start of the test. Neuman's method for unconfined aquifers with partial penetration was used to analyze the SB38s time-drawdown data. The Neuman calculated transmissivity of 1,103 ft²/d agrees with the result from the Theis analysis of SB37 time-drawdown data in the PW04 pumping test. However, the specific yield (0.002) calculated from the Neuman analysis of SB38s is questionable.

Well SB38 is screened in the basal sand interval. Like SB15, SB38 was first analyzed for assumed unconfined conditions by using Neuman's method, which accounts for partial penetration and delayed gravity response. Figure B.27 shows the visual fit of the corrected SB38 time-drawdown data to the Neuman type curves for β = 0.007. Both the Neuman Type A and Type B curves resulted in a close fit to the corrected data. The decrease in the rate of drawdown at later times might suggest that SB38 entered a period of (1) delayed gravity response in the water table or (2) leakage into a leaky confined aquifer (as described previously for SB15). The time-drawdown data from SB38 were also analyzed for assumed leaky-aquifer conditions and partial penetration of the aquifer. As Figure B.28 shows, a very close fit was achieved for the corrected SB38 drawdown data by using the Hantush-Jacob leaky type curve for r/B = 0.13. The estimated hydraulic conductivities from both analyses of the SB38 data are in close agreement. The transmissivity calculated from the SB38 Neuman analysis is 1,684 ft²/d, which yields an estimated hydraulic conductivity of 21 ft/d. Dividing the Hantush-Jacob calculated transmissivity of 1,037 ft²/d (for leaky confined conditions) by the thickness of the basal sand interval (i.e., 45 ft) produces a calculated hydraulic conductivity of 23 ft/d. The Neuman calculated specific yield for SB38 is 0.29. This $S_y$ is very reasonable for the types of sediments observed.

B.3.2.3 Estimation of the Vertical Hydraulic Conductivity of the Middle Silt/Sand Package

Estimates of the vertical hydraulic conductivity of the middle silt/sand package overlying the basal sand can be derived from the Hantush-Jacob analyses of time-drawdown data performed for SB15 and SB38, under the assumption of leaky confined conditions in the basal sand unit.
FIGURE B.26 Neuman Analysis for SB38s during the PW04 Pumping Test
SOLUTION
Aquifer Model: Unconfined
Solution Method: Quick Neuman
\[ T = 1684.1 \text{ ft}^2/\text{day} \]
\[ S = 0.001914 \]
\[ S_y = 0.2862 \]
\[ B = 0.006727 \]

AQUIFER DATA
Saturated Thickness: 81. ft

WELL DATA

<table>
<thead>
<tr>
<th>Pumping Wells</th>
<th>Observation Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Name</td>
<td>X (ft)</td>
</tr>
<tr>
<td>PWS 04</td>
<td>1.687E+006</td>
</tr>
</tbody>
</table>

FIGURE B.27 Neuman Analysis for SB38 during the PW04 Pumping Test
AGRA, KS PWS 04 AQUIFER TEST

Data Set: A:SB38D.C.AQT
Date: 10/07/96  Time: 09:52:16

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush-Jacob
T = 1037.4 ft²/day
S = 0.0009055
r/B = 0.1311

AQUIFER DATA

Saturated Thickness: 35 ft
Anisotropy Ratio (Kz/Kr): 1

WELL DATA

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<th>Well Name</th>
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<th>Y (ft)</th>
</tr>
</thead>
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<tr>
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<td>1.687E+006</td>
<td>5.209E+005</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Well Name</th>
<th>X (ft)</th>
<th>Y (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB38d</td>
<td>1.687E+006</td>
<td>5.209E+005</td>
</tr>
</tbody>
</table>

FIGURE B.28 Hantush-Jacob Analysis for SB38 during the PW04 Pumping Test
From the SB15 Hantush-Jacob analyses, $\tau/B$ is 0.4. For this value and a radial distance from SB15 to PW04 of 233 ft, $\beta$ is equal to 582.5 ft. If the basal sand interval is 35 ft thick, the overlying silt is 30 ft thick, and the hydraulic conductivity of the basal sand at SB15 is 13 ft/d, a $K_v$ value of 0.04 ft/d is indicated for the middle silt/sand package from the SB15 analysis. The same analysis applied to the Hantush-Jacob results at SB38 produces an estimate of 0.03 ft/d for the hydraulic conductivity of the overlying silt/sand interval.

Neuman's $\beta$ coefficient can also be used to estimate the vertical hydraulic conductivity of a water table aquifer. For the appropriate values from the Neuman analyses of the SB38 drawdown data, an estimate for the vertical hydraulic conductivity of the composite unconfined aquifer at Agra is 0.07 ft/d. A $K_v$ value of 0.11 ft/d was obtained from the corresponding analysis for SB15. These values are in reasonable agreement with those obtained from the Hantush-Jacob analyses.

The $K_v$ values calculated from the Neuman analyses theoretically represent the characteristics of the full saturated thickness of the aquifer, including the basal sand. The Hantush-Jacob calculations reflect the properties of only the materials overlying the basal sand. This difference in the theoretical basis for the calculations may in part account for the somewhat higher $K_v$ values obtained from the Neuman analyses. The $K_v$ values estimated from both analysis techniques are consistent with the range of hydraulic conductivities typically associated with silts or clayey sands.

### B.3.2.4 Conclusions from the PW04 Pumping Test

Table B.4 summarizes the results of the analyses of time-versus-drawdown data obtained during the PW04 pumping test. The pumping rate, 26.7 gpm, and the duration of pumping of PW04 were sufficient to produce drawdown suitable for analysis in several of the observation wells. Meaningful test results were obtained from the analysis of time-drawdown data for the observation points where drawdown was significant.

Although the upper sand and the basal sand intervals are believed to compose one unconfined groundwater system, the hydrogeologic properties of the upper sand and the basal sand differ markedly. The hydraulic conductivity of the upper sand interval is substantially less than that estimated for the basal sand interval. The presence of silt between the sands of the upper and the basal sand intervals might restrict the rapid movement of groundwater between these two units.
None of the log-log time-versus-drawdown data plots displayed a clear indication of lateral, impermeable boundary influences during the PW04 pumping test, despite the proximity of PW04 and several of the observation points to the mapped walls of the southern bedrock valley. The estimates for hydraulic conductivity obtained for piezometer SB38 were, however, consistently higher than those calculated for SB15. The apparent increase in hydraulic conductivity from SB15 to SB38 might reflect an actual increase in the permeability of the basal sand near SB38. Alternatively, the relatively greater drawdown response observed at SB15 might in part reflect the position of this piezometer immediately adjacent to the northern wall of the bedrock valley. Under this scenario, drawdown at SB15 could have been enhanced by a more restricted flow of groundwater toward the pumping well in this portion of the aquifer.

Estimates of specific yield from the aquifer test analyses are considered unreliable. The most reasonable estimate of $S_y$ obtained from the PW04 test is 0.3, calculated from the SB38 Neuman analysis.
Appendix C:

Results of Model Sensitivity Analyses
Feasibility Study for Agra, Kansas
Version 00, 11/05/96

Figure C.1 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S1 (Model Layer 1, with sand facies $K_h$ decreased by 50% to 2 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.2 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S2 (Model Layer 1, with sand facies $K_h$ increased by 50% to 6 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.3 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S3 (Model Layer 1, with silt facies $K_h$ decreased by 75% to 0.5 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.4 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S4 (Model Layer 1, with silt facies $K_h$ decreased by 50% to 1 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.5 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S5 (Model Layer 1, with sand facies $K_v$ decreased by 50% to 2 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.6 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S6 (Model Layer 1, with sand facies $K_v$ decreased by 75% to 1 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.7 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S7 (Model Layer 2, with sandy zone $K_h$ increased by 82% to 4 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.8 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S8 (Model Layer 2, with sandy zone $K_h$ decreased by 55% to 1 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.9 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S9 (Model Layer 2, with silt $K_h$ increased by 20% to 0.12 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.10 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S10 (Model Layer 2, with silt $K_h$ decreased by 75% to 0.025 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.11 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S11 (Model Layer 2, with sandy zone $K_v$ increased by 50% to 1 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.12 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S12 (Model Layer 2, with sandy zone $K_n$ decreased by 50% to 0.25 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.13 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S13 (Model Layer 2, with silt $K_v$ increased by 100% to 0.2 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.14 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S14 (Model Layer 2, with silt \( K_v \) decreased by 50% to 0.05 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.15 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S15 (Model Layer 3, with $K_h$ decreased in both zones by 50% [see Figure 5.7]. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.16  Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S16 (Model Layer 3, with $K_h$ increased in both zones by 100% [see Figure 5.7]. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.17 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S17 (Model Layer 3, with $K_v$ decreased in both zones by 50% [see Figure 5.7]. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.18 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S18 (Model Layer 3, with $K_h$ decreased in both zones by 75% [see Figure 5.7]. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.19 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S19 (Model northwestern fixed-head boundary elevation increased by 1 ft. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.20 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S20 (Model northwestern fixed-head boundary elevation decreased by 1 ft. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.21 Simulated Upper-Sand Potentiometric Surface for Sensitivity Analysis Run S21 (Model southeastern fixed-head boundary elevation increased by 1 ft. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE C.22  Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S22 (Model southeastern fixed-head boundary elevation decreased by 1 ft. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.23 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S1 (Model Layer 1, with sand facies $K_h$ decreased by 50% to 2 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.24 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S2 (Model Layer 1, with sand facies $K_h$ increased by 50% to 6 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.25 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S3 (Model Layer 1, with silt facies $K_h$ decreased by 75% to 0.5 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.26 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S4 (Model Layer 1, with silt facies $K_h$ decreased by 50% to 1 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.27 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S5 (Model Layer 1, with sand facies $K_v$ decreased by 50% to 2 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.28 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S6 (Model Layer 1, with sand facies $K_v$ decreased by 75% to 1 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.29 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S7 (Model Layer 2, with sandy zone $K_h$ increased by 82% to 4 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.30 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S8 (Model Layer 2, with sandy zone $K_h$ decreased by 55% to 1 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.31 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S9 (Model Layer 2, with silt \(K_s\) increased by 20% to 0.12 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.32 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S10 (Model Layer 2, with silt $K_f$ decreased by 75% to 0.025 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.33 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S11 (Model Layer 2, with sandy zone $K_v$ increased by 50% to 1 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.34 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S12 (Model Layer 2, with sandy zone $K_h$ decreased by 50% to 0.25 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.35 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S13 (Model Layer 2, with silt $K_v$ increased by 100% to 0.2 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.36 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S14 (Model Layer 2, with silt $K_v$ decreased by 50% to 0.05 ft/d. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.37 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S15 (Model Layer 3, with $K_h$ decreased in both zones by 50% [see Figure 5.7]. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.38 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S16 (Model Layer 3, with $K_n$ increased in both zones by 100% [see Figure 5.7]. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.39 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S17 (Model Layer 3, with $K_v$ decreased in both zones by 50% [see Figure 5.7]. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.40 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S18 (Model Layer 3, with $K_h$ decreased in both zones by 75% [see Figure 5.7]. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.41 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S19 (Model northwestern fixed-head boundary elevation increased by 1 ft. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.42 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S20 (Model northwestern fixed-head boundary elevation decreased by 1 ft. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.43 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S21 (Model southeastern fixed-head boundary elevation increased by 1 ft. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE C.44 Simulated Basal-Sand Potentiometric Surface for Sensitivity Analysis Run S22 (Model southeastern fixed-head boundary elevation decreased by 1 ft. Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 0.5 ft.)
FIGURE D.1 Simulated Upper-Sand Carbon Tetrachloride Plume Resulting from 20-Year Migration under the No-Action Scenario, for Assumed Natural Carbon Tetrachloride Decay of 1% per Year (Upper-sand potentiometric surface is as shown in Figure 5.10. Water level contour interval = 1 ft. Maximum predicted concentration = 20 µg/L. Contour interval = 10 µg/L. Labeled points 1-3 show the locations of hypothetical residences considered in the assessment of health risks; see Section 7.1.)
FIGURE D.2 Simulated Upper-Sand Carbon Tetrachloride Plume Resulting from 40-Year Migration under the No-Action Scenario, for Assumed Natural Carbon Tetrachloride Decay of 1% per Year (Upper-sand potentiometric surface is as shown in Figure 5.10. Water level contour interval = 1 ft. Maximum predicted concentration = 10 µg/L. Contour interval = 5 µg/L. Labeled points 1-3 show the locations of hypothetical residences considered in the assessment of health risks; see Section 7.1.)
FIGURE D.3 Simulated Upper-Sand Carbon Tetrachloride Plume Resulting from 60-Year Migration under the No-Action Scenario, for Assumed Natural Carbon Tetrachloride Decay of 1% per Year (Upper-sand potentiometric surface is as shown in Figure 5.10. Water level contour interval = 1 ft. Maximum predicted concentration = 7 µg/L. Contour interval = 5 µg/L. Labeled points 1-3 show the locations of hypothetical residences considered in the assessment of health risks; see Section 7.1.)
FIGURE D.4 Simulated Basal-Sand Carbon Tetrachloride Plume Resulting from 20-Year Migration under the No-Action Scenario, for Assumed Natural Carbon Tetrachloride Decay of 1% per Year (Basal-sand potentiometric surface is as shown in Figure 5.11. Water level contour interval = 1.0 ft. Maximum predicted concentration = 27 µg/L. Contour interval = 10 µg/L. Labeled points 1-3 show the locations of hypothetical residences considered in the assessment of health risks; see Section 7.1.)
FIGURE D.5 Simulated Basal-Sand Carbon Tetrachloride Plume Resulting from 40-Year Migration under the No-Action Scenario, for Assumed Natural Carbon Tetrachloride Decay of 1% per Year (Basal-sand potentiometric surface is as shown in Figure 5.11. Water level contour interval = 1.0 ft. Maximum predicted concentration = 13 µg/L. Contour interval = 5 µg/L. Labeled points 1-3 show the locations of hypothetical residences considered in the assessment of health risks; see Section 7.1.)
Appendix D:

Results of Simulations under the No-Action Alternative
FIGURE D.6 Simulated Upper-Sand Potentiometric Surface Resulting from Pumping of Well PW04 for 12 hr at a Rate of 44 gpm, on the First Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.7 Simulated Upper-Sand Potentiometric Surface Resulting from 12 hr of Recovery of Water Levels, on the First Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.8 Simulated Upper-Sand Potentiometric Surface Resulting from Pumping of Well PW04 for 12 hr at a Rate of 44 gpm, on the Third Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.9 Simulated Upper-Sand Potentiometric Surface Resulting from 12 hr of Recovery of Water Levels, on the Third Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.10  Simulated Upper-Sand Potentiometric Surface Resulting from Pumping of Well PW04 for 12 hr at a Rate of 44 gpm, on the Fifth Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.11 Simulated Upper-Sand Potentiometric Surface Resulting from 12 hr of Recovery of Water Levels, on the Fifth Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.12 Simulated Upper-Sand Potentiometric Surface Resulting from Pumping of Well PW04 for 12 hr at a Rate of 44 gpm, on the Seventh Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.13 Simulated Upper-Sand Potentiometric Surface Resulting from 12 hr of Recovery of Water Levels, on the Seventh Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.14 Simulated Basal-Sand Potentiometric Surface Resulting from Pumping of Well PW04 for 12 hr at a Rate of 44 gpm, on the First Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.15 Simulated Basal-Sand Potentiometric Surface Resulting from 12 hr of Recovery of Water Levels, on the First Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.16 Simulated Basal-Sand Potentiometric Surface Resulting from Pumping of Well PW04 for 12 hr at a Rate of 44 gpm, on the Third Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.17 Simulated Basal-Sand Potentiometric Surface Resulting from 12 hr of Recovery of Water Levels, on the Third Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.18 Simulated Basal-Sand Potentiometric Surface Resulting from Pumping of Well PW04 for 12 hr at a Rate of 44 gpm, on the Fifth Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.19 Simulated Basal-Sand Potentiometric Surface Resulting from 12 hr of Recovery of Water Levels, on the Fifth Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
FIGURE D.20 Simulated Basal-Sand Potentiometric Surface Resulting from 12 hr of Recovery of Water Levels, on the Seventh Day of a Seven-Day Pumping Cycle (Predicted water level contours are shown relative to an arbitrary reference elevation of 1,700 ft AMSL. Contour interval = 1 ft.)
Appendix E:

Summary of Risk Assessment Calculations
FIGURE E.1 Carbon Tetrachloride Concentrations Assumed for Agra, Kansas, in 2010-2040, with No Decay of Contaminant in the Lower Aquifer

FIGURE E.2 Carbon Tetrachloride Concentrations Assumed for Agra, Kansas, in 2010-2040, with 1% Annual Decay of Contaminant in the Lower Aquifer
FIGURE E.3 Carbon Tetrachloride Concentrations Assumed for Agra, Kansas, in 2011-2041, with No Decay of Contaminant in the Upper and Lower Aquifers

FIGURE E.4 Carbon Tetrachloride Concentrations Assumed for Agra, Kansas, in 2011-2041, with 1% Annual Decay of Contaminant in the Combined Upper and Lower Aquifers
Feasibility Study for Agra, Kansas  
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**FIGURE E.5** Contribution of Each Contaminant and Each Pathway to Total Adult Carcinogenic Risk at Agra, Kansas, for No Assumed Decay of Contaminant in the Lower Aquifer

**FIGURE E.6** Contribution of Each Contaminant and Each Pathway to Total Child Carcinogenic Risk at Agra, Kansas, for No Assumed Decay of Contaminant in the Lower Aquifer
FIGURE E.7 Contribution of Each Contaminant and Each Pathway to Total Adult Chronic Noncarcinogenic Risk at Agra, Kansas, for No Assumed Decay of Contaminant in the Lower Aquifer

FIGURE E.8 Contribution of Each Contaminant and Each Pathway to Total Child Chronic Noncarcinogenic Risk at Agra, Kansas, for No Assumed Decay of Contaminant in the Lower Aquifer
FIGURE E.9 Annual and Cumulative Adult Carcinogenic Risks at Agra, Kansas, for No Assumed Decay of Contaminant in the Lower Aquifer

FIGURE E.10 Annual and Cumulative Child Carcinogenic Risks at Agra, Kansas, for No Assumed Decay of Contaminant in the Lower Aquifer
FIGURE E.11 Average Adult Chronic Noncarcinogenic Risk to Date in 2010-2040 at Agra, Kansas, for No Assumed Decay of Contaminant in the Lower Aquifer

FIGURE E.12 Average Child Chronic Noncarcinogenic Risk to Date in 2010-2040 at Agra, Kansas, for No Assumed Decay of Contaminant in the Lower Aquifer
FIGURE E.13 Carbon Tetrachloride Concentrations Assumed at Agra, Kansas, in 2026-2055, with No Decay of Contaminant in the Upper and Lower Aquifers and with a Soil Source of Carbon Tetrachloride

FIGURE E.14 Carbon Tetrachloride Concentrations Assumed at Agra, Kansas, in 2026-2055, with 1% Annual Decay of Contaminant in the Upper and Lower Aquifers and with a Soil Source of Carbon Tetrachloride
TABLE E.1 Summary of Adult and Child Carcinogenic Risks for the Worst-Case 30-Year Cumulative Exposure at Agra, Kansas, for No Assumed Decay of Contaminant in the Lower Aquifer (The worst case considers a child born in 2012.)

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<th>Chronic Daily Intake (µg/kg-day)</th>
<th>Chemical-specific Risk</th>
<th>Total Pathway Risk</th>
<th>Total Exposure Risk</th>
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<tbody>
<tr>
<td><strong>CUMULATIVE ADULT CARCINOGENIC RISK</strong></td>
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<tr>
<td>Ingestion of Contaminated Drinking Water</td>
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<td></td>
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### TABLE E.2 Summary of Adult and Child Chronic Noncarcinogenic Risks for the Worst-Case 30-Year Exposure at Agra, Kansas, for No Assumed Decay of Contaminant in the Lower Aquifer

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<th>Chemical-specific Hazard Quotient</th>
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TABLE E.3 Summary of Adult and Child Subchronic Noncarcinogenic Risks, Based on the EPA Health Advisory for Exposure Lasting Less than Seven Years (EPA 1996) at Agra, Kansas, for No Assumed Decay of Contaminant in the Lower Aquifer (Maximum exposure occurs in 2016.)

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<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.36</td>
<td>0.36</td>
<td>0.36</td>
<td>0.36</td>
</tr>
</tbody>
</table>
### TABLE E.4 Assumptions Used in the Risk Assessment for Agra, Kansas

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Assumed Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>BWa</td>
<td>Body Weight (Adult)</td>
<td>70</td>
<td>kg</td>
</tr>
<tr>
<td>BWc</td>
<td>Body Weight (Child)</td>
<td>15</td>
<td>kg</td>
</tr>
<tr>
<td>EF</td>
<td>Exposure frequency</td>
<td>350</td>
<td>days/year</td>
</tr>
<tr>
<td>EDa</td>
<td>Exposure duration (30 years = 90th percentile at one residence)</td>
<td>30</td>
<td>years</td>
</tr>
<tr>
<td>EDc</td>
<td>Exposure duration (Child)</td>
<td>6</td>
<td>years</td>
</tr>
<tr>
<td>AT</td>
<td>Lifetime exposure (70 yrs * 365 days/yr), for carcinogens</td>
<td>25550</td>
<td>days</td>
</tr>
<tr>
<td>IRDa</td>
<td>Ingestion Rate, Drinking Water (Adult)</td>
<td>2</td>
<td>liters/day</td>
</tr>
<tr>
<td>IRDc</td>
<td>Ingestion Rate, Drinking Water (Child)</td>
<td>1</td>
<td>liters/day</td>
</tr>
<tr>
<td>IRSa</td>
<td>Ingestion Rate, Soils (Adult)</td>
<td>100</td>
<td>mg/day</td>
</tr>
<tr>
<td>IRSc</td>
<td>Ingestion Rate, Soils (Child)</td>
<td>200</td>
<td>mg/day</td>
</tr>
<tr>
<td>IRla</td>
<td>Inhalation Rate Indoors (Adult)</td>
<td>0.6</td>
<td>m³/hour</td>
</tr>
<tr>
<td>IRlc</td>
<td>Inhalation Rate Indoors (Child)</td>
<td>0.8</td>
<td>m³/hour</td>
</tr>
<tr>
<td>IROa</td>
<td>Inhalation Rate Outdoors (Adult)</td>
<td>1.4</td>
<td>m³/hour</td>
</tr>
<tr>
<td>IROc</td>
<td>Inhalation Rate Outdoors (Child)</td>
<td>1.4</td>
<td>m³/hour</td>
</tr>
<tr>
<td>SAA</td>
<td>Skin Surface Area Available for Contact (Adult)</td>
<td>19,400</td>
<td>cm²</td>
</tr>
<tr>
<td>SAC</td>
<td>Skin Surface Area Available for Contact (Child)</td>
<td>7,200</td>
<td>cm²</td>
</tr>
<tr>
<td>ETS</td>
<td>Exposure Time (shower duration), Adult</td>
<td>0.2</td>
<td>hours</td>
</tr>
<tr>
<td>Fs</td>
<td>Flow rate of shower</td>
<td>750</td>
<td>liters/hour</td>
</tr>
<tr>
<td>Ws</td>
<td>Total Water Used per shower (ETS * Fs)</td>
<td>150</td>
<td>liters</td>
</tr>
<tr>
<td>Vb</td>
<td>Bathroom Volume</td>
<td>6</td>
<td>cu. meters</td>
</tr>
<tr>
<td>ETB</td>
<td>Exposure Time (bath duration)</td>
<td>0.25</td>
<td>hours</td>
</tr>
<tr>
<td>Fb</td>
<td>Tub Capacity (1.67 ft x 4.5 ft x .5 ft)</td>
<td>105</td>
<td>liters/hour</td>
</tr>
<tr>
<td>Wb</td>
<td>Total Water Used per bath</td>
<td>105</td>
<td>liters</td>
</tr>
<tr>
<td>Do</td>
<td>Dust Concentration, Outdoors</td>
<td>75</td>
<td>µg/m³</td>
</tr>
<tr>
<td>Di</td>
<td>Dust Concentration, Indoors (75% of outdoor concentration)</td>
<td>56</td>
<td>µg/m³</td>
</tr>
<tr>
<td>RD</td>
<td>Respirable fraction of dust (percent particles &lt; 10µ in diameter)</td>
<td>73%</td>
<td>fraction</td>
</tr>
<tr>
<td>Df</td>
<td>Contaminated fraction of dust</td>
<td>80%</td>
<td>fraction</td>
</tr>
<tr>
<td>SI</td>
<td>Contaminated fraction of ingested soil</td>
<td>100%</td>
<td>fraction</td>
</tr>
<tr>
<td>ETO</td>
<td>Exposure Time, Dust, Outdoors</td>
<td>3</td>
<td>hours</td>
</tr>
<tr>
<td>ETI</td>
<td>Exposure Time, Dust, Indoors</td>
<td>21</td>
<td>hours</td>
</tr>
<tr>
<td>CFI</td>
<td>Conversion Factor (liters/cubic centimeter)</td>
<td>1.0E-03</td>
<td>l/cc</td>
</tr>
<tr>
<td>CFk</td>
<td>Conversion Factor (kilograms/milligram)</td>
<td>1.0E-06</td>
<td>kg/mg</td>
</tr>
<tr>
<td>CFu</td>
<td>Conversion Factor (kilograms/microgram)</td>
<td>1.0E-09</td>
<td>kg/µg</td>
</tr>
</tbody>
</table>
### TABLE E.5 Summary of Calculations of Exposure and Risk at Agra, Kansas

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Intake Calculation</th>
<th>Exposure Pathway &amp; Risk/Hazard Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CARCINOGENIC EXPOSURE</strong></td>
<td><strong>CARCINOGENIC RISK</strong></td>
</tr>
<tr>
<td>Ingestion of contaminated drinking water</td>
<td>Ingestion of contaminated drinking water</td>
</tr>
<tr>
<td>Adult: ( (C\text{wa}^* \text{IRda}^* \text{EF}^* \text{EDa}) / (B\text{Wa}^* \text{AT}) )</td>
<td>Adult: Risk = 1 - exp((- \text{CDI} \times \text{SFo}))</td>
</tr>
<tr>
<td>Child: ( (C\text{w}^* \text{RDc}^* \text{EF}^* \text{EDo}) / (B\text{w}^* \text{AT}) )</td>
<td>Child: &quot;</td>
</tr>
<tr>
<td>Inhalation of vapors while showering/bathing</td>
<td>Inhalation of vapors while showering/bathing</td>
</tr>
<tr>
<td>Adult: ( (C\text{As}^* \text{IRla}^* \text{ET}^* \text{EF}^* \text{EDa}) / (B\text{Wa}^* \text{AT}) )</td>
<td>Adult: Risk = 1 - exp((- \text{CDI} \times \text{SF}^i))</td>
</tr>
<tr>
<td>Child: ( (C\text{AB}^* \text{IRlc}^* \text{ET}^* \text{EF}^* \text{EDc}) / (B\text{wc}^* \text{AT}) )</td>
<td>Child: &quot;</td>
</tr>
<tr>
<td>Dermal exposure while showering/bathing</td>
<td>Dermal exposure while showering/bathing</td>
</tr>
<tr>
<td>Adult: ( (C\text{w}^* \text{SA}^* \text{PC}^* \text{ET}^* \text{EF}^* \text{EDa}^* \text{CF}) / (B\text{Wa}^* \text{AT}) )</td>
<td>Adult: Risk = 1 - exp((- \text{CDI} \times \text{SFo}))</td>
</tr>
<tr>
<td>Child: ( (C\text{w}^* \text{SA}^* \text{PC}^* \text{ETB}^* \text{EF}^* \text{EDc}^* \text{CF}) / (B\text{w}^* \text{AT}) )</td>
<td>Child: &quot;</td>
</tr>
<tr>
<td>Ingestion of chemicals in soil</td>
<td>Ingestion of chemicals in soil</td>
</tr>
<tr>
<td>Adult: ( (C\text{s}^* \text{IRsa}^* \text{SF}^* \text{EF}^* \text{EDa}^* \text{CF}) / (B\text{Wa}^* \text{AT}) )</td>
<td>Adult: Risk = 1 - exp((- \text{CDI} \times \text{SFo}))</td>
</tr>
<tr>
<td>Child: ( (C\text{s}^* \text{IRsc}^* \text{SF}^* \text{EF}^* \text{EDc}^* \text{CF}) / (B\text{wc}^* \text{AT}) )</td>
<td>Child: &quot;</td>
</tr>
<tr>
<td>Inhalation of particulates indoors</td>
<td>Inhalation of particulates indoors</td>
</tr>
<tr>
<td>Adult: ( (C\text{AI}^* \text{IRla}^* \text{ET}^* \text{EF}^* \text{EDa}) / (B\text{Wa}^* \text{AT}) )</td>
<td>Adult: Risk = 1 - exp((- \text{CDI} \times \text{SF}^i))</td>
</tr>
<tr>
<td>Child: ( (C\text{AI}^* \text{IRlc}^* \text{ET}^* \text{EF}^* \text{EDc}) / (B\text{wc}^* \text{AT}) )</td>
<td>Child: &quot;</td>
</tr>
<tr>
<td>Inhalation of particulates outdoors</td>
<td>Inhalation of particulates outdoors</td>
</tr>
<tr>
<td>Adult: ( (C\text{AO}^* \text{IRoa}^* \text{ETO}^* \text{EF}^* \text{EDa}) / (B\text{Wa}^* \text{AT}) )</td>
<td>Adult: Risk = 1 - exp((- \text{CDI} \times \text{SF}^i))</td>
</tr>
<tr>
<td>Child: ( (C\text{AO}^* \text{IRoc}^* \text{ETO}^* \text{EF}^* \text{EDc}) / (B\text{wc}^* \text{AT}) )</td>
<td>Child: &quot;</td>
</tr>
<tr>
<td><strong>NONCARCINOGENIC EXPOSURE</strong></td>
<td><strong>NONCARCINOGENIC RISK</strong></td>
</tr>
<tr>
<td>Ingestion of contaminated drinking water</td>
<td>Ingestion of contaminated drinking water</td>
</tr>
<tr>
<td>Adult: ( (C\text{wa}^* \text{IRda}^* \text{EF}^* \text{EDa}^* \text{365}) / (B\text{Wa}^* \text{EF}^* \text{EDa}^* \text{365}) )</td>
<td>Adult: Hazard Quotient = ( E / \text{RFDo} )</td>
</tr>
<tr>
<td>Child: ( (C\text{w}^* \text{RDc}^* \text{EF}^* \text{EDo}^* \text{365}) / (B\text{w}^* \text{EF}^* \text{EDc}^* \text{365}) )</td>
<td>Child: &quot;</td>
</tr>
<tr>
<td>Inhalation of vapors while showering/bathing</td>
<td>Inhalation of vapors while showering/bathing</td>
</tr>
<tr>
<td>Adult: ( (C\text{As}^* \text{IRla}^* \text{ET}^* \text{EF}^* \text{EDa}^* \text{365}) / (B\text{Wa}^* \text{EF}^* \text{EDa}^* \text{365}) )</td>
<td>Adult: Hazard Quotient = ( E / \text{RFDi} )</td>
</tr>
<tr>
<td>Child: ( (C\text{AB}^* \text{IRlc}^* \text{ET}^* \text{EF}^* \text{EDc}^* \text{365}) / (B\text{wc}^* \text{EF}^* \text{EDc}^* \text{365}) )</td>
<td>Child: &quot;</td>
</tr>
<tr>
<td>Dermal exposure while showering/bathing</td>
<td>Dermal exposure while showering/bathing</td>
</tr>
<tr>
<td>Adult: ( (C\text{w}^* \text{SA}^* \text{PC}^* \text{ET}^* \text{EF}^* \text{EDa}^* \text{CF}) / (B\text{Wa}^* \text{EF}^* \text{EDa}^* \text{365}) )</td>
<td>Adult: Hazard Quotient = ( E / \text{RFDo} )</td>
</tr>
<tr>
<td>Child: ( (C\text{w}^* \text{SA}^* \text{PC}^* \text{ETB}^* \text{EF}^* \text{EDc}^* \text{CF}) / (B\text{w}^* \text{EF}^* \text{EDc}^* \text{365}) )</td>
<td>Child: &quot;</td>
</tr>
<tr>
<td>Ingestion of chemicals in soil</td>
<td>Ingestion of chemicals in soil</td>
</tr>
<tr>
<td>Adult: ( (C\text{s}^* \text{IRsa}^* \text{SF}^* \text{EF}^* \text{EDa}^* \text{CF}) / (B\text{Wa}^* \text{EF}^* \text{EDa}^* \text{365}) )</td>
<td>Adult: Hazard Quotient = ( E / \text{RFDo} )</td>
</tr>
<tr>
<td>Child: ( (C\text{s}^* \text{IRsc}^* \text{SF}^* \text{EF}^* \text{EDc}^* \text{CF}) / (B\text{wc}^* \text{EF}^* \text{EDc}^* \text{365}) )</td>
<td>Child: &quot;</td>
</tr>
<tr>
<td>Inhalation of particulates indoors</td>
<td>Inhalation of particulates indoors</td>
</tr>
<tr>
<td>Adult: ( (C\text{AI}^* \text{IRla}^* \text{ET}^* \text{EF}^* \text{EDa}^* \text{365}) / (B\text{Wa}^* \text{EF}^* \text{EDa}^* \text{365}) )</td>
<td>Adult: Hazard Quotient = ( E / \text{RFDi} )</td>
</tr>
<tr>
<td>Child: ( (C\text{AI}^* \text{IRlc}^* \text{ET}^* \text{EF}^* \text{EDc}^* \text{365}) / (B\text{wc}^* \text{EF}^* \text{EDc}^* \text{365}) )</td>
<td>Child: &quot;</td>
</tr>
<tr>
<td>Inhalation of particulates outdoors</td>
<td>Inhalation of particulates outdoors</td>
</tr>
<tr>
<td>Adult: ( (C\text{AO}^* \text{IRoa}^* \text{ETO}^* \text{EF}^* \text{EDa}^* \text{365}) / (B\text{Wa}^* \text{EF}^* \text{EDa}^* \text{365}) )</td>
<td>Adult: Hazard Quotient = ( E / \text{RFDi} )</td>
</tr>
<tr>
<td>Child: ( (C\text{AO}^* \text{IRoc}^* \text{ETO}^* \text{EF}^* \text{EDc}^* \text{365}) / (B\text{wc}^* \text{EF}^* \text{EDc}^* \text{365}) )</td>
<td>Child: &quot;</td>
</tr>
</tbody>
</table>
TABLE E.6 Preliminary Calculations of Remediation Goals for Carbon Tetrachloride for Agra, Kansas

1. CARCINOGENIC RISK GOALS - GROUNDWATER

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Average Concentration (µg/l) that will Reduce Adult Risk to:</th>
<th>Average Concentration (µg/l) that will Reduce Child Risk to:</th>
<th>ARAR GOALS MCL (µg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1E-04</td>
<td>1E-06</td>
<td>1E-04</td>
</tr>
<tr>
<td>Drinking Water</td>
<td>65.5</td>
<td>0.7</td>
<td>52.4</td>
</tr>
<tr>
<td>Vapors in Bath</td>
<td>120.2</td>
<td>1.2</td>
<td>61.1</td>
</tr>
<tr>
<td>Dermal Contact</td>
<td>1535.0</td>
<td>15.3</td>
<td>1287.5</td>
</tr>
<tr>
<td>COMBINED</td>
<td>41.3</td>
<td>0.4</td>
<td>27.6</td>
</tr>
</tbody>
</table>

2. CARCINOGENIC RISK GOALS - SOIL

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Average Concentration (µg/l) that will Reduce Adult Risk to:</th>
<th>Average Concentration (µg/l) that will Reduce Child Risk to:</th>
<th>ARAR GOALS MCL (µg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1E-04</td>
<td>1E-06</td>
<td>1E-04</td>
</tr>
<tr>
<td>Soil Ingestion</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Dust, Indoors</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Dust, Outdoors</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>COMBINED</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

3. NONCARCINOGENIC RISK GOALS - GROUNDWATER

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Average Concentration (µg/l) that reduce Adult Hazard Quotient to 1.0</th>
<th>Average Concentration (µg/l) that reduce Child Hazard Quotient to 1.0</th>
<th>ARAR GOALS MCL (µg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drinking Water</td>
<td>26</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Vapors in Shower</td>
<td>77</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Dermal Contact</td>
<td>599</td>
<td>494</td>
<td></td>
</tr>
<tr>
<td>COMBINED</td>
<td>19</td>
<td>13</td>
<td>5</td>
</tr>
</tbody>
</table>

4. NONCARCINOGENIC RISK GOALS - SOIL

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Average Concentration (µg/l) that reduce Adult Hazard Quotient to 1.0</th>
<th>Average Concentration (µg/l) that reduce Child Hazard Quotient to 1.0</th>
<th>ARAR GOALS MCL (µg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Ingestion</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Dust, Indoors</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Dust, Outdoors</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>COMBINED</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

NA = Concentration is currently lower than required to meet goal.
### TABLE E.7 Contaminant Characteristics Assumed for Agra, Kansas

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Description</th>
<th>Reference</th>
<th>Carbon Tetrachloride</th>
<th>Chloroform</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Values</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CW</td>
<td>µg/I</td>
<td>Chemical Concentration in Water</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CS</td>
<td>µg/kg</td>
<td>Chemical Concentration in Soil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAS</td>
<td>µg/m³</td>
<td>Concentration in Shower Air (= CW<em>W</em>S*K/Vb)</td>
<td>4.18E+02</td>
<td>0.00E+00</td>
<td></td>
</tr>
<tr>
<td>CAB</td>
<td>µg/m³</td>
<td>Concentration in Bath Air (= CW<em>Wb</em>K/Vb)</td>
<td>3.06E+02</td>
<td>0.00E+00</td>
<td></td>
</tr>
<tr>
<td>CAO</td>
<td>µg/m³</td>
<td>Concentration in Outdoor Air, Particulates (AS<em>RD</em>Do)</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
</tr>
<tr>
<td>CAI</td>
<td>µg/m³</td>
<td>Concentration in Indoor Air, Particulates (AS<em>RD</em>Do)</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
</tr>
<tr>
<td>Decay percent/yr</td>
<td></td>
<td>Natural Decay Rate</td>
<td></td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

**Toxicity - Carcinogenic**

<table>
<thead>
<tr>
<th>SFo</th>
<th>1/(µg/kg-day)</th>
<th>Ingestion Slope Factor</th>
<th>IRIS</th>
<th>1.30E-04</th>
<th>6.10E-06</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFi</td>
<td>1/(µg/kg-day)</td>
<td>Inhalation Unit Risk</td>
<td>IRIS</td>
<td>1.50E-05</td>
<td>2.30E-05</td>
</tr>
<tr>
<td>SMi</td>
<td>m³/µg</td>
<td>Weight of Evidence Class</td>
<td>IRIS</td>
<td>5.25E-05</td>
<td>9.03E-05</td>
</tr>
<tr>
<td>Type of Cancer</td>
<td></td>
<td></td>
<td></td>
<td>B2 *</td>
<td></td>
</tr>
<tr>
<td>Adjustment for Adsorption</td>
<td></td>
<td></td>
<td></td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

**Toxicity - Noncarcinogenic**

<table>
<thead>
<tr>
<th>RDo</th>
<th>µg/kg-day</th>
<th>Oral Reference Dose</th>
<th>IRIS</th>
<th>0.70</th>
<th>10.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIC</td>
<td>µg/m³</td>
<td>Inhalation Reference Concentration</td>
<td>ATSDR,1992 (CCL4)</td>
<td>10.0</td>
<td>No value</td>
</tr>
<tr>
<td>RDI</td>
<td>µg/kg-day</td>
<td>Inhalation Dose Equivalent</td>
<td>Calculated</td>
<td>2.9</td>
<td>No Value</td>
</tr>
</tbody>
</table>

**EPA Drinking Water Standards**

<table>
<thead>
<tr>
<th>Status Reg.</th>
<th>Regulation Status</th>
<th>USEPA Advisories</th>
<th>Final</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCLG</td>
<td>Maximum Contaminant Level Goal</td>
<td>USEPA Advisories</td>
<td>zero</td>
<td>100</td>
</tr>
<tr>
<td>MCL</td>
<td>Maximum Contaminant Level</td>
<td>USEPA Advisories</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>DWEL</td>
<td>Drinking Water Equivalent Level</td>
<td>USEPA Advisories</td>
<td>700</td>
<td>7000</td>
</tr>
</tbody>
</table>

**EPA Health Advisories - 10 kg Child, maximum safe exposure**

| 1-day             | µg/l | Up to 5 consecutive days | USEPA Advisories | 4000 | 4000 |
| 10-day            | µg/l | Up to 14 consecutive days | USEPA Advisories | 200  | 4000 |
| Longer term       | µg/l | Up to 7 years            | USEPA Advisories | 70   | 100  |

**EPA Health Advisories - 70-kg Adult, maximum safe exposure**

| Longer term       | µg/l | Up to 7 years            | USEPA Advisories | 300  | 400  |
| Lifetime          | µg/l | Lifetime of exposure     | USEPA Advisories | -    | -    |
| 10e-4 risk        | µg/l | Concentration producing Cancer Risk of .0001 | USEPA Advisories | 30   | 600  |
| µg/kg-day         | Equivalent 7-year dose | USEPA Advisories | 8.57  | 11.43 |

**Physical Characteristics**

<table>
<thead>
<tr>
<th>PC</th>
<th>cm/hr</th>
<th>Dermal Permeability Constant</th>
<th>0.022</th>
<th>0.13</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>fraction</td>
<td>Volatization Factor</td>
<td>0.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>

* Class B2: Probable human carcinogen; sufficient evidence from animal studies.

** No causal relationships with specific cancers established.

§ Total for all THMs combined (currently 100 µg/l; .08 µg/l is proposed limit)
### TABLE E.8 Summary of Potential Exposure Routes at Agra, Kansas

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Selected for Evaluation</th>
<th>Reason for Selection or Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion</td>
<td>Yes</td>
<td>Potential for use of contaminated groundwater for drinking.</td>
</tr>
<tr>
<td>Dermal Contact</td>
<td>Yes</td>
<td>Contaminated groundwater used for bathing.</td>
</tr>
<tr>
<td>Soil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion</td>
<td>No</td>
<td>No contamination in near-surface soils.</td>
</tr>
<tr>
<td>Dermal Contact</td>
<td>No</td>
<td>Insignificant contribution to total exposure.</td>
</tr>
<tr>
<td>Air</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Vapor Phase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indoors</td>
<td>Yes</td>
<td>Vapor phase of contaminants could be inhaled in shower or bath.</td>
</tr>
<tr>
<td>Outdoors</td>
<td>No</td>
<td>Toxicity of contaminants quickly reduced to safe levels in air.</td>
</tr>
<tr>
<td>Inhalation of Particulates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indoors</td>
<td>No</td>
<td>No contamination in near-surface soils.</td>
</tr>
<tr>
<td>Outdoors</td>
<td>No</td>
<td>No contamination in near-surface soils.</td>
</tr>
<tr>
<td>Surface Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion</td>
<td>No</td>
<td>No contamination measured in surface waters.</td>
</tr>
<tr>
<td>Dermal Contact</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Sediments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incidental Ingestion</td>
<td>No</td>
<td>No contamination measured in sediments.</td>
</tr>
<tr>
<td>Dermal Contact</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Food</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish and Shellfish</td>
<td>No</td>
<td>No contaminated measured in surface waters.</td>
</tr>
<tr>
<td>Meat and Game</td>
<td>No</td>
<td>No animals use site as food source.</td>
</tr>
<tr>
<td>Dairy</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Eggs</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Vegetables</td>
<td>No</td>
<td>No projected land use includes gardening.</td>
</tr>
<tr>
<td>Fruits</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>
TABLE E.9 Summary of Adult and Child Carcinogenic Risks for the Worst-Case 30-Year Cumulative Exposure at Agra, Kansas, for 1% Annual Decay of Contaminant in the Lower Aquifer (The worst case considers a child born in 2012.)

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Chronic Daily Intake (µg/kg-day)</th>
<th>Chemical-specific Risk</th>
<th>Total Pathway Risk</th>
<th>Total Exposure Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CUMULATIVE ADULT CARCINOGENIC RISK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>1.44E-01</td>
<td>1.87E-05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>1.87E-05</td>
<td></td>
</tr>
<tr>
<td>Inhalation of Vapors While Showering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>1.94E-01</td>
<td>1.02E-05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>1.02E-05</td>
<td></td>
</tr>
<tr>
<td>Dermal Exposure While Showering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>6.13E-03</td>
<td>7.97E-07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>7.97E-07</td>
<td></td>
</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
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<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td></td>
<td></td>
<td>2.97E-05</td>
<td>2.97E-05</td>
</tr>
<tr>
<td>Chloroform</td>
<td></td>
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<td>0.00E+00</td>
<td></td>
</tr>
<tr>
<td><strong>CUMULATIVE CHILD CARCINOGENIC RISK</strong></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>1.82E-01</td>
<td>2.37E-05</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>2.37E-05</td>
<td></td>
</tr>
<tr>
<td>Inhalation of Vapors While Bathing</td>
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</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>3.97E-01</td>
<td>2.08E-05</td>
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</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>2.08E-05</td>
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</tr>
<tr>
<td>Dermal Exposure While Bathing</td>
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<td></td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>7.52E-03</td>
<td>9.78E-07</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>9.78E-07</td>
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</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
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</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td></td>
<td></td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
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<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
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</tr>
<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
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<tr>
<td>Carbon Tetrachloride</td>
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<td>4.55E-05</td>
<td>4.55E-05</td>
</tr>
<tr>
<td>Chloroform</td>
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<td>0.00E+00</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE E.10 Summary of Adult and Child Chronic Noncarcinogenic Risks for the Worst-Case 30-Year Exposure at Agra, Kansas, for 1% Annual Decay of Contaminant in the Lower Aquifer

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Exposure Level (μg/kg-day)</th>
<th>Chemical-specific Hazard Quotient</th>
<th>Total Pathway Hazard Index</th>
<th>Total Exposure Hazard Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADULT NONCARCINOGENIC RISK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
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<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>3.35E-01</td>
<td>0.48</td>
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</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Vapors While Showering</td>
<td></td>
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</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>4.52E-01</td>
<td>0.16</td>
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<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dermal Exposure While Showering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>1.43E-02</td>
<td>0.02</td>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td>Chloroform</td>
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<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
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<td></td>
</tr>
<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
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</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.66</td>
<td>0.66</td>
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<td>0.66</td>
</tr>
<tr>
<td>Chloroform</td>
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<td>0.66</td>
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<td></td>
</tr>
<tr>
<td><strong>CHILD NONCARCINOGENIC RISK</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>4.25E-01</td>
<td>0.61</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Vapors While Bathing</td>
<td></td>
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</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>9.26E-01</td>
<td>0.32</td>
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<td>0.32</td>
</tr>
<tr>
<td>Chloroform</td>
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<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dermal Exposure While Bathing</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>1.76E-02</td>
<td>0.03</td>
<td></td>
<td>0.03</td>
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<tr>
<td>Chloroform</td>
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<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.96</td>
<td>0.96</td>
<td></td>
<td>0.96</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00</td>
<td>0.96</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE E.11 Summary of Adult and Child Subchronic Noncarcinogenic Risks, Based on the EPA Health Advisory for Exposure Lasting Less than Seven Years (EPA 1996) at Agra, Kansas, for 1% Annual Decay of Contaminant in the Lower Aquifer (Maximum exposure occurs in 2016.)

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Exposure Level (µg/kg-day)</th>
<th>Chemical-specific Hazard Quotient</th>
<th>Total Pathway Hazard Index</th>
<th>Total Exposure Hazard Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADULT NONCARCINOGENIC RISK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>5.23E-01</td>
<td>0.06</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
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<td>Inhalation of Particulates Outdoors</td>
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### TABLE E.12 Summary of Adult and Child Carcinogenic Risks for the Worst-Case 30-Year Cumulative Exposure at Agra, Kansas, for No Assumed Decay of Contaminant in the Combined Upper and Lower Aquifers (The worst case considers a child born in 2013.)

<table>
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<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Chronic Daily Intake (µg/kg-day)</th>
<th>Chemical-specific Risk</th>
<th>Total Pathway Risk</th>
<th>Total Exposure Risk</th>
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<tr>
<td>Inhalation of Particulates Outdoors</td>
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<td><strong>TOTAL ALL PATHWAYS:</strong></td>
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### TABLE E.13 Summary of Adult and Child Chronic Noncancerigenic Risks for the Worst-Case 30-Year Exposure at Agra, Kansas, for No Assumed Decay of Contaminant in the Combined Upper and Lower Aquifers

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<th>Exposure Pathway &amp; Chemical</th>
<th>Exposure Level (µg/kg-day)</th>
<th>Chemical-specific Hazard Quotient</th>
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TABLE E.14 Summary of Adult and Child Subchronic Noncarcinogenic Risks, Based on the EPA Health Advisory for Exposure Lasting Less than Seven Years (EPA 1996) at Agra, Kansas, for No Assumed Decay of Contaminant in the Combined Upper and Lower Aquifers (Maximum exposure occurs in 2016.)

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Exposure Level (μg/kg-day)</th>
<th>Chemical-specific Hazard Quotient</th>
<th>Total Pathway Hazard Index</th>
<th>Total Exposure Hazard Index</th>
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<td><strong>ADULT NONCANCINOGENIC RISK</strong></td>
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<td>Ingestion of Contaminated Drinking Water</td>
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<td>Chloroform 0.00E+00</td>
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<td>Dermal Exposure While Showering</td>
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<tr>
<td>Ingestion of Chemicals in Soil</td>
<td>Carbon Tetrachloride 0.00E+00</td>
<td>0.00</td>
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<td>Chloroform 0.00E+00</td>
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<tr>
<td>Inhalation of Particulates Indoors</td>
<td>Carbon Tetrachloride 0.00E+00</td>
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<tr>
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<td>Chloroform 0.00E+00</td>
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<tr>
<td>Inhalation of Particulates Outdoors</td>
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<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
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<td>Chloroform 0.00</td>
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<td><strong>CHILD NONCANCINOGENIC RISK</strong></td>
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<td>Ingestion of Contaminated Drinking Water</td>
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<tr>
<td>Ingestion of Chemicals in Soil</td>
<td>Carbon Tetrachloride 0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
<td>0.00</td>
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</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td>Carbon Tetrachloride 0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
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<td>Chloroform 0.00E+00</td>
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<tr>
<td>Inhalation of Particulates Outdoors</td>
<td>Carbon Tetrachloride 0.00E+00</td>
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<tr>
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<td>Chloroform 0.00E+00</td>
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<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
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<td></td>
<td>Chloroform 0.00</td>
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TABLE E.15 Summary of Adult and Child Carcinogenic Risks for the Worst-Case 30-Year Cumulative Exposure at Agra, Kansas, for 1% Annual Decay of Contaminant in the Combined Upper and Lower Aquifers (The worst case considers a child born in 2013.)

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Chronic Daily Intake (μg/kg-day)</th>
<th>Chemical-specific Risk</th>
<th>Total Pathway Risk</th>
<th>Total Exposure Risk</th>
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<tbody>
<tr>
<td><strong>CUMULATIVE ADULT CARCINOGENIC RISK</strong></td>
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<tr>
<td>Ingestion of Contaminated Drinking Water Carbon Tetrachloride</td>
<td>1.38E-01</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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</tr>
<tr>
<td>Inhalation of Vapors While Showering Carbon Tetrachloride</td>
<td>1.86E-01</td>
<td>9.77E-06</td>
<td>9.77E-06</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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</tr>
<tr>
<td>Dermal Exposure While Showering Carbon Tetrachloride</td>
<td>5.88E-03</td>
<td>7.65E-07</td>
<td>7.65E-07</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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</tr>
<tr>
<td>Ingestion of Chemicals in Soil Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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<tr>
<td>Chloroform</td>
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<tr>
<td>Inhalation of Particulates Indoors Carbon Tetrachloride</td>
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<td>0.00E+00</td>
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<tr>
<td>Chloroform</td>
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<td>0.00E+00</td>
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<tr>
<td>Inhalation of Particulates Outdoors Carbon Tetrachloride</td>
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<td>0.00E+00</td>
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<tr>
<td>Chloroform</td>
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<tr>
<td>TOTAL ALL PATHWAYS:</td>
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<td><strong>CUMULATIVE CHILD CARCINOGENIC RISK</strong></td>
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<td>Inhalation of Vapors While Bathing Carbon Tetrachloride</td>
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<td>Ingestion of Chemicals in Soil Carbon Tetrachloride</td>
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<tr>
<td>Inhalation of Particulates Indoors Carbon Tetrachloride</td>
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<td>Chloroform</td>
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<tr>
<td>Inhalation of Particulates Outdoors Carbon Tetrachloride</td>
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<tr>
<td>Chloroform</td>
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<tr>
<td>TOTAL ALL PATHWAYS:</td>
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</table>
TABLE E.16 Summary of Adult and Child Chronic Noncancerogenic Risks for the Worst-Case 30-Year Exposure at Agra, Kansas, for 1% Annual Decay of Contaminant in the Combined Upper and Lower Aquifers

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Exposure Level (μg/kg-day)</th>
<th>Chemical-specific Hazard Quotient</th>
<th>Total Pathway Hazard Index</th>
<th>Total Exposure Hazard Index</th>
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<tbody>
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<td><strong>ADULT NONCARCINOGENIC RISK</strong></td>
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<tr>
<td>Inhalation of Vapors While Showering</td>
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<tr>
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<td>Dermal Exposure While Showering</td>
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<td>Ingestion of Chemicals in Soil</td>
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<tr>
<td>Chloroform</td>
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<tr>
<td>Inhalation of Particulates Indoors</td>
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<tr>
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<td>Chloroform</td>
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<td>Inhalation of Particulates Outdoors</td>
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<td>Chloroform</td>
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<td><strong>TOTAL ALL PATHWAYS:</strong></td>
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<tr>
<td><strong>CHILD NONCARCINOGENIC RISK</strong></td>
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<tr>
<td>Ingestion of Contaminated Drinking Water</td>
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<tr>
<td>Inhalation of Vapors While Bathing</td>
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<td>Dermal Exposure While Bathing</td>
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<td>Ingestion of Chemicals in Soil</td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
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</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
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<tr>
<td>Inhalation of Particulates Outdoors</td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
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<td>Chloroform</td>
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<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
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</table>
TABLE E.17 Summary of Adult and Child Subchronic Noncarcinogenic Risks, Based on the EPA Health Advisory for Exposure Lasting Less than Seven Years (EPA 1996) at Agra, Kansas, for 1% Annual Decay of Contaminant in the Combined Upper and Lower Aquifers (Maximum exposure occurs in 2016.)

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Exposure Level (µg/kg-day)</th>
<th>Chemical-specific Hazard Quotient</th>
<th>Total Pathway Hazard Index</th>
<th>Total Exposure Hazard Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADULT NONCARCINOGENIC RISK</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
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</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>4.87E-01</td>
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<td>Chloroform</td>
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<tr>
<td>Inhalation of Vapors While Showering</td>
<td></td>
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</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>6.57E-01</td>
<td>0.02</td>
<td>0.02</td>
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</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Dermal Exposure While Showering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>2.08E-02</td>
<td>0.00</td>
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</tr>
<tr>
<td>Chloroform</td>
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<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td></td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.08</td>
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<td></td>
</tr>
<tr>
<td>Chloroform</td>
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<tr>
<td><strong>CHILD NONCARCINOGENIC RISK</strong></td>
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</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
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<td></td>
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<tr>
<td>Carbon Tetrachloride</td>
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</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
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<tr>
<td>Inhalation of Vapors While Bathing</td>
<td></td>
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<td>Carbon Tetrachloride</td>
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<tr>
<td>Chloroform</td>
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<td>0.00</td>
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<tr>
<td>Dermal Exposure While Bathing</td>
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<td>Chloroform</td>
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<tr>
<td>Ingestion of Chemicals in Soil</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
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</tr>
</tbody>
</table>
TABLE E.18 Summary of Adult and Child Carcinogenic Risks for the Worst-Case 30-Year Cumulative Exposure at Agra, Kansas, for No Assumed Decay of Contaminant in the Combined Upper and Lower Aquifers, with a Soil Source of Carbon Tetrachloride (The worst case considers a child born in 2034.)

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Chronic Daily Intake (µg/kg-day)</th>
<th>Chemical-specific Risk</th>
<th>Total Pathway Risk</th>
<th>Total Exposure Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CUMULATIVE ADULT CARCINOGENIC RISK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>2.58E-01</td>
<td>3.35E-05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>3.35E-05</td>
<td></td>
</tr>
<tr>
<td>Inhalation of Vapors While Showering</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>3.48E-01</td>
<td>1.83E-05</td>
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</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>1.83E-05</td>
<td></td>
</tr>
<tr>
<td>Dermal Exposure While Showering</td>
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<td></td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>1.10E-02</td>
<td>1.43E-06</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>1.43E-06</td>
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<tr>
<td>Ingestion of Chemicals in Soil</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL ALL PATHWAYS:</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>5.32E-05</td>
<td></td>
<td>5.32E-05</td>
<td>5.32E-05</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td></td>
<td>5.32E-05</td>
<td>5.32E-05</td>
</tr>
</tbody>
</table>

| **CUMULATIVE CHILD CARCINOGENIC RISK** | | | | |
| Ingestion of Contaminated Drinking Water | | | | |
| Carbon Tetrachloride | 2.78E-01 | 3.61E-05 | | |
| Chloroform | 0.00E+00 | 0.00E+00 | 3.61E-05 | |
| Inhalation of Vapors While Bathing | | | | |
| Carbon Tetrachloride | 5.57E-01 | 2.92E-05 | | |
| Chloroform | 0.00E+00 | 0.00E+00 | 2.92E-05 | |
| Dermal Exposure While Bathing | | | | |
| Carbon Tetrachloride | 1.16E-02 | 1.50E-06 | | |
| Chloroform | 0.00E+00 | 0.00E+00 | 1.50E-06 | |
| Ingestion of Chemicals in Soil | | | | |
| Carbon Tetrachloride | 0.00E+00 | 0.00E+00 | | |
| Chloroform | 0.00E+00 | 0.00E+00 | | |
| Inhalation of Particulates Indoors | | | | |
| Carbon Tetrachloride | 0.00E+00 | 0.00E+00 | | |
| Chloroform | 0.00E+00 | 0.00E+00 | | |
| Inhalation of Particulates Outdoors | | | | |
| Carbon Tetrachloride | 0.00E+00 | 0.00E+00 | | |
| Chloroform | 0.00E+00 | 0.00E+00 | | |
| TOTAL ALL PATHWAYS: | | | | |
| Carbon Tetrachloride | 6.69E-05 | | 6.69E-05 | 6.69E-05 |
| Chloroform | 0.00E+00 | | 6.69E-05 | 6.69E-05 |
TABLE E.19 Summary of Adult and Child Chronic Noncancerogenic Risks for the Worst-Case 30-Year Exposure at Agra, Kansas, for No Assumed Decay of Contaminant in the Combined Upper and Lower Aquifers, with a Soil Source of Carbon Tetrachloride

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Exposure Level (µg/kg-day)</th>
<th>Chemical-specific Hazard Quotient</th>
<th>Total Pathway Hazard Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADULT NONCARCINOGENIC RISK</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
<td>Carbon Tetrachloride: 6.01E-01, Chloroform: 0.00E+00</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>Inhilation of Vapors While Showering</td>
<td>Carbon Tetrachloride: 8.12E-01, Chloroform: 0.00E+00</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>Dermal Exposure While Showering</td>
<td>Carbon Tetrachloride: 2.57E-02, Chloroform: 0.00E+00</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Ingestion of Chemicals in Soil</td>
<td>Carbon Tetrachloride: 0.00E+00, Chloroform: 0.00E+00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Inhalation of Particulates Indoors</td>
<td>Carbon Tetrachloride: 0.00E+00, Chloroform: 0.00E+00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Inhalation of Particulates Outdoors</td>
<td>Carbon Tetrachloride: 0.00E+00, Chloroform: 0.00E+00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
<td>Carbon Tetrachloride: 1.18, Chloroform: 0.00</td>
<td>1.18</td>
<td>1.18</td>
</tr>
<tr>
<td><strong>CHLORAL NONCARCINOGENIC RISK</strong></td>
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</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
<td>Carbon Tetrachloride: 6.49E-01, Chloroform: 0.00E+00</td>
<td>0.93</td>
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<tr>
<td></td>
<td>Inhalation of Vapors While Bathing</td>
<td>Carbon Tetrachloride: 1.30E+00, Chloroform: 0.00E+00</td>
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<td>Dermal Exposure While Bathing</td>
<td>Carbon Tetrachloride: 2.70E-02, Chloroform: 0.00E+00</td>
<td>0.04</td>
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<td>Ingestion of Chemicals in Soil</td>
<td>Carbon Tetrachloride: 0.00E+00, Chloroform: 0.00E+00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Inhalation of Particulates Indoors</td>
<td>Carbon Tetrachloride: 0.00E+00, Chloroform: 0.00E+00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Inhalation of Particulates Outdoors</td>
<td>Carbon Tetrachloride: 0.00E+00, Chloroform: 0.00E+00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
<td>Carbon Tetrachloride: 1.42, Chloroform: 0.00</td>
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<td>1.42</td>
</tr>
</tbody>
</table>
TABLE E.20 Summary of Adult and Child Subchronic Noncarcinogenic Risks Based on the EPA Health Advisory for Exposure Lasting Less than Seven Years (EPA 1996) at Agra, Kansas, for No Assumed Decay of Contaminant in the Combined Upper and Lower Aquifers, with a Soil Source of Carbon Tetrachloride (Maximum exposure occurs in 2055.)

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Exposure Level (µg/kg-day)</th>
<th>Chemical-specific Hazard Quotient</th>
<th>Total Pathway Hazard Index</th>
<th>Total Exposure Hazard Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADULT NONCARCINOGENIC RISK</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
<td>Carbon Tetrachloride</td>
<td>9.10E-01</td>
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<tr>
<td></td>
<td>Chloroform</td>
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<td>0.00</td>
</tr>
<tr>
<td>Inhalation of Vapors While Showering</td>
<td>Carbon Tetrachloride</td>
<td>1.23E+00</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Dermal Exposure While Showering</td>
<td>Carbon Tetrachloride</td>
<td>3.88E-02</td>
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<tr>
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<td>Chloroform</td>
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</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
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<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
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<tr>
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<td>Chloroform</td>
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<td>0.00</td>
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<tr>
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<td>Chloroform</td>
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<tr>
<td></td>
<td>Chloroform</td>
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<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Inhalation of Vapors While Bathing</td>
<td>Carbon Tetrachloride</td>
<td>1.23E+00</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Dermal Exposure While Bathing</td>
<td>Carbon Tetrachloride</td>
<td>3.88E-02</td>
<td>0.01</td>
<td>0.01</td>
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<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
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<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
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<tr>
<td>Inhalation of Particulates Indoors</td>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
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<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
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<td></td>
<td>Chloroform</td>
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</tr>
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</tr>
</tbody>
</table>
TABLE E.21 Summary of Adult and Child Carcinogenic Risks for the Worst-Case 30-Year Cumulative Exposure at Agra, Kansas, for 1% Annual Decay of Contaminant in the Combined Upper and Lower Aquifers, with a Soil Source of Carbon Tetrachloride (The worst case considers a child born in 2032.)

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Chronic Daily Intake (µg/kg-day)</th>
<th>Chemical-specific Risk</th>
<th>Total Pathway Risk</th>
<th>Total Exposure Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUMULATIVE ADULT CARCINOGENIC RISK</td>
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</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>1.60E-01</td>
<td>2.08E-05</td>
<td>2.08E-05</td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Vapors While Showering</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>2.16E-01</td>
<td>1.14E-05</td>
<td>1.14E-05</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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</tr>
<tr>
<td>Dermal Exposure While Showering</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>6.84E-03</td>
<td>8.90E-07</td>
<td>8.90E-07</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td></td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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<tr>
<td>TOTAL ALL PATHWAYS:</td>
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</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>3.31E-05</td>
<td>3.31E-05</td>
<td>3.31E-05</td>
<td>3.31E-05</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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<tr>
<td>CUMULATIVE CHILD CARCINOGENIC RISK</td>
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<tr>
<td>Ingestion of Contaminated Drinking Water</td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>1.76E-01</td>
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<tr>
<td>Inhalation of Vapors While Bathing</td>
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<tr>
<td>Dermal Exposure While Bathing</td>
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<tr>
<td>Carbon Tetrachloride</td>
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<td>0.00E+00</td>
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<tr>
<td>Ingestion of Chemicals in Soil</td>
<td></td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
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<tr>
<td>Inhalation of Particulates Indoors</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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</tr>
<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td></td>
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<tr>
<td>Inhalation of Particulates Outdoors</td>
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<tr>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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<tr>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
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<tr>
<td>TOTAL ALL PATHWAYS:</td>
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TABLE E.22 Summary of Adult and Child Chronic Noncarcinogenic Risks for the Worst-Case 30-Year Exposure at Agra, Kansas, for 1% Annual Decay of Contaminant in the Combined Upper and Lower Aquifers, with a Soil Source of Carbon Tetrachloride

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Exposure Level (μg/kg-day)</th>
<th>Chemical-specific Hazard Quotient</th>
<th>Total Pathway Hazard Index</th>
<th>Total Exposure Hazard Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADULT NONCARCINOGENIC RISK</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
<td>Carbon Tetrachloride</td>
<td>3.74E-01</td>
<td>0.53</td>
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<td></td>
<td>Chloroform</td>
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<td>0.00</td>
</tr>
<tr>
<td>Inhalation of Vapors While Showering</td>
<td>Carbon Tetrachloride</td>
<td>5.05E-01</td>
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<td>0.18</td>
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<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Dermal Exposure While Showering</td>
<td>Carbon Tetrachloride</td>
<td>1.60E-02</td>
<td>0.02</td>
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</tr>
<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
<td>Carbon Tetrachloride</td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
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<td></td>
<td>Chloroform</td>
<td>0.00</td>
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<tr>
<td><strong>CHILD NONCARCINOGENIC RISK</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
<td>Carbon Tetrachloride</td>
<td>4.11E-01</td>
<td>0.59</td>
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<td></td>
<td>Chloroform</td>
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</tr>
<tr>
<td>Inhalation of Vapors While Bathing</td>
<td>Carbon Tetrachloride</td>
<td>8.07E-01</td>
<td>0.28</td>
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<td>Chloroform</td>
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<td>0.00</td>
</tr>
<tr>
<td>Dermal Exposure While Bathing</td>
<td>Carbon Tetrachloride</td>
<td>1.71E-02</td>
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<tr>
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<td>Chloroform</td>
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<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td>Carbon Tetrachloride</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Chloroform</td>
<td>0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
<td>Carbon Tetrachloride</td>
<td>0.89</td>
<td>0.89</td>
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<tr>
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<td>Chloroform</td>
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</tbody>
</table>
TABLE E.23  Summary of Adult and Child Subchronic Noncarcinogenic Risks Based on the EPA Health Advisory for Exposure Lasting Less than Seven Years (EPA 1996) at Agra, Kansas, for 1% Annual Decay of Contaminant in the Combined Upper and Lower Aquifers, with a Soil Source of Carbon Tetrachloride (Maximum exposure occurs in 2055.)

<table>
<thead>
<tr>
<th>Exposure Pathway &amp; Chemical</th>
<th>Exposure Level (µg/kg-day)</th>
<th>Chemical-specific Hazard Quotient</th>
<th>Total Pathway Hazard Index</th>
<th>Total Exposure Hazard Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADULT NONCARCINOGENIC RISK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Contaminated Drinking Water</td>
<td>Carbon Tetrachloride 5.03E-01</td>
<td>0.06</td>
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<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Vapors While Showering</td>
<td>Carbon Tetrachloride 6.79E-01</td>
<td>0.02</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dermal Exposure While Showering</td>
<td>Carbon Tetrachloride 2.15E-02</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td>Carbon Tetrachloride 0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
<td>0.00</td>
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<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td>Carbon Tetrachloride 0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
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<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
<td>0.00</td>
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</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td>Carbon Tetrachloride 0.00E+00</td>
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<td></td>
<td>Chloroform 0.00E+00</td>
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<tr>
<td><strong>TOTAL ALL PATHWAYS:</strong></td>
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<tr>
<td><strong>CHILD NONCARCINOGENIC RISK</strong></td>
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<tr>
<td>Ingestion of Contaminated Drinking Water</td>
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<td>Chloroform 0.00E+00</td>
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<td></td>
</tr>
<tr>
<td>Inhalation of Vapors While Bathing</td>
<td>Carbon Tetrachloride 6.79E-01</td>
<td>0.02</td>
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<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
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<tr>
<td>Dermal Exposure While Bathing</td>
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<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of Chemicals in Soil</td>
<td>Carbon Tetrachloride 0.00E+00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Indoors</td>
<td>Carbon Tetrachloride 0.00E+00</td>
<td>0.00</td>
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<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation of Particulates Outdoors</td>
<td>Carbon Tetrachloride 0.00E+00</td>
<td>0.00</td>
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<tr>
<td></td>
<td>Chloroform 0.00E+00</td>
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<tr>
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<td>Chloroform 0.00</td>
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