CENTRAL TRUCKEE MEADOWS REMEDIATION DISTRICT

Remediation Management Plan

Volume 2

CTM
REMEDIATION
DISTRICT

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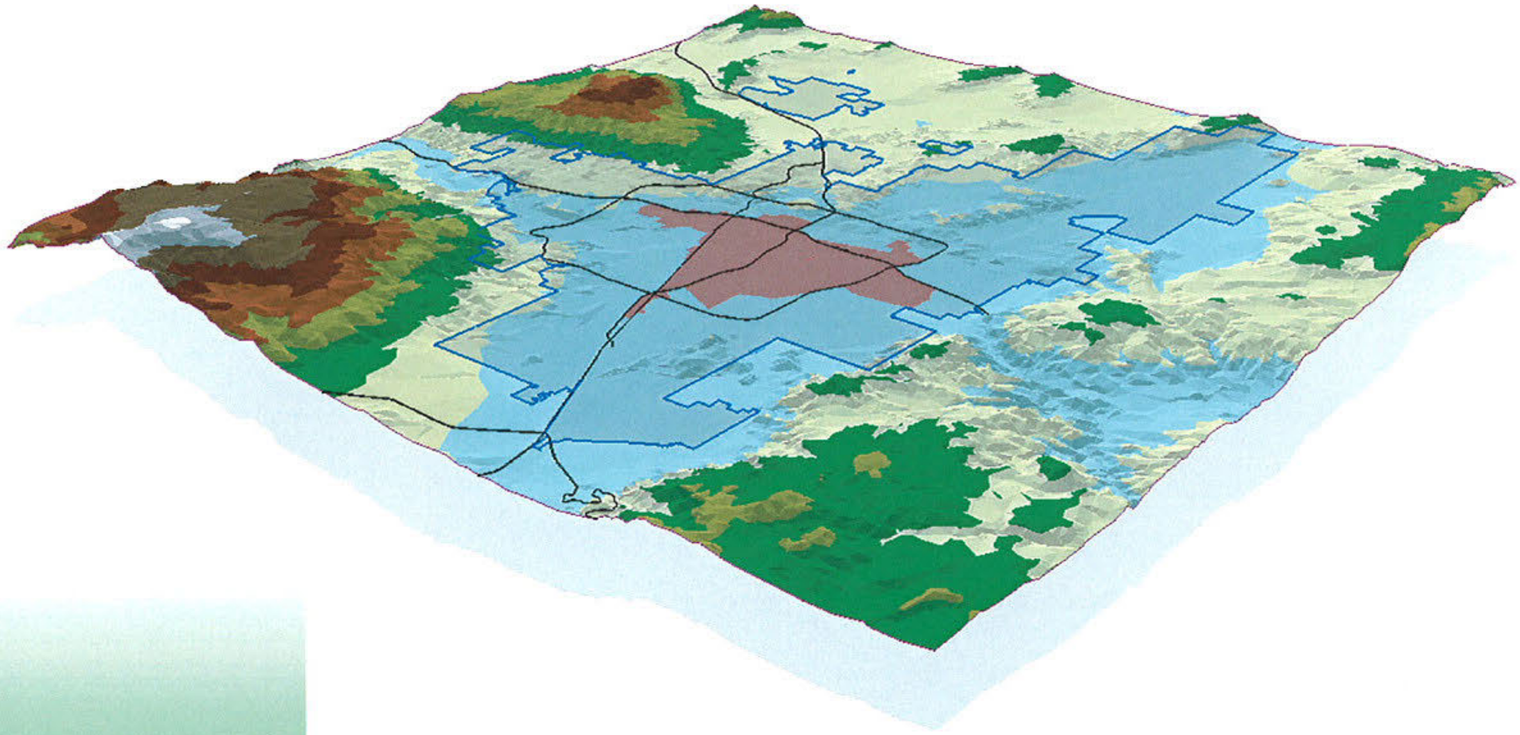

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Appendix C

Technical Memorandum – Human Health and Environmental Risk Analysis

Central Truckee Meadows Remediation District

Technical Memorandum
Human Health and Environmental Risk Analysis

Revised July 9, 2002

Technical Memorandum

Contents

Appendices

List of Tables

List of Figures

Section 1
Introduction

This Technical Memorandum – Human Health and Environmental Impacts Analysis (Technical Memorandum) was prepared by Camp Dresser & McKee Inc. (CDM) on behalf of the Washoe County Department of Water Resources (Washoe County). The work documented in this Technical Memorandum was performed as an element of the Central Truckee Meadows (CTM) Remediation District project. The primary objective of the CTM Remediation District project is to characterize and evaluate groundwater contamination in the CTM. In addition to the human health and ecological impacts analyses, project elements include implementation of an extensive field investigation program, development of a groundwater flow model, development and evaluation of a range of remedial alternatives, and preparation of a remediation plan.

1.1 Background and Objectives

Tetrachloroethene (PCE), an organic solvent used in a variety of commercial/industrial operations (e.g., commercial dry cleaning, paint manufacturing and distribution, auto repair) was initially found in groundwater within the limits of the City of Reno. Subsequent groundwater investigations have identified widespread occurrences of PCE and other volatile organic compounds (VOCs) in shallow groundwater. A detailed discussion regarding site history, geology and hydrology, and sampling collection and analysis is compiled in the Final Updated Work Plan (CDM, 2001).

To address the presence of PCE in groundwater, the Nevada legislature established the Remediation District by enacting the State of Nevada Statute NRS 540A.250 through NRS 540A.285. The Remediation District was tasked to define the nature and extent of PCE in groundwater, to evaluate human health and environmental impacts associated with the presence of PCE in shallow groundwater, and to develop and implement remedial actions addressing PCE impacts to the deep groundwater drinking water supply. This technical memorandum documents the analysis of human health risk associated with the presence of PCE and its degradation products in groundwater within the CTM.

The specific objectives of this technical memorandum are:

- To evaluate potential current and future human health risks and environmental impacts associated with PCE-impacted groundwater in the CTM.

By statute, the focus of Remediation District efforts is PCE and its degradation products in groundwater used for drinking water. Therefore, the primary focus of this risk analysis is PCE and the potential human health risk associated with ingestion of PCE in drinking water. However, the approach taken for the analysis of risk was influenced by several factors, including:

- **Presence of Other Groundwater Contaminants.** Groundwater contaminants other than PCE were included in the risk analysis in order to develop a comprehensive estimate of potential risk associated with groundwater within the CTM. Guidance for risk analyses typically requires that all contaminants that could contribute significantly to exposure be included in risk evaluations.

- **Exposure Pathways.** Exposure pathways associated with PCE in groundwater are not limited to dermal contact or ingestion of PCE in groundwater used for drinking. Release of PCE from groundwater to soil gas or the effects of PCE-contaminated groundwater on surface water were also considered as exposure pathways. Additional potential exposure pathways are discussed in detail below.

- **Deep Groundwater.** PCE has been detected in the deep water-bearing zone. This zone serves as a significant water supply source within the CTM. Currently, deep wells that draw water from contaminated supplies are protected by wellhead treatment systems. These treatment systems ensure that the municipal water supply source meets regulation standards (maximum concentration limits [MCLs]). Nevertheless, given the widespread distribution of PCE and uncertainties related to the PCE migration pathways, a qualitative risk analysis based on potential impacts to this drinking water supply is performed. This Technical Memorandum quantitatively addresses PCE and degradation products only in the shallow water-bearing zone.

Provided below is an overview of the analyses performed to evaluate risk to human health and to ecological receptors.

1.2 Human Health Risk Analysis

The risk analysis evaluates human health risk associated with contaminants in shallow groundwater and media that may be impacted by contaminants in shallow groundwater (e.g., indoor air). The purpose of this evaluation is to determine the need for remediation of these media. Potential human health impacts associated with contaminants in deep groundwater are evaluated only qualitatively. Because deep groundwater in the CTM is used for drinking water purposes, existing state and federal drinking water standards (e.g., MCLs) will be used to determine the requirements governing remedial actions in the deep aquifer. Quantitative risk analyses for deep groundwater are therefore not necessary.

Shallow groundwater at the Site is not currently used for drinking water purposes and is not expected to be used for such purposes in the future. However, construction workers who excavate below the groundwater table could be exposed directly to contaminants in shallow groundwater. This possibility is evaluated in the risk analysis.

Other media that could potentially be impacted by contaminants migrating from groundwater include indoor air, ambient air, and surface water and sediment in the

Truckee River. Volatile organic compounds (VOCs) in groundwater may be released into soil gas and subsequently migrate to indoor air through the foundation of buildings. This potential exposure pathway is evaluated in the risk analysis. Inhalation of contaminants in ambient air is generally not considered an important exposure pathway, since VOCs tend to be rapidly diluted in ambient air. Inhalation of VOCs inside excavations, where airflow and dilution of VOCs may be reduced is, however, evaluated. Groundwater contaminants might also discharge into surface water and sediment in the Truckee River and may subsequently be released into air. Subsequently, people recreating in or near the Truckee River could be exposed to these contaminants. However, contaminants released into surface water and sediment are expected to be rapidly diluted by the water in the Truckee River, and significant volatilization to ambient air is also not expected. Exposure to contaminants in surface water, sediment or air at the Truckee River is therefore not expected to be an important scenario for the site.

This Technical Memorandum provides further evidence for these assumptions. The human health risk analysis was conducted using the following U.S. Environmental Protection Agency (USEPA) health risk analysis guidelines, and other guidance, literature, or site-specific information as appropriate:

- Alternate Concentration Limit Guidance, Part 1. ACL Policy and Information Requirements. Office of Solid Waste/Waste Management Division. EPA/530-SW-87-017. July 1987.
- Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part A). EPA/540/1-89/002. December 1989.
- Exposure Factors Handbook. Office of Research and Development. National Center for Environmental Assessment. EPA/600/P-95/002Fa. August 1997.
- Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual. Supplemental Guidance "Standard Default Exposure Factors." March 1991.
- Guidelines for Exposure Assessment, Federal Register, Volume 57, No. 104, May 29, 1992.

The terms impacts and risk analysis (RA) are used interchangeably in the text.

1.3 Ecological Risk Evaluation

Currently available hydrologic information suggests that the Truckee River is a gaining stream during a portion of the year and a loosing stream during other parts of the year. Therefore, groundwater may discharge PCE into the Truckee River during part of the year. Because any groundwater discharged into the Truckee River will be rapidly diluted in the surface water, significant impacts to ecological receptors are not expected. However, ecological impacts are theoretically possible, potential ecological impacts are evaluated.

1.4 Organization of the Technical Memorandum

In addition to this Introduction, the technical memorandum is organized into the following sections:

- Section 2 – Site Conceptual Exposure Model
- Section 3 – Data Evaluation and Selection of Chemicals of Potential Concern
- Section 4 – Human Health Risk Analysis
- Section 5 – Screening Ecological Impacts Analysis
- Section 6 - Summary
- Section 7 – References

Section 2
Site Conceptual Exposure Model

This section presents the site conceptual exposure model (SCEM) for the CTM study area. The SCEM is a description of potential exposure pathways associated within the CTM, and includes potential sources of contamination, transport mechanisms, exposure routes, and potentially exposed populations. The information presented in the SCEM is used to develop site-specific screening criteria in Section 3 and to quantitatively evaluate chemicals and media that do not pass screening in Section 4. Only exposure pathways likely to be complete and to contribute significantly to overall exposure are used as a basis for screening-level development and for quantitative risk analyses.

2.1 Potentially Exposed Populations and Potential Exposure Pathways

The SCEM for the CTM, illustrated in Figure 2-1, depicts potentially exposed populations and pathways by which these populations may be exposed. A complete exposure pathway consists of the following four elements:

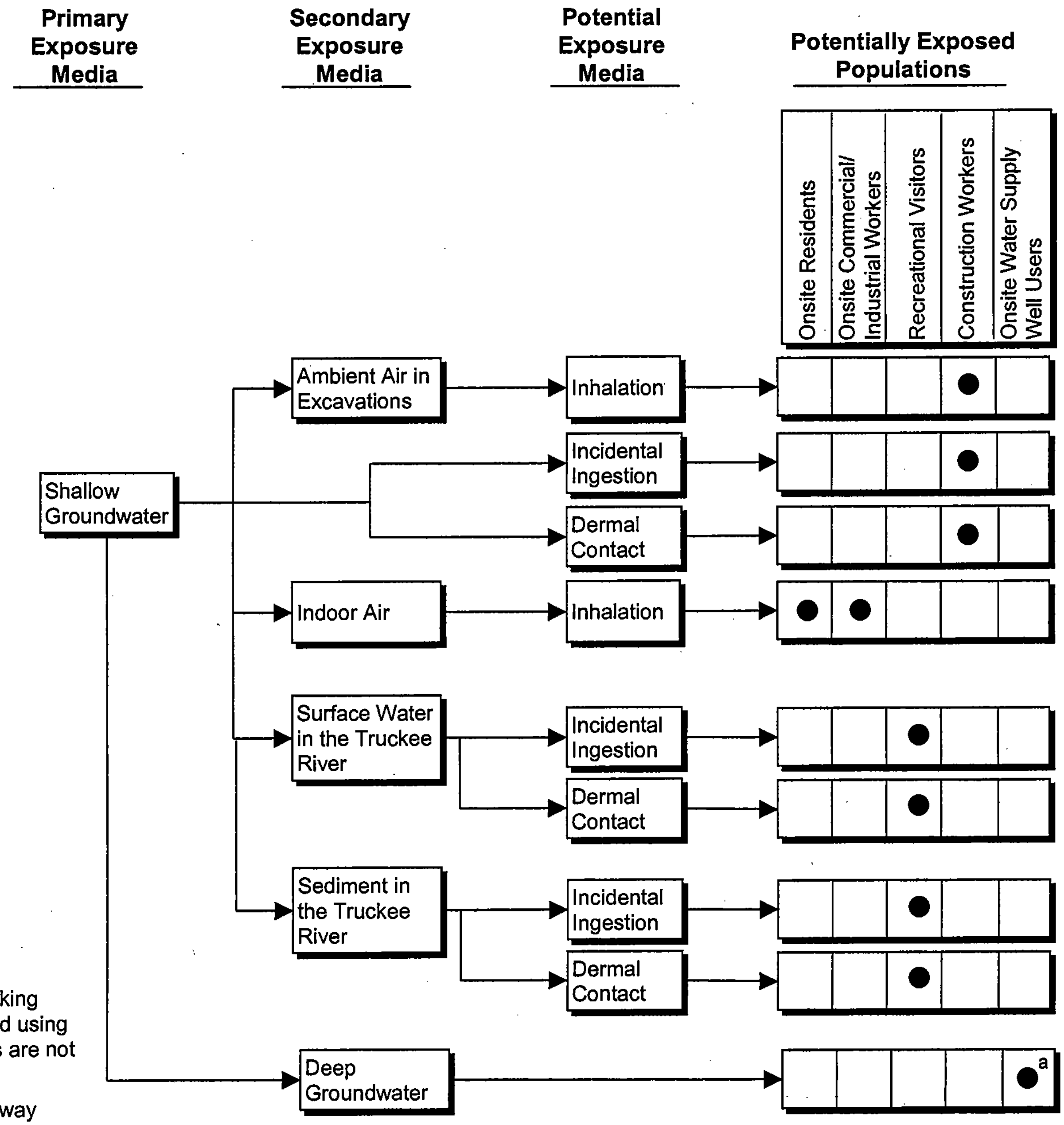
- A source and mechanism of release of chemicals to the environment
- A transport medium for the released chemical
- An exposure point (the point of potential contact between receptor and medium)
- An exposure route (e.g., inhalation, ingestion)

As shown in the SCEM, populations that could theoretically be exposed to contaminants associated with shallow or deep groundwater in the CTM study area include:

- Residents
- Commercial/industrial workers
- Construction workers
- Recreational visitors at the Truckee River

Potential exposure pathways for these populations include:

- Inhalation of volatiles released from shallow groundwater into indoor air (residents and commercial/industrial workers)



[a] Potential Impacts to drinking water wells are evaluated using MCLs. Risk calculations are not necessary.

● Potential Exposure Pathway

Figure 2-1
Site Conceptual Exposure Model
Central Truckee Meadows Remediation District

- Incidental ingestion of shallow groundwater, dermal contact with groundwater and inhalation of volatiles released from shallow groundwater into ambient air inside an excavation (construction worker)
- Incidental ingestion of, dermal contact with and inhalation of groundwater contaminants discharged from shallow groundwater into surface water (recreational visitors)
- Incidental ingestion and dermal contact with groundwater contaminants discharged from shallow groundwater into sediment (recreational visitors)
- Ingestion of groundwater contaminants in deep groundwater (residents)

Shallow groundwater is not currently being used for drinking water and other domestic purposes and is not expected to be used for such purposes in the future. Pathways associated with domestic groundwater uses are therefore not complete.

Potential exposure scenarios for the Site are discussed in more detail in the following sections.

2.1.1 Inhalation of Indoor Air by Residents and Commercial/Industrial Workers

Contaminants may be released from groundwater into soil gas. If VOCs within soil gas exist below buildings, VOCs may migrate indoors through foundation cracks. People living or working where vapor intrusion may occur may inhale contaminants in indoor air. Where high concentrations of VOCs are present below buildings, inhalation of indoor air may result in significant exposure. Since PCE was detected at high concentrations in some areas within the CTM study area, this exposure scenario is potentially significant and was quantitatively evaluated. Only volatile chemicals are evaluated for vapor intrusion into indoor air (see Section 3).

2.1.2 Incidental Ingestion of and Dermal Contact with Shallow Groundwater by Construction Workers

Depth to groundwater within the CTM study area occurs at approximately 20 to 25 feet below ground surface. Since some construction in the area may require excavation to these depths, dewatering of excavations may be necessary during some construction activities. During dewatering operations, construction workers may incidentally ingest groundwater or dermally contact groundwater. These pathways are theoretically significant for construction workers and was therefore quantitatively evaluated.

2.1.3 Inhalation of Volatiles Released from Shallow Groundwater into Ambient Air by Construction Workers

Volatile groundwater contaminants may be released to ambient air. If released into air inside an excavation, some accumulation of vapors may occur. The ambient air inhalation pathway is therefore considered potentially significant for construction workers, and is quantitatively evaluated.

2.1.4 Incidental Ingestion, Inhalation, and Dermal Contact with Contaminants in Surface Water by Recreational Visitors

Groundwater discharges into the Truckee River in some portions of the CTM study area (i.e. the Truckee River is a gaining stream in these areas). In other areas, the Truckee River loses water (i.e. is a losing stream). The locations along the Truckee River in which water is gaining or losing varies seasonally.

In areas where groundwater discharges into the Truckee River, recreational visitors may be exposed to contaminants directly. Because any contaminants discharged into the Truckee River will be rapidly diluted, substantial impacts from discharge of groundwater into the Truckee River are not expected. Similarly, any groundwater contaminants discharged to surface water and then volatilized to ambient air will be rapidly diluted. Therefore, the recreational exposure scenario is not expected to be significant. Analyses conducted in Section 3 demonstrate that no significant impacts to the Truckee River have occurred.

2.1.5 Incidental Ingestion and Dermal Contact with Contaminants in Sediment by Recreational Visitors

Groundwater contaminants that discharge into the Truckee River could theoretically adhere to sediment. However, contaminants evaluated for groundwater within the CTM do not have a tendency to partition to soil or sediment. VOCs in sediment are expected to rapidly migrate from sediments to surface water and no significant concentrations are anticipated in sediments. Exposure to contaminants in sediment is therefore not considered an important exposure scenario for the CTM site and is not quantitatively evaluated in this Technical Memorandum.

2.1.6 Ingestion of Deep Groundwater by Residents

Field investigation data indicate deep aquifer groundwater is contaminated with VOCs. Currently, five existing deep aquifer water supply wells deep aquifer are protected by wellhead treatment systems. Health impacts for people using water from the currently protected wells are not likely. However, if contaminants migrate to water supply wells, which are not protected by wellhead treatment systems, residents may be exposed to groundwater contaminants. During recent sampling events, data from two untreated deep aquifer water supply wells indicate impacts by VOCs. Because drinking water supplies must meet state and federal MCLs, it is not necessary to conduct quantitative risk analyses and to determine site-specific remediation goals for the deep aquifer. Section 3 identifies chemicals that exceed MCLs and that need to be addressed in the remediation plan that will be prepared as part of the CTM Remediation District Project.

2.1.7 Summary of Populations and Exposure Pathways Selected for Quantitative Evaluation

Potentially exposed populations and potential exposure pathways have been discussed and potentially significant exposure pathways have been identified. Potential exposure scenarios identified in this section are used to identify appropriate screening criteria for selection of COPCs in Section 3. These scenarios are further evaluated for chemicals and media that pass screening in Section 4.

The following exposure pathways for residents, commercial/industrial workers, recreational visitors, and construction workers are further evaluated in Section 3:

- Inhalation of volatiles released from shallow groundwater into soil gas and into indoor air (residents and commercial/industrial workers)
- Incidental ingestion of shallow groundwater (construction worker)
- Dermal contact with shallow groundwater (construction worker)
- Inhalation of volatiles released from shallow groundwater into ambient air inside in excavation (construction worker)
- Recreational exposure to contaminants discharged from groundwater into the Truckee River.
- Ingestion of deep groundwater (residents).

Section 3
Data Evaluation and Selection of Chemicals of Potential Concern

This section describes the analytical data from sampling activities performed within the CTM and discusses adequacy of the data for performance of the quantitative human health risk analysis. Section 3.1 describes the available data for the site, discusses data quality and data representativeness, and selects data for use in the human health risk analysis. Section 3.2 identifies chemicals of potential concern (COPCs) for inclusion in the risk analysis.

3.1 Data Evaluation

In the data evaluation, historic site data and data collected during the summer of 2001 field investigation were evaluated for usability in the quantitative risk analysis. The data evaluation was performed in accordance with procedures recommended in USEPA's (1992) Guidance for Data Usability in Risk Assessments, and included consideration of the following issues: data source, adequacy of documentation, data quality control, analytical methods, reporting limits and completeness, comparability, and representativeness of the data for current conditions and potential exposures within CTM. Data evaluation, performed for groundwater and other media (i.e., soil gas and surface water), is presented in the following sections.

3.1.1 Groundwater

Approximately 200 shallow groundwater samples collected from July 1999 to July 2001 and 220 deep groundwater samples (from wells greater than 100 feet deep) collected from July 1999 to July 2001 were considered for inclusion in the risk analysis. Grab samples were also included in the data sets. Monitoring wells were located in areas suspected to be contaminated with PCE or in locations used to delineate PCE contamination. Well locations are widely spread across the CTM site. The most recent data are expected to be most representative of current conditions within the CTM. Therefore, only samples collected in the past two years were considered. Groundwater samples were analyzed for VOCs by EPA Method SW8260B or Method 502.1. Some samples were also analyzed for dichlorobenzene by EPA Method SW8270C. Overall, the shallow groundwater data collected from July 1999 to July 2001 and the deep groundwater data collected from July 1999 to July 2001 are expected to adequately represent site conditions.

Detection limits for the groundwater data are adequate. Reporting limits are below MCLs and EPA Region IX risk-based concentrations for tap water and are therefore also low enough to be protective of potential exposures that may occur at the site. Compounds that have been detected in the shallow and deep groundwater, their observed range of detections and frequencies of detections are summarized in Tables 3-1 and 3-2, respectively. Groundwater data used in this technical memorandum are provided in Appendix A (Table A-1a, A-1b, and A-1c). These data were used to select COPCs (Section 3.2) and for quantitative risk evaluations (Section 4).

Table 3-1
Summary of Detected Chemicals in Shallow Groundwater Wells

Detected Chemical	Average (µg/l)	Minimum (µg/l)	Maximum (µg/l)	Number of Detections	Total Number of Samples	Frequency
1,1,1-Trichloroethane	7.35	1.5	15	19	205	9.3%
1,1-Dichloroethane	8.82	4.3	11	5	205	2.4%
Benzene	313.75	1	6,312	33	205	16.1%
CFC-11	25.30	25.3	25.3	1	205	0.5%
Chloroform	2.81	1	8.4	27	205	13.2%
cis-1,2-Dichloroethene	2.83	2.4	3.1	3	87	3.4%
Dichloromethane	6.60	6.6	6.6	1	205	0.5%
Ethylbenzene	90.66	1	1,049	65	205	31.7%
MTBE	523.07	3.1	8,758	18	205	8.8%
o-Xylene	1.50	1	2.1	7	87	8.0%
Tetrachloroethene (PCE)	56.70	1.1	1,108	139	215	64.7%
Toluene	106.79	1	2,872	137	205	66.8%
Trichloroethylene	4.98	1	34.8	23	207	11.1%
Xylenes	583.33	1.1	38,013	85	186	45.7%

Notes:
1) CFC-11 is also referred to as trichlorofluoromethane and Freon-11
2) Dichloromethane is also referred to as methylene dichloride and methylene chloride
3) Toluene is reported under its synonym name methylbenzene in the database.

Table 3-2
Summary of Detected Chemicals in Deep Groundwater Wells

Detected Chemical	Average (µg/l)	Minimum (µg/l)	Maximum (µg/l)	Number of Detections	Total Number of Samples	Frequency
1,1,1-Trichloroethane	2.01	1	2.6	8	222	3.6%
1,1,1-Trichloroethane	1.20	1.2	1.2	1	222	0.5%
Benzene	3.94	1	8.3	8	223	3.6%
Bromodichloromethane	2.90	2.9	2.9	1	221	0.5%
Chloroform	1.77	0.2	13.5	37	221	16.7%
cis-1,2-Dichloroethene	5.29	1.3	18	15	152	9.9%
Ethylbenzene	5.67	2.5	9.1	3	223	1.3%
MTBE	51.89	1	150	19	184	10.3%
Tetrachloroethene (PCE)	19.14	0.9	440	154	225	68.4%
Toluene	22.00	1	210	42	223	18.8%
Trichloroethylene	1.93	0.3	5.9	45	223	20.2%
Xylenes	3.16	1.1	15.4	12	211	5.7%

Note:
1) Toluene is reported under its synonym name methylbenzene in the database.

3.1.2 Soil Gas

Analytical data for soil gas were used to evaluate the potential for VOCs in groundwater to migrate to ambient and indoor air. Thirty-four soil gas samples from depths of 10 to 50 feet bgs were collected during the site investigation. Of the 34 samples, 21 samples are duplicates (4 duplicates analyzed for the full analyses and 17 duplicates analyzed for PCE only). All samples were analyzed for VOCs by EPA Method SW8260B. No data quality issues were identified in the soil gas data (e.g., data qualifiers) and the detection limits were sufficiently low to be protective of human health. Detection limits were below risk-based screening levels for soil gas (see Section 3.2 for development of screening concentrations for soil gas). All soil gas data collected during the site investigation are considered adequate for use in the quantitative risk analysis. Duplicates were reviewed and resolved with the original sample by taking the highest detected concentration for each compound analyzed resulting in 13 samples in the soil gas dataset. Soil gas data used in this technical memorandum are provided in Appendix A (Tables A-3a and A-3b). A comparison of reporting limits to screening levels is presented in Appendix A (Table A-4).

The data from all depths sampled (10 to 50 feet bgs) are used to ensure a protective risk analysis. Higher soil vapor concentrations are found at greater depths. These vapors may not migrate efficiently through many feet of soil. However, data from samples collected at depth are included in the exposure concentrations. Resulting exposure and risk estimates will be conservative.

Soil gas samples were collected at locations of suspected contamination and may be biased toward higher concentrations. Soil gas data should not underestimate the potential for VOC migration from groundwater. Exposure and risk estimates based on these data should be conservative. The issue of sampling location bias is further discussed in the analysis of uncertainties in Section 4.3.3. Compounds that were detected in soil gas within the CTM study area are summarized in Table 3-3.

Table 3-3
Summary of Detected Chemicals in Soil Gas

Detected Chemical	Average (mg/m^3)	Minimum (mg/m^3)	Maximum (mg/m^3)	Number of Detections	Total Number of Samples	Frequency
Benzene	0.17	0.1	0.25	3	13	23.1%
Toluene	0.20	0.1	0.39	3	13	23.1%
MTBE	1.3	1.3	1.3	1	13	7.7%
Tetrachloroethene (PCE)	3.96	0.21	7.7	2	13	15.4%
Xylenes	0.11	0.11	0.11	1	13	7.7%

Note:
1) Toluene is reported under its synonym name methylbenzene in the database.

3.1.3 Surface Water

Four rounds of surface water sampling were conducted by Washoe County staff in April, September, and October of 1999 and September 2001. The surface water sampling program included sample collection from six sampling locations within the Truckee River and at outfall discharge locations. All of the outfall locations and three of the discharge locations are located in downtown Reno. The detection limits for the samples were 1.0 mg/l for all VOCs, except chloromethane and dichloromethane, which had a detection limit of 2.0 mg/l. These detection limits are below MCLs and considered sufficient for risk analysis. Low VOCs concentrations were detected in outfall discharge point sampling locations. No VOCs were detected in surface water samples. Surface water sampling data suggest that either no contaminants are discharged from groundwater into the Truckee River or any groundwater discharges are so rapidly diluted that they are not detectable.

3.2 Selection of Chemicals of Potential Concern (COPC)

This section presents methods used to select a subset of chemicals from those detected at the site for quantitative evaluation in the human health risk analysis. COPCs were selected for groundwater, soil gas, and surface water. COPC screening is discussed by medium below.

3.2.1 COPCs for Groundwater

All groundwater samples, including grab samples, were used to select COPCs for groundwater. This approach is conservative, because it includes all available data for the site.

3.2.1.1 Shallow Groundwater

Selection of COPCs for shallow groundwater includes the following steps:

- Evaluation of frequency of detection
- Comparison of maximum detected concentrations with site-specific risk-based concentrations

In the first step of the screening analysis, chemicals with detection frequencies of less than five percent are identified and, usually, eliminated from further analysis. However, prior to eliminating these chemicals, the distribution detections is assessed. Chemicals that occur in a cluster (i.e., hotspot) but not anywhere else on-site are not eliminated. Although infrequently detected chemicals may not be important for the site as a whole, they may contribute substantially to risks in the small area where they do occur. As shown in Table 3-4, infrequently detected chemicals were typically not detected more than once. One detection does not signify a hot spot provided that data are representative (see Section 3.1.1) and these chemicals were eliminated. The two chemicals that were detected at a frequency of less than five percent but in more than one sample had maximum concentrations below the risk-based screening level.

Since these chemicals were not eliminated solely based on frequency of detection, an evaluation of a potential hotspot areas was not necessary.

In the second step of the COPC screening analysis, maximum detected concentrations of chemicals are compared to site-specific risk-based concentrations. Construction worker contact with chemicals in shallow groundwater was the only exposure scenario considered in the screening risk analysis. Risk-based screening concentrations are therefore based on a construction worker scenario. Calculations for these site-specific screening levels are presented in Appendix B. The screening levels are based on a target cancer risk of 1 x 10^{-7} or a hazard index of 0.1. Chemicals with maximum detected concentrations less than screening criteria are excluded from further analysis. COPCs for shallow groundwater at the CTM study area are selected in Table 3-4. PCE, benzene and MTBE were the only COPCs for shallow groundwater based on site-specific screening. These chemicals were evaluated in subsequent analysis of risk.

Table 3-4
Chemicals of Potential Concern for Direct Contact with Groundwater and Inhalation of Volatiles Released to Ambient Air from Shallow Groundwater

Detected Chemical	***Maximum (µg/l)***	***Frequency of Detection***	***Number of Detections***	***Risk-based Screening Levels for Construction Worker (µg/l)***	***COPC?***
1,1,1-Trichloroethane	15	9.3%	19	3,071	NO
1,1-Dichloroethane	11	2.4%	5	26,385	NO
Benzene	6,312	16.1%	33	158	YES
CFC-11	25.3	0.5%	1	41,543	NO
Chloroform	8.4	13.2%	27	348	NO
cis-1,2-Dichloroethene	3.1	3.4%	3	2,378	NO
Dichloromethane	6.6	0.5%	1	4,405	NO
Ethylbenzene	1,049	31.7%	65	3,748	NO
MTBE	8,758	8.8%	18	3,585	YES
o-Xylene	2.1	8.0%	7	62,580	NO
Tetrachloroethene (PCE)	1,108	64.7%	139	77	YES
Toluene	2,872	66.8%	137	11,789	NO
Trichloroethylene	34.8	11.1%	23	864	NO
Xylenes	38,013	45.7%	85	62,580	NO

Notes:

1) CFC-11 is also referred to as trichlorofluoromethane and Freon-11
2) Dichloromethane is also referred to as methylene dichloride and methylene chloride
3) Toluene is reported under its synonym name methylbenzene in the database.
4) Risk-based Screening Level is based on direct contact with groundwater (incidental ingestion and dermal contact) and inhalation of volatiles released to ambient air from groundwater

Chemicals with maximum detected concentrations in shallow groundwater that exceed MCLs are summarized in Table 3-5. The federal MCLs published by the Office of Water (USEPA, 2001) are shown as well as the MCLs published by the State of Nevada Bureau of Health Protection Services (NBHPS, 2001). Shallow groundwater is not used for drinking water purposes and a drinking water pathway was not evaluated in the risk analysis. However, shallow groundwater at the site could theoretically impact municipal water supply wells in the deep aquifer and protection of existing municipal wells in the deep aquifer is an important objective of the Remediation District. Identification of chemicals that exceed MCLs is therefore an important component of the risk analysis. As shown in Table 3-5, the maximum detected concentrations for 1,1-dichloroethane, benzene, dichloromethane, ethylbenzene, MTBE, PCE, toluene, trichloroethylene (TCE), and xylenes in shallow groundwater wells exceed MCLs. This information can be used to develop remedial objectives in the remediation plan but is not further addressed in this technical memorandum.

Table 3-5
Chemicals of Potential Concern for
Ingestion of Groundwater in Drinking Water from Shallow Wells

Detected Chemical	***Maximum (µg/l)***	***Frequency***	***MCL (µg/l))***		***Exceed MCL?***
			USEPA	***NDEP***	
1,1,1-Trichloroethane	15	9.3%	200	200	NO
1,1-Dichloroethane	11	2.4%	5	NR	YES
Benzene	6,312	16.1%	5	5	YES
CFC-11	25.3	0.5%	150	DM	NO
Chloroform	8.4	13.2%	100	NR	NO
cis-1,2-Dichloroethene	3.1	3.4%	70	70	NO
Dichloromethane	6.6	0.5%	5	5	YES
Ethylbenzene	1,049	31.7%	700	700	YES
MTBE	8,758	8.8%	13	NL	YES
o-Xylene	2.1	8.0%	10,000	10,000	NO
Tetrachloroethene (PCE)	1,108	64.7%	5	5	YES
Toluene	2,872	66.8%	1,000	1,000	YES
Trichloroethylene	34.8	11.1%	5	5	YES
Xylenes	38,013	45.7%	10,000	10,000	YES

Notes:

1) CFC-11 is also referred to as trichlorofluoromethane and Freon-11
2) MCL for total trihalomethanes is 100 µg/l
3) Dichloromethane is also referred to as methylene dichloride and methylene chloride
4) Toluene is reported under its synonym name methylbenzene in the database.
5) DM – discretionary monitoring.
6) NR – not regulated.
7) NL – not listed.

3.2.1.2 Deep Groundwater

COPCs for deep groundwater are selected by comparing the maximum detected concentrations of chemicals in deep groundwater to MCLs. The federal MCLs published by the Office of Water (USEPA, 2001) are shown as well as the MCLs published by the State of Nevada Bureau of Health Protection Services (NBHPS, 2001). Since the CTM study area has municipal water supply wells that are installed in the deep aquifer, MCLs are the appropriate screening criteria. As shown in Table 3-6, the maximum detected concentrations for benzene, MTBE, PCE, and trichloroethylene in the deep groundwater wells exceed MCLs. Chemical concentrations above MCLs indicate a potential for adverse human health affects. Statutory requirements for the deep aquifer require well head treatment or other controls if concentrations exceed MCLs. Chemicals that exceed MCLs in the deep aquifer need to be considered in the remediation plan. Quantitative risk analyses for these chemicals are not necessary and are not performed in this Technical Memorandum.

Table 3-6
Chemicals of Potential Concern for
Ingestion of Groundwater in Drinking Water from Deep Wells

Detected Chemical	**Maximum (µg/l)**	**Frequency**	**MCL (µg/l)**		**COPC?**
			USEPA	**NDEP**	
1,1,1-Trichloroethane	2.6	3.6%	200	200	NO
1,1,2-Trichloroethane	1.2	0.5%	3	5	NO
Benzene	8.3	3.6%	5	5	YES
Bromodichloromethane	2.9	0.5%	100	NR	NO
Chloroform	13.5	16.7%	100	NR	NO
cis-1,2-Dichloroethene	18	9.9%	70	70	NO
Ethylbenzene	9.1	1.3%	700	700	NO
MTBE	150	10.3%	13	NL	YES
Tetrachloroethene (PCE)	440	68.4%	5	5	YES
Toluene	210	18.8%	1,000	1,000	NO
Trichloroethylene	5.9	20.2%	5	5	YES
Xylenes	15.4	5.7%	10,000	10,000	NO

Notes:

1) CFC-11 is also referred to as trichlorofluoromethane and Freon-11
2) MCL for total trihalomethanes is 100 µg/l
3) Dichloromethane is also referred to as methylene dichloride and methylene chloride
4) Toluene is reported under its synonym name methylbenzene in the database.
5) NR – not regulated.
6) NL – not listed.

3.2.2 Selection of COPCs for Soil Gas

COPCs for soil gas are selected by comparing maximum detected concentrations of chemicals in soil gas with risk-based concentrations for soil gas. Risk-based screening levels for soil gas were developed using the USEPA spreadsheet (Windows™ - Excel) for the Johnson and Ettinger vapor intrusion model (USEPA, 2001). Target cancer risk levels of $1x10^{-7}$ and target hazard quotient of 0.1 were used to develop the screening levels for soil gas.

Acceptable concentrations for chemicals in soil gas, developed based on the modeling spreadsheets are presented in Table 3-7. Assumptions for calculations and a summary of the calculations are presented in Appendix B. All chemicals detected in soil gas were below their screening criteria. Therefore, no chemicals were selected as COPCs for soil gas. As a result, risk analysis to evaluate the exposure pathway associated with release of chemicals from groundwater into soil gas and subsequently into indoor or ambient air was not necessary.

Table 3-7
Soil Gas Chemicals of Potential Concern

Detected Chemical	***Maximum (mg/m^3)***	***Frequency***	***Risk-based Screening Level (mg/m^3)***	***COPC?***
Benzene	0.25	23.1%	2.6	NO
Toluene	0.39	23.1%	3,463	NO
MTBE	1.3	7.7%	3.10	NO
Tetrachloroethene (PCE)	7.7	15.4%	35	NO
Xylenes	0.11	7.7%	60,561	NO

Notes:

1) The Johnson and Ettinger Model (http:/www.epa.gov/superfund/programs/risk/airmodel/Johnson_ettinger.htm) was used to calculate acceptable chemical concentrations in soil gas based on migration to indoor air. The presented values are based on a residential exposure scenario and a target cancer risk of 10^{-7} and/or HI of 0.1.
2) Toluene is reported under its synonym name methylbenzene in the database.
3) The current version of the Johnson and Ettinger Model does not include MTBE. An acceptable concentration for MTBE in soil gas was therefore not calculated. The presented value is the EPA Region IX Preliminary Remediation Goal (PRG) for indoor air. This value is a conservative screening criterion for the comparison with detected concentrations in soil gas, because the soil gas to indoor air attenuation factor is typically several orders in magnitude. The maximum detected concentration of MTBE in soil gas is less than the indoor air screening value for MTBE, MTBE is therefore not selected as a COPC for soil gas.

3.2.3 Selection of COPCs for Surface Water

VOCs were not detected in surface water in the Truckee River. Therefore, no COPCs were selected for surface water exposure pathway. Further evaluation of potential exposures associated with surface water in the Truckee River was, therefore, not necessary.

Low concentrations of VOCs were detected in surface water samples collected from discharge pipes are regulated by NPDES permits. Since NPDES permits exist for these sources, they are not evaluated in the risk analysis. In addition, these discharges are not expected to significantly impact the water quality in the Truckee River. This is supported by the absence of VOCs in surface water samples collected downstream from the discharge pipes.

3.3 COPC Screening Summary

No COPCs were selected for soil gas and surface water. These media are therefore not further evaluated in the risk analysis. PCE, benzene and MTBE were selected as COPCs for shallow groundwater. Further analysis of risk was conducted to evaluate potential risks associated with these chemicals in shallow groundwater. COPCs for deep groundwater in the CTM were selected by comparing maximum detected concentrations to MCLs. COPCs for the deep aquifer will be considered in the remediation plan but are not further considered in the risk analysis.

Section 4
Human Health Risk Analysis

This section presents methods and assumptions used to estimate potential risks within the CTM and provides a characterization of these risks. Risk estimates are provided for media for which COPCs were selected in Section 3. With the exception of deep groundwater, which is not further evaluated in this technical memorandum, COPCs were only selected for shallow groundwater, but not any of the other potentially impacted media (e.g. surface water, soil gas). Shallow groundwater is further evaluated in this section. Risk estimates are provided for construction workers who may be directly exposed to groundwater during construction activities within the CTM.

4.1 Exposure Assessment

The exposure assessment presents exposure assumptions for the construction worker scenario, identifies areas within the CTM of exposure and describes methods used to calculate exposure point concentrations. Methods used to calculate dose estimates for construction workers are also presented.

4.1.1 Exposure Assumptions

Construction workers were evaluated for incidental ingestion of groundwater and dermal contact with groundwater. Exposure assumptions for these pathways are summarized in Table 4-1 below. A discussion of these assumptions is presented in Appendix B.

Table 4-1
Exposure Assumptions for Construction Workers

Exposure Parameter	***Exposure Pathway for which the Parameter is Used***	***Parameter Value***	***Source***
Ingestion Rate	Incidental Ingestion of Groundwater	5 ml/day	Professional Judgment
Dermal Permeability Constant	Dermal Contact with Groundwater	Chemical Specific	EPA 1992
Exposure Time	Dermal Contact with Groundwater	1 hr/day	EPA 1989
Skin Surface Area	Dermal Contact with Groundwater	3,600 cm^2 (head, hands and Forearms)	EPA 1997
Body Weight	All	70 kg	EPA 1989
Exposure Frequency	All	250 days/year	Professional Judgment
Exposure Duration	All	1 year	Professional Judgment
Averaging Time for Carcinogens	All	25,550 days	EPA 1989
Averaging Time for Noncarcinogens	All	182 days	Professional Judgment

4.1.2 Exposure Areas and Exposure Point Concentrations

Exposure areas used to evaluate construction workers consist of the CTM study areas A through H, defined in the Final Updated Work Plan (CDM, 2001). These areas are shown in Figure 4-1. Areas F, G, and H were expanded from their delineations in the work plan to incorporate groundwater sampling locations that were adjacent to the areas. Risk estimates for construction workers were calculated separately for each area using the methods described below.

Exposure point concentrations were calculated using methods outlined in USEPA's (1992) guidance entitled Calculating the Concentration Term. In accordance with this guidance, the maximum detected concentration was used as the exposure concentration for datasets with less than 10 datapoints. For datasets with more than 10 datapoints, the upper 95th percent confidence limit (UCL) on the mean of the data was calculated using the methods described below.

To reduce sampling location bias (overrepresentation of a single well location since some locations were sampled several times more than others), the data from each well for each chemical was averaged over the two-year dataset sampling period. This averaged data set is provided in Appendix A (Table A-1c). The data distribution is then tested using the Shapiro and Wilk test. For lognormally distributed datasets the UCL is calculated using the following equation:

$$UCL = e^{\left[\bar{x}+0.5s^2+\frac{sH}{\sqrt{(n-1)}}\right]}$$

where: 0 = The arithmetic mean of the dataset

H = H-statistic

s = Standard deviation

n = The number of samples

For normally distributed datasets the UCL is calculated using the following equation:

$$UCL = \bar{x} + t \cdot \left(\frac{s}{\sqrt{n}}\right)$$

where: 0 = The arithmetic mean of the dataset

t = Student t-statistic

s = Standard deviation

n = The number of samples

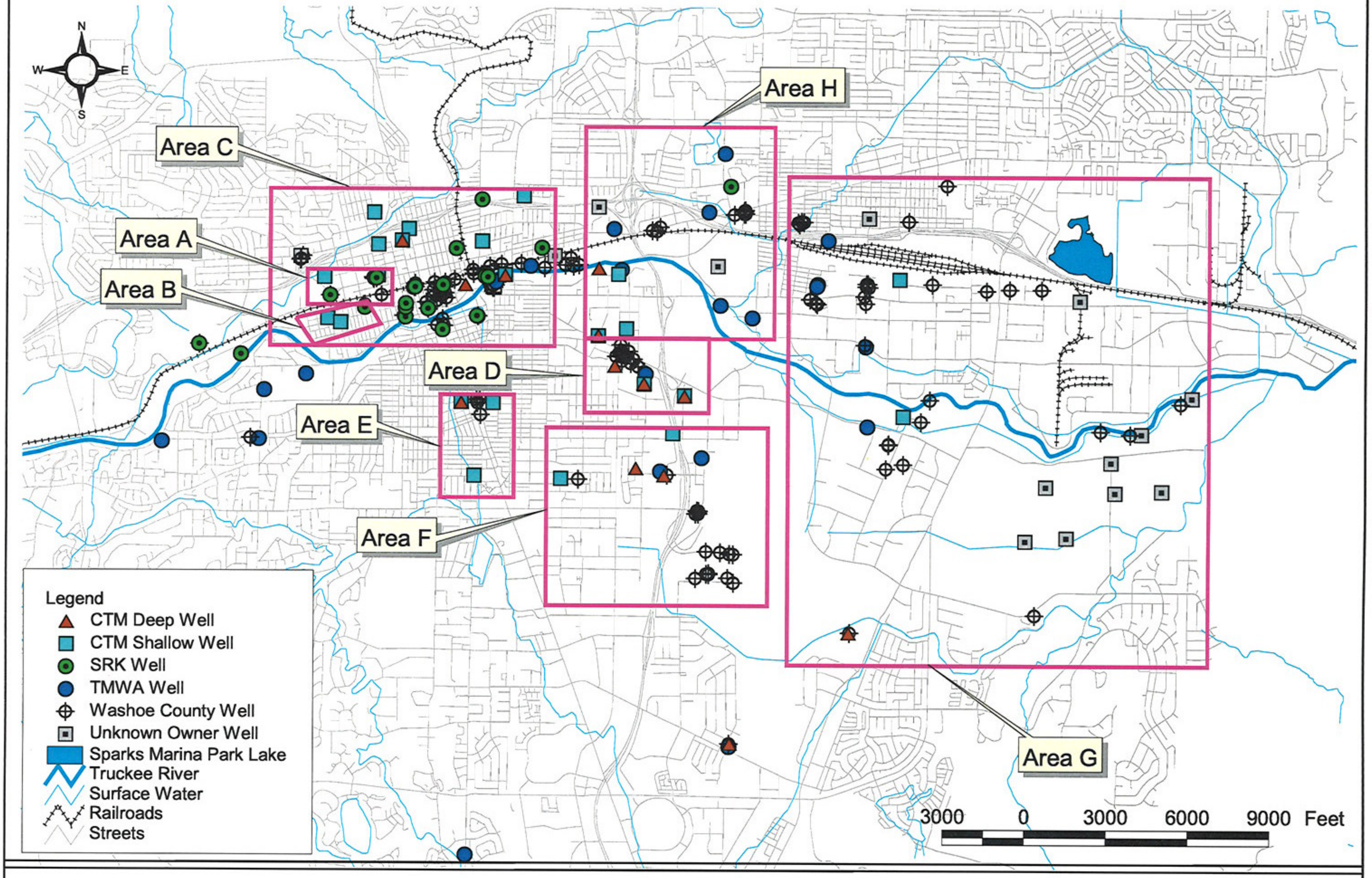


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Figure 4-1
Cancer Risk and Hazard Index Areas
Central Truckee Meadows Remediation District

Datasets that were neither lognormally nor normally distributed were assumed to be non-parametric and the maximum detected concentration was used for the exposure concentration. The maximum detected concentration was also used if the calculated UCL for either a lognormally or normally distributed dataset exceeds the maximum concentration.

UCLs were calculated using one-half of the reporting limit for nondetected datapoints. UCL calculations were conducted using all available data from the last two years for each exposure area, except for data from grab samples. Grab samples often contain sediment (not collected from purged wells) possibly resulting in artificially high contaminant concentrations. Additionally, grab samples are collected from discrete depths; therefore, they are not representative of the average concentration within the shallow groundwater column. Data from the grab samples were not consistent with samples from monitoring wells and were not included in subsequent quantitative analyses.

Exposure point concentrations for all exposure areas are presented in Table 4-2. Table 4-2 also shows distributions of the data and the calculated UCLs, compares UCLs to average maximum concentrations, and indicates for each exposure area whether the UCL or maximum was used as the exposure point concentration.

4.1.3 Calculation of Chronic Daily Intakes

Chronic daily intakes (CDIs) for all pathways evaluated for construction workers were calculated using the following general formula:

$$\text{Intake} \quad (\text{mg/kg} - \text{day}) \quad = \quad \frac{\text{C} \ \text{x} \ \text{IR} \ \text{x} \ \text{EF} \ \text{x} \ \text{ED}}{\text{BW} \ \text{x} \ \text{AT}}$$

where:

C = Chemical Concentration in water or air (mg/L or mg/m3)

IR = Groundwater Ingestion or Air Inhalation Rate (L/day or m3/day)

ED = Exposure Duration (years)

EF = Exposure Frequency (days/year)

BW = Body Weight (kg)

AT = Averaging Time (time over which exposure is averaged - years)

To evaluate dermal exposures, skin surface area and permeability constants are used rather than intake rates. Exposure equations are taken directly from USEPA (1989). Equations for all pathways used to calculate chemical intakes are presented in Appendix C.

Table 4-2

Exposure Concentrations for Groundwater COPCs by Area

	Area A				Area B			
Chemical	**Distribution**	**UCL-95 (µg/l)**	**Maximum Average Detected (µg/l)**	**Exposure Concentration (µg/l)**	**Distribution**	**UCL-95 (µg/l)**	**Maximum Average Detected (µg/l)**	**Exposure Concentration (µg/l)**
Benzene	ND	NA	ND	ND	ND	NA	ND	ND
MTBE	NON-PARAMETRIC	NA	8.4	8.4	ND	NA	ND	ND
Tetrachloroethene	NON-PARAMETRIC	NA	113	113	NON-PARAMETRIC	NA	8.7	8.7
	Area C				Area D			
Chemical	**Distribution**	**UCL-95 (µg/l)**	**Maximum Average Detected (µg/l)**	**Exposure Concentration (µg/l)**	**Distribution**	**UCL-95 (µg/l)**	**Maximum Average Detected (µg/l)**	**Exposure Concentration (µg/l)**
Benzene	NON-PARAMETRIC	NA	8.3	8.3	NON-PARAMETRIC	NA	1,263	1,263
MTBE	ND	NA	NA	ND	NON-PARAMETRIC	NA	40.7	40.7
Tetrachloroethene	LOGNORMAL	19.66	24.33	19.66	LOGNORMAL	816	528	528
	Area E				Area F			
Chemical	**Distribution**	**UCL-95 (µg/l)**	**Maximum Average Detected (µg/l)**	**Exposure Concentration (µg/l)**	**Distribution**	**UCL-95 (µg/l)**	**Maximum Average Detected (µg/l)**	**Exposure Concentration (µg/l)**
Benzene	ND	NA	NA	ND	NON-PARAMETRIC	NA	6,312	6,312
MTBE	ND	NA	NA	ND	NON-PARAMETRIC	NA	8,758	8,758
Tetrachloroethene	NON-PARAMETRIC	NA	4.05	4.05	NON-PARAMETRIC	NA	28.6	28.6
	Area G				Area H			
Chemical	**Distribution**	**UCL-95 (µg/l)**	**Maximum Average Detected (µg/l)**	**Exposure Concentration (µg/l)**	**Distribution**	**UCL-95 (µg/l)**	**Maximum Average Detected (µg/l)**	**Exposure Concentration (µg/l)**
Benzene	NON-PARAMETRIC	NA	621	621	LOGNORMAL	536.7	62.5	62.5
MTBE	NON-PARAMETRIC	NA	142	140	NON-PARAMETRIC	NA	28.4	28.4
Tetrachloroethene	LOGNORMAL	3.72	13.0	3.72	NON-PARAMETRIC	NA	5	5

Notes:
1) ND - Not Detected
2) NA - Not Available

4.2 Toxicity Assessment

The purpose of the toxicity assessment was to evaluate the potential for each COPC to cause adverse impacts in exposed individuals. For humans, adverse effects include both noncarcinogenic and carcinogenic health effects.

Sources of toxicity information, in order of descending priority, include:

- USEPA's Integrated Risk Information System (IRIS)
- Health Effects Assessment Summary Tables (HEAST), and USEPA criteria documents
- Agency for Toxic Substances and Disease Registry (ATSDR) Toxicological Profiles

The hierarchy of toxicological information sources used in this risk analysis follows procedures defined in USEPA (1989). This section explains how toxicity criteria for carcinogens and noncarcinogens are developed and expressed, and summarizes toxicity values for each COPC. Individual chemical profiles in support of toxicity values are presented in Appendix D. These profiles describe important toxicokinetic findings (absorption into, distribution in, metabolism by, and excretion from the body), outline major adverse effects, discuss uncertainties and important data gaps, and summarize important studies used in the derivation of toxicity values. The general basis for the development of toxicity values for carcinogens and noncarcinogens is presented in subsections 4.2.1 and 4.2.2, respectively, along with a summary of the toxicity values for all COPCs.

4.2.1 Carcinogens

Evidence of Carcinogenicity

USEPA has developed a classification system for carcinogens, which characterizes the overall weight of evidence of carcinogenicity based on the availability of human, animal, and other supportive data. Three major factors are considered:

- The quality of evidence from human studies
- The quality of evidence from animal studies
- Other supportive data assessed to determine whether the overall weight of evidence should be modified

USEPA classification system for the characterization of the overall weight of carcinogenicity has the following five categories:

- **Group A** - Human Carcinogen. This category indicates that there is sufficient evidence from epidemiological studies to support a causal association between an agent and cancer.

- **Group B** - Probable Human Carcinogen. This category generally indicates that there is at least limited evidence from epidemiological studies of carcinogenicity to humans (Group B1) or that, in the absence of adequate data on humans, there is sufficient evidence of carcinogenicity in animals (Group B2).

- **Group C** - Possible Human Carcinogen. This category indicates that there is limited evidence of carcinogenicity in animals in the absence of adequate data on humans.

- **Group D** - Not Classified. This category indicates that the evidence for carcinogenicity in animals is inadequate.

- **Group E** - Evidence of Noncarcinogenicity to Humans. This category indicates that there is evidence for noncarcinogenicity in at least two adequate animal tests in different species or in both epidemiological and animal studies.

Cancer Slope Factors

USEPA Cancer Assessment Group (CAG) (now the Cancer Review and Validation Effort, or CRAVE Committee) has used a variety of specialized models to estimate the upper bound risk of carcinogenesis for more than 50 compounds. Data from animal or epidemiological studies are used to determine slope factors, which are expressed as (mg/kg-day)-1 for a lifetime exposure. The cancer slope factor (CSF) describes the increase in an individual's risk of developing cancer over a 70-year lifetime per unit of exposure where the unit of exposure is expressed as mg/kg-day.

CSFs are calculated using methods protective of human health and are based on the assumption that cancer risks decrease linearly with decreasing dose. The 95 percent upper confidence limit estimate for the slope is used in most cases to compensate for animal to human extrapolation and other uncertainties. The resulting CSFs are considered to be upper range estimates that are unlikely to underestimate carcinogenic potential in humans.

When the upper-bound CSF is multiplied by the lifetime average daily dose of a potential carcinogen, the product is the upper-bound lifetime individual cancer risk associated with exposure at that dose. The calculated risk is thus an estimate of the increased likelihood of cancer resulting from exposure to a chemical. For example, if the product of the CSF and the average daily dose is 1×10^{-6}, the predicted upper-bound cancer risk for the exposed population is one in one million, or 0.0001 percent. This risk is in addition to any "background" risk of cancer not related to the chemical exposure.

Calculation of risk often relies on data derived from chronic animal bioassays. The likelihood that an animal carcinogen is also a human carcinogen is a function of the following factors:

- The number of tissues affected by the chemical

- The number of animal species, strains, sexes, and number of experiments and doses showing a carcinogenic response

- The occurrence of clear-cut dose-response relationships as well as a high level of statistical significance of the increased tumor incidence in treated compared to control groups

- A dose-related decrease in time-to-tumor occurrence or time-to-death with tumor

- A dose-related increase in the proportion of malignant tumors

Animal studies are usually conducted using relatively high doses to observe adverse effects. Because humans are expected to be exposed at lower doses, data are adjusted using a mathematical model. Data from animal studies are fitted to a linearized multi-stage model and a dose-response curve is obtained. The low-dose slope of the dose-response curve is subjected to various adjustments (e.g., calculation of 95 percent UCL), and inter-species scaling factors are often applied to derive slope factors for humans. Dose-response data derived from human epidemiological studies are fitted to dose-time-response curves on an individual basis. These models provide conservative but plausible estimates of upper limits on lifetime risk. Although the actual risk is unlikely to be higher than the estimated risk, it could be considerably lower. In some instances, it may even be zero.

CSFs for carcinogenic COPC for the Site are listed in Table 4-3. Data used to develop CSFs for chemicals associated with the site are summarized in the toxicity profiles presented in Appendix D.

Table 4-3
Slope Factors for COPCs

Compound	***SF_oral 1/(mg/kg/day)***	***Ref***	***SF_inhal 1/(mg/kg/day)***	***Ref***
Organic Compounds				
1,2-Dichloroethane	9.10E-02	I	9.10E-02	I
Benzene	5.50E-02	I	2.70E-02	I
Chloroform	6.10E-03	I	8.05E-02	I
Dichloromethane	7.50E-03	I	1.60E-03	I
Tetrachloroethene (PCE)	5.20E-02	E	2.03E-03	E
Trichloroethylene	1.10E-02	E	6.00E-03	E
Vinyl Chloride	7.50E-01	I	1.60E-02	H

Notes:
1) $(mg/kg\text{-}day)^{-1}$ - per milligram per kilogram per day
2) SF_oral - Oral Slope Factor
3) SF_inhal - Inhalation Slope Factor
4) I - IRIS online database August 2001
5) E - EPA.1998. NCEA Regional Support provisional value
6) H - EPA, 1993. Health Effects Summary Tables (HEAST).Office of Research and Development. OERR 9200.6-303.
7) Dichloromethane is a synonym for methylene chloride

4.2.2 Noncarcinogens

Reference doses (RfDs) are toxicity values developed by USEPA for chemicals exhibiting noncarcinogenic effects. RfDs are usually derived from no observable adverse effect levels (NOAELs) taken either from human studies, often involving workplace exposures, or from animal studies, and are adjusted downward using uncertainty or modifying factors. For example, a modifying factor of 2 to 10 may be applied if the database on a particular chemical lacks information on possible reproductive or developmental toxicity.

Uncertainty factors are generally applied to adjust for the possibility that humans are more sensitive than experimental animals and that there may be sensitive subpopulations of humans (e.g., children, pregnant women, individuals with hay fever or asthma). Depending upon the information available, other factors may also be applied.

The RfD is intended as an estimate of the daily exposure to a COPC that would not cause adverse effects even if the exposure occurs continuously over a lifetime. RfDs are presented in units of mg/kg-day for comparison with estimated chronic daily intake into the body. Chronic exposure in this instance is not clearly defined, but need not be a lifetime exposure. Generally, exposures must continue for several years to be considered chronic. Intakes less than the RfD are not likely to cause adverse health effects. Chronic daily intakes greater than the RfD indicate a possibility for adverse effects. Whether such exposures actually produce adverse effects, however, is a function of a number of factors such as accuracy of uncertainty factors applied to the NOAEL, appropriateness of animal models used in studies extrapolated to humans, and potential for the chemical to cause effects in organs or systems (e.g., reproductive and immune systems) that have not been adequately studied. Generally, protective assumptions made by USEPA in deriving RfDs will, in most cases, mean that exposures slightly in excess of the RfD will be associated with a low risk for adverse effects, with the probability of adverse effects increasing with increasing exposure.

RfDs can be generated for subchronic exposures as well as chronic exposures. Subchronic is generally assumed to be exposures of several weeks to a few years. Since construction workers at the site are expected to be exposed for no more than 8 weeks, a subchronic reference dose is most appropriate for assessing risks to these receptors. Subchronic RfDs are derived in the same manner as RfDs for chronic exposure, except that data from shorter term animal studies, or human exposures, are used. The RfDs for COPC for the Site are presented in Table 4-4.

Table 4-4
Reference Doses, Reference Concentrations and Unit Risks for COPCs

Compound	*RfD_oral (mg/kg/day)*	*Ref*	*RfD_inhal (mg/kg/day)*	*Ref*
Carcinogenic VOCs				
1,2-Dichloroethane	3.00E-02	E	1.40E-03	E
Benzene	3.00E-03	E	1.70E-03	E
Chloroform	1.00E-02	I	8.60E-05	E
Dichloromethane	6.00E-02	I	8.60E-01	H
Tetrachloroethene (PCE)	1.00E-02	I	1.40E-01	E
Trichloroethylene	6.00E-03	E	6.00E-03	r
Vinyl Chloride	3.00E-03	I	2.86E-02	I
Noncarcinogenic VOCs				
1,1-Dichloroethane	1.00E-01	H	1.43E-01	A
1,1,1-Trichloroethane	2.00E-02	E	2.86E-01	E
cis-1,2-Dichloroethene	1.00E-02	H	1.00E-02	r
Ethylbenzene	1.00E-01	I	2.86E-01	I
MTBE	5.00E-03	E	8.57E-01	I
Toluene	2.00E-01	I	1.14E-01	I
Xylenes	2.00E+00	I	2.00E-01	PRG
CFC-11	3.00E-01	I	2.00E-01	H

Notes:
1) mg/kg-day - milligram per kilogram per day
2) RfD_oral - Oral Reference Dose
3) RfD_inhal - Inhalation Reference Dose
4) I - IRIS online database September 2001
5) E - EPA, 1998. NCEA Regional Support provisional value
6) A - Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites, ASTM, ES 38-94.
7) PRG - withdrawn from IRIS but used in Region 9 PRG
8) H - EPA, 1993. Health Effects Summary Tables (HEAST).Office of Research and Development. OERR 9200.6-303.
9) r - route extrapolation
10) MTBE - Methyl-tert-butyl-ether
11) Dichloromethane is a synonym for methylene chloride
12) Toluene is reported under its synonym name methylbenzene in the database.

4.3 Risk Characterization

In the final step of risk analysis, chronic daily intakes (CDI) calculated in the exposure assessment (Section 4.1) are combined with the toxicological criteria presented in the toxicity assessment (Section 4.2) to develop estimates of risks. To estimate cancer risks, estimated chemical intakes are multiplied by cancer slope factors. Noncancer health effects are estimated by comparing chemical exposures to reference doses (RfDs) to determine if exposures are within a range that is likely to cause adverse health effects for construction workers at the CTM study area. Cancer risks for carcinogens are presented in Section 4.3.1 and hazard estimates for noncarcinogens are presented in Section 4.3.2. Section 4.3.3 discusses uncertainties associated with risk characterization.

4.3.1 Cancer Risk Estimates

To evaluate potential cancer risks for construction workers from exposure to groundwater, CDI estimates for COPCs are multiplied by cancer slope factors to develop upper range incremental lifetime cancer risks. Cancer risks associated with

COPCs in groundwater were estimated using the following equation from USEPA guidance (USEPA, 1989):

$$Risk_{gw} = CDI \text{ x } SF$$

Where: Risk_{gw} = Cancer Risk for groundwater pathway

SF = Cancer Slope Factor $(\text{mg/kg-day})^{-1}$

CDI = Chronic Daily Intake (mg/kg-day)

Cancer risks are then summed for all COPCs to develop a total cancer risk estimate. As outlined in the National Contingency Plan (NCP), incremental cancer risks to an individual in the range of 10^{-6} to 10^{-4} are generally considered acceptable by USEPA (1990). However, site-specific considerations, including types of exposure, uncertainties in estimating exposure, and limitations of remedial activities determine the cancer risk level acceptable for a site.

Cancer risk estimates are presented by exposure area in Table 4-5. Cancer risks are also graphically presented in Figure 4-2. Total incremental cancer risk estimates from exposure to groundwater by construction workers range from 5×10^{-9} at Area E to 4×10^{-6} at Area F. Total cancer risk estimates for all areas except Area F are equal to or less than 10^{-6}. The estimated cancer risk for Areas F is 4×10^{-6}. This risk estimate is at the bottom of the acceptable 10^{-6} to 10^{-4} risk range. Approximately 99% percent of the cancer risk estimate for Area F is from exposure to benzene and approximately 1% of the risk estimate is from PCE. These results suggest no unacceptable cancer risks from exposure to PCE for construction workers within the CTM. The cancer risk estimate for benzene is at the bottom of the acceptable risk range, suggesting no substantial risks from exposure to benzene in groundwater.

4.3.2 Hazard Quotients and Hazard Indices for Noncarcinogens

To evaluate noncancer health effects, estimated chemical exposures are compared to RfDs to determine if exposures are within a range that is likely to cause adverse health effects. The ratio of exposure to toxicity for a single chemical is called a hazard quotient (HQ) and is calculated as follows:

$$HQ_{gw} = \frac{CDI}{RfD_o}$$

Where: HQ_{gw} = Hazard quotient for groundwater pathway

Table 4-5
Calculation of Cancer Risk and Hazard Index

COPCs	SF_oral $(mg/kg\text{-}day)^{-1}$	PC (cm/hr)	Cancer Risk (unitless)							
Carcinogenic Exposure			**Area A**	**Area B**	**Area C**	**Area D**	**Area E**	**Area F**	**Area G**	**Area H**
Benzene	5.50E-02	0.021	ND	ND	5E-09	8E-07	ND	4E-06	4E-07	4E-08
Tetrachloroethene (PCE)	5.20E-02	0.048	1E-07	1E-08	3E-08	7E-07	5E-09	4E-08	5E-09	6E-09
		TOTAL CANCER RISK	**1E-07**	**1E-08**	**3E-08**	**1E-06**	**5E-09**	**4E-06**	**4E-07**	**5E-08**
COPCs	**RfD_oral (mg/kg-day)**	**PC (cm/hr)**	**Hazard Index (unitless)**							
Noncarcinogenic Exposure			**Area A**	**Area B**	**Area C**	**Area D**	**Area E**	**Area F**	**Area G**	**Area H**
Benzene	3.00E-03	0.021	ND	ND	0.002	0.3	ND	1.7	0.16	0.016
MTBE	5.00E-03	0.0026	0.0002	ND	ND	0.001	ND	0.2	0.004	0.0008
Tetrachloroethene (PCE)	1.00E-02	0.048	0.020	0.002	0.004	0.09	0.0007	0.005	0.0006	0.0009
		TOTAL HAZARD INDEX	**0.02**	**0.002**	**0.006**	**0.4**	**0.0007**	**2**	**0.2**	**0.02**

Parameters	Abbreviation	Unit	Value
Body Weight	BW	(kg)	70
Averaging Time for Carcinogens	ATcarc	(days)	25,550
Averaging Time for Noncarcinogens	ATnoncar	(days)	365
Ingestion Rate	IRgw	(l/day)	0.005
Exposure Duration	ED	(years)	1
Exposure Frequency	EF	(days/year)	250
Exposure Time	ET	(hours/day)	1
Surface Area	SA	(cm^2)	3,600
Conversion Factor	CF1	(l/cm^3)	0.001

Notes:

1) Cancer Risk = [(Cgw x EF x ED)/(BW x AT)] x [(IRgw x SFo) + (SA x PC x ET x CF1 x SFo)]
2) Hazard Index = [(Cgw x EF X ED)/(BW x AT)] x [(IRgw/RfDo) + (SA x PC x ET x CF1/RfDo)]
3) Cgw - Concentration in groundwater
4) PC - Permeability Coefficient
5) RfD_oral - Oral Reference Dose
6) SF_oral - Oral Slope Factor

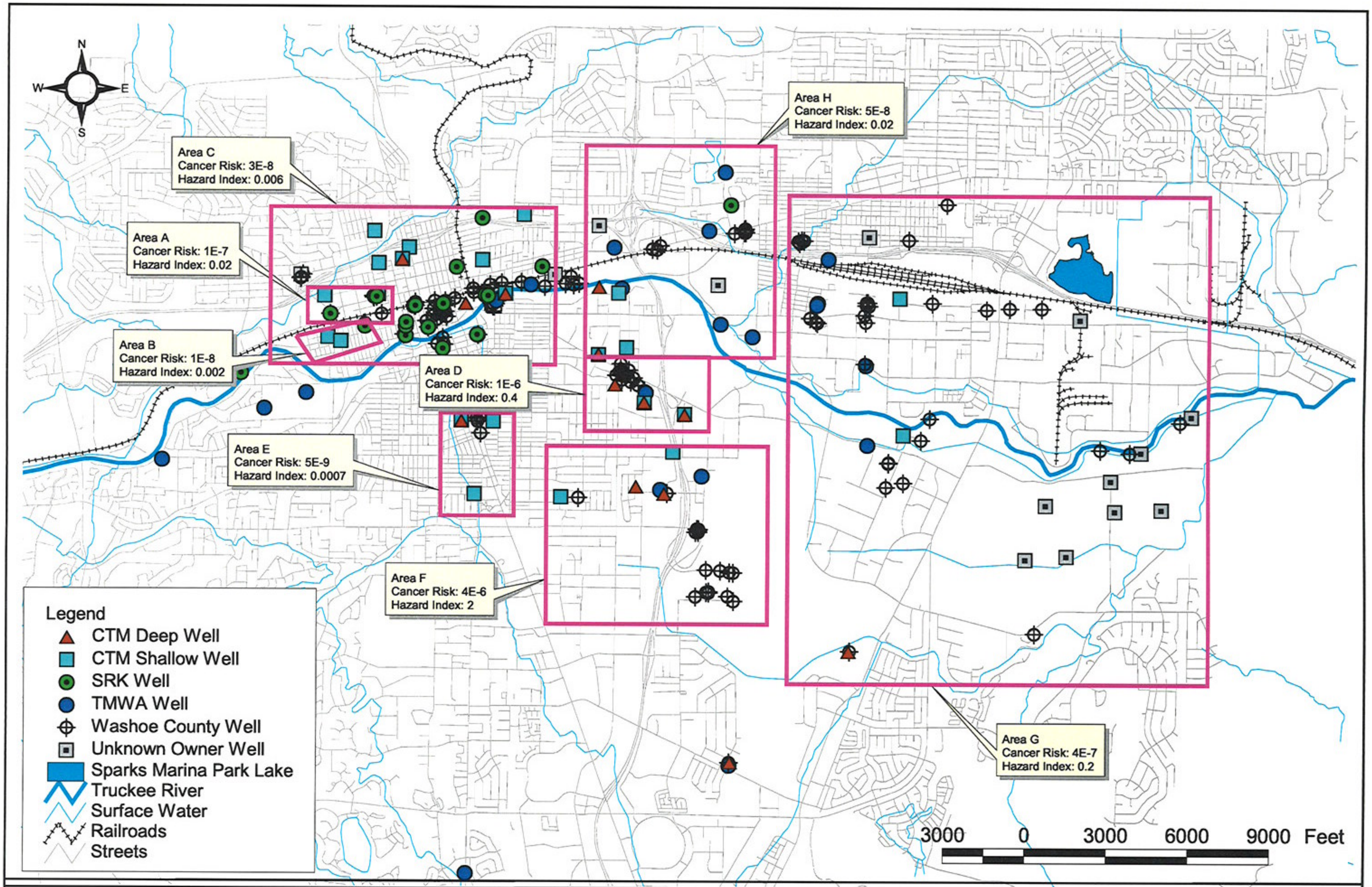

Figure 4-2
Cancer Risk and Hazard Index Values
Central Truckee Meadows Remediation District

CDM
consulting · engineering · construction · operations

CDI = Chronic Daily Intake (mg/kg-day)

RfD = Reference Dose (mg/kg-day)

The HQ is based on the assumption that there is a level of daily exposure (RfD) below which it is unlikely that even sensitive populations will experience adverse health effects. If the CDI exceeds the RfD (i.e., CDI/RfD > 1), a potential for adverse health effects may exist.

The HI is a summation of HQs for a particular pathway or from several pathways. If the HI exceeds 1, further evaluation is required. Summation of HQs may overestimate risks since chemicals may affect a variety of different organs or systems within the body. Chemicals affecting different organs or systems may act independently, and it is not appropriate to add HQs for such chemicals. Thus, if the HI for a pathway or a combination of pathways is 1 or above, HIs will be further evaluated by grouping together those chemicals that may affect the same organ.

HI estimates for exposure to groundwater by construction workers are presented by exposure area in Table 4-5. HI estimates are also graphically illustrated in Figure 4-2. Estimated HIs are less than one for all exposure areas except Area F. The estimated HI for this area is 2. Approximately 90% of this HI estimate is from benzene and approximately 9% is from MTBE and the remaining 1% is from PCE. The estimated HI is above one, indicating some potential for adverse noncancer health effects from exposure to benzene for construction workers who have relative intensive exposure to groundwater in Area F (e.g., ingest 5 ml of groundwater almost daily for an entire year).

4.3.3 Uncertainties Associated with the Human Health Risk Analysis

This section discusses uncertainties associated with the risk analysis. Significant uncertainties associated with the database, exposure assumptions, and the toxicity assessment have been identified and discussed in Sections 2, 3, and 4, respectively. This section describes the impact of uncertainties in the database, exposure assumptions, and toxicity assessment on the final step of the risk analysis and risk characterization. In addition, uncertainties inherent in risk characterization are identified and discussed.

4.3.3.1 Uncertainties Associated with the Data

Groundwater Data

Concentrations of organic chemicals in groundwater are considered adequately characterized for the purposes of the risk analysis. A large number of samples have been collected, from many different locations and seasonal variations have been characterized. Metals data for groundwater are limited, however. Although approximately 150 samples (historic and current) were collected, data are only available for arsenic, iron and manganese.

Most groundwater sampling was conducted in areas with known contamination. Data are therefore biased toward contaminated areas. As a result, risk estimates for the CTM study area may overestimate potential exposures and risks.

The risk analyses are based on current contaminant concentrations in groundwater. It is theoretically possible that concentrations of COPCs or their degradation products could increase in the future. Modeling to estimate the potential for such increases was not incorporated into the risk analyses. Some uncertainty remains as a result of no having future concentration estimates. However, the data indicate that none of the degradation products for PCE (TCE, 1,2-DCE, vinyl chloride) occur at sufficiently high concentrations in groundwater to be selected as COPCs.

Soil Gas Data and Approach to Soil Gas COPC Screening

Soil gas data were used to determine whether release of VOCs from groundwater to indoor air is an exposure pathway of concern for the CTM. This was done by selecting COPCs for soil gas. Since no COPCs were selected for soil gas, the conclusion that no significant migration of VOCs into soil gas and subsequently into indoor air will take place, is supported. This section discusses uncertainties associated with this conclusion.

Soil gas data are considered adequate to evaluate vapor migration from groundwater. Thirteen soil gas samples were collected and sampling locations were biased towards contaminated areas within the CTM study area. Soil gas sampling was conducted in areas associated with high concentrations of PCE in groundwater. PCE was detected in only two of the thirteen samples. Detection limits for PCE and the detected concentrations of PCE were below conservative screening concentrations for soil gas. These concentrations were backcalculated from acceptable indoor air concentrations based on residential exposure assumptions using target risks of 10^{-7} and target HIs of 0.1. The maximum detected concentration of only one chemical, PCE, was within (and below) one order of magnitude of the screening concentration. Since an adequate number of samples was collected and the detected concentrations were much lower than acceptable concentrations, the approach to soil gas COPC screening appears well justified.

Detection Limits for Vinyl Chloride

Vinyl chloride is a known human carcinogen and therefore important from a risk management perspective for the CTM. Vinyl chloride was not detected in groundwater or soil gas at the site. This section evaluates the reporting limits of vinyl chloride in soil gas and groundwater to assure that these limits were protective of human health.

For groundwater, the reporting limit for vinyl chloride was 1 µg/l. The MCL for vinyl chloride is 2 µg/l and the risk-based screening level for vinyl chloride is 946 µg/l. Therefore, the reporting limit for vinyl chloride in groundwater is adequate for health risk determination.

For soil gas, the reporting limit for vinyl chloride was 0.2 mg/m^3. The risk-based screening level for vinyl chloride using the Johnson and Ettinger model is 5 mg/m^3. Therefore, the reporting limit for vinyl chloride in soil gas is adequate for health risk determination.

Uncertainties Associated with the Acceptable Concentrations for Soil Gas

Acceptable soil gas concentrations were estimated using the Johnson and Ettinger Model fate and transport model. There is a level of uncertainty associated with modeling. Model input parameters were generally conservative, however, and are more likely to overestimate than underestimate acceptable soil gas concentrations, especially when conservative target risk levels are used.

The analysis assumed that current concentrations of COPCs in soil gas will remain constant into the future. Data are not available, however, to help establish the accuracy of this assumption. A moderate to high degree of uncertainty is associated with using current soil gas concentrations to estimate exposures that continue into the future.

4.3.3.2 Uncertainties Associated with the Exposure Assessment

Quantitative estimates of chemical exposure may contain uncertainty. Assumptions used in the exposure assessment are derived from a combination of USEPA guidance, site-specific information, and professional judgement, with each of the potential information sources being subject to uncertainty. However, exposure assumptions used in this technical memorandum were generally conservative and are expected to overestimate rather than underestimate potential exposure and risk for construction workers. It was assumed, for example, that construction workers would incidentally ingest 5 mL of contaminated groundwater five days per week for an entire year. This assumption is expected to be overly conservative given that incidental ingestion of groundwater during dewatering is typically a rare event if it occurs at all.

4.3.3.3 Uncertainties Associated with the Toxicity Assessment

A potentially large source of uncertainty is inherent in the derivation of USEPA toxicity criteria (i.e., RfDs, and cancer slope factors). In many cases, data must be extrapolated from animals to sensitive humans by the application of uncertainty factors to an estimated NOAEL or lowest-observed adverse effects level (LOAEL) for noncancer effects. While designed to be protective, in many cases uncertainty factors overestimate the magnitude of differences that may exist between human and animals, and among humans.

In some cases, however, toxicity criteria may be based on studies that did not detect the most sensitive adverse effects. For example, many past studies have not measured possible toxic effects on the immune system. Moreover, some chemicals may cause subtle effects not easily recognized in animal studies.

In addition, derivation of cancer slope factors often involves linear extrapolation of effects at high doses to potential effects a lower doses commonly seen in environmental exposure settings. Currently, it is not known whether linear extrapolation is appropriate. Probably, the shape of the dose response curve for carcinogenesis varies with different chemicals and mechanisms of action. It is not possible at this time to describe such differences in quantitative terms.

A large source of uncertainty is inherent in the derivation of USEPA toxicity criteria (i.e., RfDs and CSFs). As discussed in detail in Section 4.2, the main sources of potential error in the derivation of toxicity criteria include extrapolation from animal data to humans and the assumption of linearity in carcinogenic dose response relationships. Safety factors are incorporated into USEPA toxicity criteria, however, and they are generally considered more likely to overestimate than underestimate potential cancer and noncancer risk. The conservative methods used in establishing cancer slope factors may substantially overestimate risk from small daily exposures. For some chemicals and exposure conditions, risks may be essentially zero.

4.3.3.4 Uncertainties in Risk Characterization

Use of Oral RfDs for Evaluation of Inhalation Exposures

In the development of risk-based screening values for noncancer effects from inhalation of COPCs, some oral toxicity criteria were substituted for inhalation toxicity criteria when inhalation toxicity criteria were not available. This approach introduces uncertainties, because absorption efficiencies may differ between routes of entry.

Section 5
Screening Ecological Impacts Analysis

Contaminants in groundwater in the CTM area could theoretically discharge to the Truckee River. Several endangered species have been identified in the Truckee River, including the Lahontan Cutthroat Trout. Impacts to surface water in the Truckee River are therefore of potential concern. However, PCE was not detected in samples collected from the Truckee River.

Three rounds of surface water sampling were conducted by Washoe County staff in April, September, and October of 1999. An additional sample was collected by Washoe County in September 2001. Although some VOCs were detected in surface water samples collected directly from discharge points at outfalls, no VOCs were detected in surface water samples not associated with the outfalls. This suggests that either no contaminants are discharged from groundwater into the Truckee River or any contaminants present in discharged groundwater are so rapidly diluted that they are not detectable.

Groundwater contaminants that discharge into the Truckee River could theoretically adhere to sediment. However, VOCs were detected at low concentrations at the outfalls and not detected in surface water samples not associated with the outfalls indicating little to no discharge of contaminants from the groundwater. Therefore, it is likely that these groundwater contaminants are not present in the sediment. Exposure to these contaminants in sediment is therefore not considered an important exposure scenario for the CTM site and is not further considered in this technical memorandum.

Because site-related contaminants were not detected in surface water in the Truckee River, and are not expected to be present in sediment, further evaluation of ecological impacts was not necessary.

Section 6
Summary

6.1 Human Health Impacts Analysis

6.1.1 Shallow Groundwater

Potential human health risk associated with contaminants in shallow groundwater and media that may be impacted by shallow groundwater (surface water, sediment, indoor air, and ambient air) were evaluated. Residents, commercial/industrial workers, construction workers, and recreational visitors were identified as potentially exposed populations.

No chemicals were selected as COPCs for soil gas, since the maximum detected concentrations for all chemicals were below the screening criteria. Exposure pathways associated with indoor and ambient air were therefore not considered complete and were not further evaluated. In addition, no VOCs were detected in the surface water sampling locations not directly associated with outfalls. Exposure pathways associated with surface water were therefore not considered complete and were not further evaluated. Sediment data for the CTM are not available. However, because the COPCs for shallow groundwater at the CTM do not tend to partition to sediment, exposure pathways associated with sediment were not considered complete and were not further evaluated

Three COPCs – benzene, MTBE, and PCE – were selected as COPCs for shallow groundwater. Exposure to shallow groundwater was quantitatively evaluated for construction workers. The following pathways were evaluated:

- Incidental ingestion of shallow groundwater
- Dermal contact with shallow groundwater

For the analysis, the CTM study areas A through H from the Final Updated Work Plan (CDM, 2001) were slightly revised to incorporate all of the groundwater sampling points. These areas were used to divide the data for calculation of the human health risks. Exposure point concentrations for these areas where 95th percent UCLs on the mean of the data, except where data were insufficient for UCL calculations. In these cases, maximum detected concentrations were used as the exposure point concentrations for an area.

Total incremental cancer risk estimates from exposure to groundwater by construction workers range from 5×10^{-9} at Area E to 4×10^{-6} at Area F. Total cancer risk estimates for all areas except Area F are equal to or less than 10^{-6}. The estimated cancer risk for Area F (4×10^{-6}) is at the bottom of the acceptable 10^{-6} to 10^{-4} risk range. Approximately 99% percent of the cancer risk estimate for Area F is from exposure to benzene and approximately 1% of the risk estimate is from PCE. These results suggest no unacceptable cancer risks from exposure to PCE for construction workers within the CTM. The cancer risk estimate for benzene is at the bottom of the acceptable risk range, suggesting no substantial risks from exposure to benzene in groundwater.

Similarly, estimated HIs are less than one for all exposure areas except Area F, which had an estimated HI of 2. Approximately 90% of this HI estimate is from benzene and approximately 9% is from MTBE and the remaining 1% is from PCE. The estimated HI above one indicates some potential for adverse noncancer health effects from exposure to benzene for construction workers, who have relative intensive exposure to groundwater in Area F (e.g., ingest 5 ml of groundwater almost daily for an entire year).

6.1.2 Deep Groundwater

Field investigation data indicate deep aquifer groundwater is contaminated with VOCs. Benzene, MTBE, PCE, and trichloroethylene are present at concentrations that exceed MCLs. Statutory requirements require wellhead treatment or control if concentrations of any contaminants exceed MCLs. Currently, five existing deep aquifer water supply wells deep aquifer are protected by wellhead treatment systems. Health impacts for people using water from the currently protected wells are not likely. However, if contaminants migrate to water supply wells, which are not protected by wellhead treatment systems, residents may be exposed to groundwater contaminants. During recent sampling events, data from two untreated deep aquifer water supply wells indicate impacts by VOCs. Concentrations above MCLs indicate a potential for adverse health effects. Because drinking water supplies must meet state and federal MCLs, it is not necessary to conduct quantitative risk analyses and to determine site-specific remediation goals for the deep aquifer. However, chemicals that exceed MCLs need to be addressed in the remediation plan that will be prepared as part of the CTM Remediation District Project.

6.2 Environmental Impacts Analysis

Contaminants in shallow groundwater could theoretically be discharged into surface water and sediment in the Truckee River where they may impact ecological receptors. Site-related contaminants were, however, not detected in surface water in the Truckee River and are, therefore, likely not present in sediment. Therefore, ecological impacts associated with groundwater discharges into the Truckee River are not considered to be of concern for the CTM.

Section 7
References

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Appendix A

Analytical Data Considered for Use in Risk Assessment

Appen
Table A-1a
Summary of Shallow Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)																		
		1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene
3	31-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
3	28-Aug-00	1.9	<1	<1	<1	NA	<1	<1	<1	<1	1.3	<1	<1	<1	<1	NA	<1	<1	<1	NA
4	5-May-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	2.5	<1	<1	<1	<1	NA	<1	<1	<1	NA
5	5-May-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
18a	4-Feb-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
18a	10-Mar-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
19	29-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
22	7-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	3.5	<1	<1	<1	<1	NA	<1	<1	<1	NA
22a	7-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
23	11-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
25a	7-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	11.3	<1	<1	<1	<1	NA	<1	<1	<1	NA
25b	7-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
25c	11-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
25d	11-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	6312	<1	<1	<1	<1	NA	<1	<1	<1	NA
25e	7-Feb-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
25f	14-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
25g	21-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	5	<1	<1	<1	<1	NA	<1	<1	<1	NA
40	19-Aug-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
65	28-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
66	27-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
67	9-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
67	28-Apr-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	1.4	<1	<1	<1	<1	NA	<1	<1	<1	NA
67	7-Jun-00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
67	13-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
68	23-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
69	27-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
71	28-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
73	5-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
73	24-Mar-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
73	16-Jun-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
73	13-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
74	3-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
74	18-Feb-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
74	28-Apr-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
74	7-Jun-00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
74	28-Aug-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
75	3-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
75	16-Jun-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
75	13-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
76	5-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
76a	3-Jul-01	<5	<5	<5	<5	<5	<5	<5	<5	<5	<2.5	<5	<5	<5	<5	<5	<5	<5	<20	<5
79f	28-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
79h	28-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
79k	28-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
97	13-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	13.7	<1	<1	<1	<1	NA	<1	8.4	<1	NA
97	26-Jun-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	8.3	<1	NA

NA - Not Analyzed
<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A
Table A-1a
Summary of Shallow Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)																		
		1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene
98	14-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	16.1	<1	<1	<1	<1	NA	<1	<1	<1	NA
98	12-Jul-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
99	14-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	1.5	<1	<1	<1	<1	NA	<1	<1	<1	NA
99	12-Jul-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
101	9-Aug-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
103	26-Aug-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
103	26-May-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
104	8-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
104	18-Feb-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
104	26-May-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
106	16-Aug-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
106	18-Feb-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	7.2	<1	NA
106	16-Jun-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	7.3	<1	NA
106	13-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
108	16-Aug-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
111	6-Aug-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
111a	5-Aug-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
111a	15-Oct-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
111a	8-Feb-00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
112	21-Jul-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
112	15-Oct-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
112	10-Feb-00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
114	8-Oct-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	30	<1	<1	<1	<1	NA	<1	<1	<1	NA
115	23-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	48	<1	<1	<1	<1	NA	<1	<1	<1	NA
118	10-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	62.5	<1	<1	<1	<1	NA	<1	<1	<1	NA
118a	10-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	3.7	<1	<1	<1	<1	NA	<1	<1	<1	NA
118b	10-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	26.2	<1	<1	<1	<1	NA	<1	<1	<1	NA
118c	10-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	8	<1	<1	<1	<1	NA	<1	<1	<1	NA
118d	10-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	14.4	<1	<1	<1	<1	NA	<1	<1	<1	NA
118e	12-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
118f	12-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
119	12-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
119a	15-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	621.1	<1	<1	<1	<1	NA	<1	<1	<1	NA
119b	15-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	5.6	<1	<1	<1	<1	NA	<1	<1	<1	NA
119c	15-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
122a	17-Aug-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
122a	26-Jun-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
122b	17-Aug-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
122b	17-Jul-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
122c	14-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
122c	26-Jun-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
126a	21-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
126b	21-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133	16-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	284	<1	<1	<1	<1	NA	<1	<1	<1	NA
133	11-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133a	16-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA

NA - Not Analyzed

<1 - Indicates not detected at the indicated laboratory detection limit

Appe

Table A-1a

Summary of Shallow Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)																		
		1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene
133b	16-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133c	16-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133d	16-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133e	16-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	3	<1	<1	<1	<1	NA	<1	<1	<1	NA
133f	15-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133f	11-Feb-00	8.7	<1	<1	<1	NA	<1	<1	<1	<1	18	<1	<1	<1	<1	NA	<1	<1	<1	NA
133f	28-Apr-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	74.7	<1	<1	<1	<1	NA	<1	<1	<1	NA
133f	19-May-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	95	<1	<1	<1	<1	NA	<1	<1	<1	NA
133f	5-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133g	15-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133g	21-Apr-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133h	15-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	2520	<1	<1	<1	<1	NA	<1	<1	<1	NA
133h	10-Mar-00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
133h	11-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	5.6	<1	<1	<1	<1	NA	<1	<1	<1	NA
133i	15-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	151	<1	<1	<1	<1	NA	<1	<1	<1	NA
133i	5-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133j	15-Sep-99	4.8	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	3.6	<1	NA
133j	11-Feb-00	7.4	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133j	10-Mar-00	5.6	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133j	21-Apr-00	3.4	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	2.1	<1	NA
133j	19-May-00	4.1	<1	<1	<1	NA	<1	<1	<1	<1	1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133j	19-Jun-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133j	30-Aug-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133k	15-Sep-99	13.5	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	3.1	<1	NA
133k	11-Feb-00	14.7	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133k	28-Apr-00	8.1	<1	<1	<1	NA	<1	<1	<1	<1	2.5	<1	<1	<1	<1	NA	<1	<1	<1	NA
133k	19-Jun-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133k	11-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133l	15-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133l	11-Feb-00	10.3	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133l	19-May-00	11	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133l	11-Sep-00	1.5	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133m	15-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133m	11-Feb-00	3.4	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133m	17-Jul-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133n	16-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
133o	15-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
CTM-1S	29-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-1S	12-Jul-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1.3	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<10	<2.5
CTM-2S	9-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2.5	<2	<1
CTM-2S	12-Jul-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1.3	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	3.1	<10	<2.5
CTM-3S	2-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-3S	10-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-3S	28-Jun-01	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<5	<1.3
CTM-5S	2-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2.2	<2	<1
CTM-5S	28-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	3	<4	<1

NA - Not Analyzed

<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A
Table A-1a
Summary of Shallow Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)																		
		1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene
CTM-6S	29-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-6S	5-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-6S	5-Jul-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1.3	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<10	<2.5
CTM-7S	27-Mar-01	<1	<1	<1	<1	<1	<20	<1	<1	<20	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-7S	5-Jul-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1.3	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<10	<2.5
CTM-9S	8-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.8	<4	<1
CTM-9S	24-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-9S	26-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<2	<1
CTM-11S	10-Jul-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<4	3.1
CTM-13S	28-Mar-01	8.2	<1	<1	11	<1	<1	<1	<1	<1	1.9	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-13S	29-Mar-01	7.5	<1	<1	10	<1	<1	<1	<1	<1	2.5	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-13S	24-May-01	8	<1	<1	7.8	<1	<1	<1	<1	<1	2	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-13S	21-Jun-01	15	<1	<1	4.3	<1	<1	<1	<1	<1	4.7	<1	<1	<1	<1	<1	<1	1.8	<2	<1
CTM-14S	27-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-14S	29-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-14S	22-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-15S	27-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-15S	29-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-15S	22-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-16S	29-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-16S	27-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-18S	26-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-18S	27-Mar-01	<1	<1	<1	<1	<1	<20	<1	<1	<20	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-18S	15-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-18S	25-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-19S	30-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-19S	15-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-19S	21-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-20S	27-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-20S	21-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-21S	26-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-21S	5-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-21S	5-Jul-01	<25	<25	<25	<25	<25	<25	<25	<25	<25	<13	<25	<25	<25	<25	<25	<25	<25	<100	<25
CTM-28S	2-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-28S	9-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<4	<1
CTM-28S	24-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<4	<1
CTM-28S	28-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<4	<1
CTM-29S	29-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-29S	9-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-29S	12-Jul-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1.3	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<10	<2.5
CTM-31S	15-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2.1	<2	<1
CTM-31S	24-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2.2	<2	<1
CTM-31S	28-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.7	<2	<1
CTM-37S	28-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.1	<2	<1
CTM-37S	5-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.3	<2	<1
CTM-37S	12-Jul-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1.3	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<10	<2.5

NA - Not Analyzed

<1 - Indicates not detected at the indicated laboratory detection limit

Appen

Table A-1a

Summary of Shallow Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)																		
		1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene
CTM-39S	6-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-39S	7-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-39S	25-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-40S	6-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<2	<1
CTM-40S	7-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-40S	12-Jul-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1.3	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<10	<2.5
CTM-41S	12-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.1	<2	<1
CTM-41S	14-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.1	<2	<1
CTM-41S	10-Jul-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<4	<1

NA - Not Analyzed

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Appendix A
Table A-1a
Summary of Shallow Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)														
		cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
3	31-Jan-00	NA	<1	<1	<1	<1	NA	<1	596	NA	NA	<1	<1	<1	<1	1310
3	28-Aug-00	NA	<1	42.4	<1	<1	NA	<1	85.4	NA	NA	<1	<1	<1	<1	69.2
4	5-May-00	NA	<1	<1	<1	<1	NA	3.3	42.2	NA	NA	<1	1.6	<1	<1	11.2
5	5-May-00	NA	<1	2.2	<1	<1	NA	2.3	2.3	NA	NA	<1	<1	25.3	<1	7.9
18a	4-Feb-00	NA	<1	1.9	<1	<1	NA	158.4	23.6	NA	NA	<1	<1	<1	<1	1.2
18a	10-Mar-00	NA	<1	<1	<1	<1	NA	68.1	36.2	NA	NA	<1	<1	<1	<1	<1
19	29-Nov-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
22	7-Jan-00	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	2.3
22a	7-Jan-00	NA	<1	<1	<1	<1	NA	<1	8.6	NA	NA	<1	<1	<1	<1	<1
23	11-Jan-00	NA	<1	<1	<1	<1	NA	<1	48.5	NA	NA	<1	<1	<1	<1	<1
25a	7-Jan-00	NA	<1	25.1	<1	3.7	NA	<1	135.3	NA	NA	<1	2.9	<1	<1	229.2
25b	7-Jan-00	NA	<1	10.4	<1	4.3	NA	<1	180.9	NA	NA	<1	<1	<1	<1	39.7
25c	11-Jan-00	NA	<1	<1	<1	<1	NA	<1	48.4	NA	NA	<1	<1	<1	<1	<1
25d	11-Jan-00	NA	<1	16.3	<1	35.9	NA	<1	79.2	NA	NA	<1	<1	<1	<1	123.3
25e	7-Feb-00	NA	<1	1.6	<1	<1	NA	1.4	8.8	NA	NA	<1	<1	<1	<1	2.7
25f	14-Jan-00	NA	<1	<1	<1	8758	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
25g	21-Jan-00	NA	<1	<1	<1	<1	NA	<1	37.8	NA	NA	<1	<1	<1	<1	<1
40	19-Aug-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
65	28-Sep-99	NA	<1	<1	<1	8.4	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
66	27-Sep-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
67	9-Nov-99	NA	<1	15.6	<1	<1	NA	2.5	89.9	NA	NA	<1	<1	<1	<1	40.3
67	28-Apr-00	NA	<1	2.2	<1	<1	NA	20.6	52.7	NA	NA	<1	1	<1	<1	11.7
67	7-Jun-00	NA	NA	NA	NA	NA	NA	6.7		NA	NA		1.8			
67	13-Sep-00	NA	<1	6	<1	<1	NA	6.3	19.4	NA	NA	<1	<1	<1	<1	10.8
68	23-Nov-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
69	27-Sep-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
71	28-Sep-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
73	5-Nov-99	NA	<1	5.9	<1	<1	NA	12	24	NA	NA	<1	<1	<1	<1	15.7
73	24-Mar-00	NA	<1	<1	<1	<1	NA	9.2	29	NA	NA	<1	<1	<1	<1	<1
73	16-Jun-00	NA	<1	<1	<1	<1	NA	14	13.1	NA	NA	<1	<1	<1	<1	2.9
73	13-Sep-00	NA	<1	3.8	<1	<1	NA	9.9	12.1	NA	NA	<1	<1	<1	<1	7.7
74	3-Nov-99	NA	<1	36.6	<1	<1	NA	38.5	186.6	NA	NA	<1	2.1	<1	<1	99.6
74	18-Feb-00	NA	<1	<1	<1	<1	NA	35.4	82.2	NA	NA	<1	<1	<1	<1	<1
74	28-Apr-00	NA	<1	<1	<1	<1	NA	29.2	20.4	NA	NA	<1	<1	<1	<1	9.6
74	7-Jun-00	NA	NA	NA	NA	NA	NA	26	NA	NA	NA	NA	NA	NA	NA	NA
74	28-Aug-00	NA	<1	56	<1	<1	NA	14.1	101.9	NA	NA	<1	<1	<1	<1	92
75	3-Nov-99	NA	<1	2.1	<1	<1	NA	<1	10.7	NA	NA	<1	<1	<1	<1	6.2
75	16-Jun-00	NA	<1	4.6	<1	<1	NA	4.8	29.1	NA	NA	<1	<1	<1	<1	16.2
75	13-Sep-00	NA	<1	3.7	<1	<1	NA	4	12.4	NA	NA	<1	<1	<1	<1	7.8
76	5-Nov-99	NA	<1	7.8	<1	<1	NA	<1	36.3	NA	NA	<1	<1	<1	<1	20.3
76a	3-Jul-01	<5	<20	<2.5	<5	<2.5	<2.5	<5	310	<5	<5	<5	<5	<5	<5	NA
79f	28-Sep-00	NA	<1	4.5	<1	<1	NA	3.3	24.5	NA	NA	<1	<1	<1	<1	10.6
79h	28-Sep-00	NA	<1	3.2	<1	<1	NA	2.3	14.5	NA	NA	<1	<1	<1	<1	7.5
79k	28-Sep-00	NA	<1	3.2	<1	<1	NA	2.3	15.7	NA	NA	<1	<1	<1	<1	7.8
97	13-Jan-00	NA	<1	2.6	<1	<1	NA	<1	27.2	NA	NA	<1	<1	<1	<1	<1
97	26-Jun-00	NA	<1	<1	<1	<1	NA	3.5	8.9	NA	NA	<1	<1	<1	<1	<1

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Appen

Table A-1a

Summary of Shallow Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)														
		cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	rans-1,2-Dichloroethene	rans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
98	14-Jan-00	NA	<1	<1	<1	<1	NA	<1	24.7	NA	NA	<1	<1	<1	<1	1.7
98	12-Jul-00	NA	<1	<1	<1	<1	NA	5.6	38.2	NA	NA	<1	<1	<1	<1	<1
99	14-Jan-00	NA	<1	<1	<1	<1	NA	<1	3.1	NA	NA	<1	<1	<1	<1	<1
99	12-Jul-00	NA	<1	<1	<1	<1	NA	3.4	28.2	NA	NA	<1	<1	<1	<1	<1
101	9-Aug-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
103	26-Aug-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
103	26-May-00	NA	<1	1.6	<1	<1	NA	4.8	32.5	NA	NA	<1	<1	<1	<1	4.4
104	8-Sep-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
104	18-Feb-00	NA	<1	<1	<1	<1	NA	20.6	70.2	NA	NA	<1	<1	<1	<1	<1
104	26-May-00	NA	<1	1.3	<1	<1	NA	8	21.6	NA	NA	<1	<1	<1	<1	3.7
106	16-Aug-99	NA	<1	<1	<1	<1	NA	1.1	<1	NA	NA	<1	<1	<1	<1	<1
106	18-Feb-00	NA	<1	<1	<1	<1	NA	6	75.7	NA	NA	<1	<1	<1	<1	<1
106	16-Jun-00	NA	<1	3.5	<1	<1	NA	5.3	11.3	NA	NA	<1	<1	<1	<1	12.2
106	13-Sep-00	NA	<1	1.2	<1	<1	NA	1.3	3.9	NA	NA	<1	<1	<1	<1	1.8
108	16-Aug-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
111	6-Aug-99	NA	NA	NA	NA	NA	NA	2.4	NA	NA	NA	NA	NA	NA	NA	NA
111a	5-Aug-99	NA	NA	NA	NA	NA	NA	1.9	NA	NA	NA	NA	NA	NA	NA	NA
111a	15-Oct-99	NA	NA	NA	NA	NA	NA	12	NA	NA	NA	NA	NA	NA	NA	NA
111a	8-Feb-00	NA	NA	NA	NA	NA	NA	25	NA	NA	NA	NA	NA	NA	NA	NA
112	21-Jul-99	NA	NA	NA	NA	NA	NA	6.2	NA	NA	NA	NA	NA	NA	NA	NA
112	15-Oct-99	NA	NA	NA	NA	NA	NA	4.8	NA	NA	NA	NA	NA	NA	NA	NA
112	10-Feb-00	NA	NA	NA	NA	NA	NA	3.1	NA	NA	NA	NA	NA	NA	NA	NA
114	8-Oct-99	NA	<1	392	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	751
115	23-Sep-99	NA	<1	1049	<1	142	NA	<1	1645	NA	NA	<1	<1	<1	<1	38013
118	10-Nov-99	NA	<1	670	<1	28.4	NA	<1	542.8	NA	NA	<1	<1	<1	<1	1114.7
118a	10-Nov-99	NA	<1	138.7	<1	<1	NA	<1	281.8	NA	NA	<1	<1	<1	<1	<1
118b	10-Nov-99	NA	<1	807.5	<1	<1	NA	<1	207.8	NA	NA	<1	<1	<1	<1	506.2
118c	10-Nov-99	NA	<1	731.9	<1	<1	NA	<1	268.4	NA	NA	<1	<1	<1	<1	865.3
118d	10-Nov-99	NA	<1	629.9	<1	<1	NA	<1	66.8	NA	NA	<1	<1	<1	<1	246.5
118e	12-Nov-99	NA	<1	63.5	<1	<1	NA	<1	50.6	NA	NA	<1	<1	<1	<1	69.7
118f	12-Nov-99	NA	<1	31.1	<1	<1	NA	<1	19.8	NA	NA	<1	<1	<1	<1	34.9
119	12-Nov-99	NA	<1	48.8	<1	<1	NA	<1	39.7	NA	NA	<1	<1	<1	<1	55.9
119a	15-Nov-99	NA	<1	67.1	<1	139.9	NA	<1	131	NA	NA	<1	<1	<1	<1	273.1
119b	15-Nov-99	NA	<1	11.2	<1	<1	NA	<1	8.7	NA	NA	<1	<1	<1	<1	14.9
119c	15-Nov-99	NA	<1	16.7	<1	<1	NA	<1	15.1	NA	NA	<1	<1	<1	<1	24.3
122a	17-Aug-99	NA	<1	<1	<1	<1	NA	2.8	<1	NA	NA	<1	<1	<1	<1	<1
122a	26-Jun-00	NA	<1	3.9	<1	<1	NA	5.3	10.8	NA	NA	<1	<1	<1	<1	11.5
122b	17-Aug-99	NA	<1	<1	<1	<1	NA	2	10.8	NA	NA	<1	<1	<1	<1	<1
122b	17-Jul-00	NA	<1	2.2	<1	<1	NA	5.6	43.5	NA	NA	<1	<1	<1	<1	5.6
122c	14-Sep-99	NA	<1	<1	<1	<1	NA	2.3	<1	NA	NA	<1	<1	<1	<1	<1
122c	26-Jun-00	NA	<1	<1	<1	<1	NA	<1	5.9	NA	NA	<1	<1	<1	<1	<1
126a	21-Jan-00	NA	<1	<1	<1	<1	NA	<1	6.4	NA	NA	<1	<1	<1	<1	<1
126b	21-Jan-00	NA	<1	<1	<1	<1	NA	<1	9.5	NA	NA	<1	<1	<1	<1	<1
133	16-Sep-99	NA	<1	<1	<1	<1	NA	30.7	470	NA	NA	<1	<1	<1	<1	417.4
133	11-Sep-00	NA	<1	2.4	<1	10.4	NA	5	4.8	NA	NA	<1	<1	<1	<1	9.7
133a	16-Sep-99	NA	<1	<1	<1	<1	NA	11.7	<1	NA	NA	<1	2	<1	<1	<1

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<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A
Table A-1a
Summary of Shallow Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)														
		cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
133b	16-Sep-99	NA	<1	<1	<1	<1	NA	5.5	<1	NA	NA	<1	<1	<1	<1	<1
133c	16-Sep-99	NA	<1	<1	<1	<1	NA	20	<1	NA	NA	<1	<1	<1	<1	<1
133d	16-Sep-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	810
133e	16-Sep-99	NA	<1	<1	<1	<1	NA	16.3	<1	NA	NA	<1	2.2	<1	<1	<1
133f	15-Sep-99	NA	<1	<1	<1	<1	NA	112	<1	NA	NA	<1	<1	<1	<1	<1
133f	11-Feb-00	NA	<1	2.2	<1	6.1	NA	338	16.6	NA	NA	<1	13.8	<1	<1	2.4
133f	28-Apr-00	NA	<1	23.2	<1	15.6	NA	73.8	40.1	NA	NA	<1	22.5	<1	<1	103.6
133f	19-May-00	NA	<1	113	<1	181	NA	33	56	NA	NA	<1	<1	<1	<1	141
133f	5-Sep-00	NA	<1	4.7	<1	<1	NA	1.8	20.1	NA	NA	<1	<1	<1	<1	12.8
133g	15-Sep-99	NA	<1	<1	<1	<1	NA	36.2	<1	NA	NA	<1	<1	<1	<1	<1
133g	21-Apr-00	NA	<1	<1	<1	<1	NA	36.5	12	NA	NA	<1	<1	<1	<1	<1
133h	15-Sep-99	NA	<1	164	<1	<1	NA	240	2872	NA	NA	<1	<1	<1	<1	3284
133h	10-Mar-00	NA	NA	NA	NA	NA	NA	448.9	NA	NA	NA	NA	34.8	NA	NA	NA
133h	11-Sep-00	NA	<1	3.2	<1	49.5	NA	11.9	30.3	NA	NA	<1	<1	<1	<1	16.7
133i	15-Sep-99	NA	<1	586	<1	<1	NA	<1	950	NA	NA	<1	<1	<1	<1	395
133i	5-Sep-00	NA	<1	2.6	<1	<1	NA	2.1	9.9	NA	NA	<1	<1	<1	<1	6.6
133j	15-Sep-99	NA	<1	<1	<1	<1	NA	720	<1	NA	NA	<1	3	<1	<1	<1
133j	11-Feb-00	NA	<1	1.2	<1	6.4	NA	702	12.8	NA	NA	<1	3.6	<1	<1	<1
133j	10-Mar-00	NA	<1	<1	<1	<1	NA	1108	<1	NA	NA	<1	2.9	<1	<1	<1
133j	21-Apr-00	NA	<1	<1	<1	<1	NA	341.3	14.3	NA	NA	<1	2	<1	<1	<1
133j	19-May-00	NA	<1	10.9	<1	<1	NA	428.3	19.7	NA	NA	<1	3.5	<1	<1	13.8
133j	19-Jun-00	NA	<1	1.8	<1	3.1	NA	229.9	11.5	NA	NA	<1	1	<1	<1	5.3
133j	30-Aug-00	NA	<1	12.2	<1	<1	NA	165.3	48.6	NA	NA	<1	<1	<1	<1	27.3
133k	15-Sep-99	NA	<1	<1	<1	<1	NA	35.9	<1	NA	NA	<1	<1	<1	<1	<1
133k	11-Feb-00	NA	<1	<1	<1	<1	NA	224	46.6	NA	NA	<1	<1	<1	<1	<1
133k	28-Apr-00	NA	<1	2.5	<1	<1	NA	218.5	40.4	NA	NA	<1	2.1	<1	<1	18.4
133k	19-Jun-00	NA	<1	<1	<1	<1	NA	61.1	2.5	NA	NA	<1	<1	<1	<1	2.8
133k	11-Sep-00	NA	<1	5.2	<1	<1	NA	235.1	18.9	NA	NA	<1	<1	<1	<1	12.7
133l	15-Sep-99	NA	6.6	14.6	<1	<1	NA	22.9	<1	NA	NA	<1	<1	<1	<1	34.2
133l	11-Feb-00	NA	<1	<1	<1	<1	NA	119.4	11.1	NA	NA	<1	<1	<1	<1	<1
133l	19-May-00	NA	<1	1	<1	<1	NA	216.3	15.4	NA	NA	<1	2.4	<1	<1	3.5
133l	11-Sep-00	NA	<1	3.8	<1	3.2	NA	6.4	68.2	NA	NA	<1	<1	<1	<1	27.8
133m	15-Sep-99	NA	<1	<1	<1	<1	NA	33.3	<1	NA	NA	<1	<1	<1	<1	<1
133m	11-Feb-00	NA	<1	1.4	<1	<1	NA	28.5	7.6	NA	NA	<1	<1	<1	<1	2.4
133m	17-Jul-00	NA	<1	<1	<1	9.5	NA	30.6	<1	NA	NA	<1	2.7	<1	<1	<1
133n	16-Sep-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
133o	15-Sep-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
CTM-1S	29-Mar-01	<1	<2	<1	<1	<1	<1	1.2	<1	<1	<1	<1	<1	<1	<1	<1
CTM-1S	12-Jul-01	<2.5	<10	<1.3	<2.5	<1.3	<1.3	<2.5	260	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	NA
CTM-2S	9-Apr-01	<1	<2	<1	<1	<1	<1	10	22	<1	<1	<1	<1	<1	<1	1.1
CTM-2S	12-Jul-01	<2.5	<10	<1.3	<2.5	<1.3	<1.3	7.4	300	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	NA
CTM-3S	2-Apr-01	<1	<2	<1	<1	<1	<1	7.7	5.5	<1	<1	<1	<1	<1	<1	<1
CTM-3S	10-Apr-01	<1	<2	<1	<1	<1	<1	7.6	11	<1	<1	<1	<1	<1	<1	2.7
CTM-3S	28-Jun-01	<1.3	<5	<1	<1.3	<1	<1	8.3	200	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	NA
CTM-5S	2-Apr-01	<1	<2	<1	<1	<1	<1	11	1	<1	<1	<1	<1	<1	<1	<1
CTM-5S	28-Jun-01	<1	<4	<1	<1	<1	<1	27	77	<1	<1	<1	<1	<1	<1	NA

NA - Not Analyzed

<1 - Indicates not detected at the indicated laboratory detection limit

Appen

Table A-1a

Summary of Shallow Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)														
		cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
CTM-6S	29-Mar-01	<1	<2	<1	<1	<1	<1	28	<1	<1	<1	<1	1.6	<1	<1	<1
CTM-6S	5-Apr-01	<1	<2	<1	<1	<1	<1	20	8.4	<1	<1	<1	1.1	<1	<1	2.4
CTM-6S	5-Jul-01	<2.5	<10	<1.3	<2.5	<1.3	<1.3	25	150	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	NA
CTM-7S	27-Mar-01	<1	<2	<1	<20	<1	<1	2.8	1.6	<1	<1	<1	<1	<1	<1	2.7
CTM-7S	5-Jul-01	<2.5	<10	<1.3	<2.5	<1.3	<1.3	4.5	130	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	NA
CTM-9S	8-May-01	<1	<4	1.5	<1	<1	1.8	4.8	22	<1	<1	<1	<1	<1	<1	5.6
CTM-9S	24-May-01	<1	<2	<1	<1	<1	<1	<1	2	<1	<1	<1	<1	<1	<1	<1
CTM-9S	26-Jun-01	<1	<2	<1	<1	<1	<1	3.8	13	<1	<1	<1	<1	<1	<1	NA
CTM-11S	10-Jul-01	<1	<4	<1	<1	9.8	<1	7.1	46	<1	<1	<1	2.3	<1	<1	NA
CTM-13S	28-Mar-01	<1	<2	1.5	<1	<1	<1	15	<1	<1	<1	<1	<1	<1	<1	4.2
CTM-13S	29-Mar-01	<1	<2	2	<1	<1	1.5	15	3	<1	<1	<1	<1	<1	<1	6.6
CTM-13S	24-May-01	<1	<2	<1	<1	<1	<1	14	2.4	<1	<1	<1	<1	<1	<1	1.5
CTM-13S	21-Jun-01	<1	<2	<1	<1	<1	<1	16	3	<1	<1	<1	<1	<1	<1	1.3
CTM-14S	27-Mar-01	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-14S	29-Mar-01	<1	<2	1.5	<1	<1	1.7	2.4	3.9	<1	<1	<1	<1	<1	<1	6.2
CTM-14S	22-Jun-01	<1	<2	<1	<1	<1	<1	<1	24	<1	<1	<1	<1	<1	<1	<1
CTM-15S	27-Mar-01	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-15S	29-Mar-01	<1	<2	<1	<1	<1	1	2.7	2.3	<1	<1	<1	<1	<1	<1	3.6
CTM-15S	22-Jun-01	<1	<2	<1	<1	<1	<1	<1	2.3	<1	<1	<1	<1	<1	<1	<1
CTM-16S	29-Mar-01	<1	<2	1.8	<1	<1	2.1	12	5.9	<1	<1	<1	<1	<1	<1	7.4
CTM-16S	27-Jun-01	<1	<2	<1	<1	<1	<1	14	5.6	<1	<1	<1	<1	<1	<1	NA
CTM-18S	26-Mar-01	<1	<2	<1	<1	<1	<1	2.8	<1	<1	<1	<1	<1	<1	<1	<1
CTM-18S	27-Mar-01	<1	<2	<1	<20	<1	1	5.1	2.2	<1	<1	<1	<1	<1	<1	3.6
CTM-18S	15-May-01	<1	<2	<1	<1	<1	<1	1.9	6	<1	<1	<1	<1	<1	<1	<1
CTM-18S	25-Jun-01	<1	<2	<1	<1	<1	<1	3.1	7.9	<1	<1	<1	<1	<1	<1	NA
CTM-19S	30-Apr-01	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-19S	15-May-01	<1	<2	<1	<1	<1	<1	1.2	4.3	<1	<1	<1	<1	<1	<1	<1
CTM-19S	21-Jun-01	<1	<2	<1	<1	<1	<1	<1	4.7	<1	<1	<1	<1	<1	<1	<1
CTM-20S	27-Mar-01	<1	<2	<1	<1	<1	<1	2.2	1.5	<1	<1	<1	<1	<1	<1	2.8
CTM-20S	21-Jun-01	<1	<2	<1	<1	<1	<1	<1	1.8	<1	<1	<1	<1	<1	<1	<1
CTM-21S	26-Mar-01	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-21S	5-Apr-01	<1	<2	<1	<1	<1	<1	2	1.8	<1	<1	<1	<1	<1	<1	2.7
CTM-21S	5-Jul-01	<25	<100	<13	<25	<13	<13	<25	1400	<25	<25	<25	<25	<25	<25	NA
CTM-28S	2-Apr-01	<1	<2	<1	<1	<1	<1	51	1.4	<1	<1	<1	<1	<1	<1	<1
CTM-28S	9-Apr-01	<1	<4	<1	<1	<1	<1	39	15	<1	<1	<1	<1	<1	<1	<1
CTM-28S	24-May-01	<1	<4	<1	<1	<1	<1	130	2.7	<1	<1	<1	<1	<1	<1	<1
CTM-28S	28-Jun-01	<1	<4	<1	<1	<1	<1	110	130	<1	<1	<1	<1	<1	<1	NA
CTM-29S	29-Mar-01	<1	<2	<1	<1	<1	<1	1.5	<1	<1	<1	<1	<1	<1	<1	<1
CTM-29S	9-Apr-01	<1	<2	<1	<1	<1	<1	3.7	26	<1	<1	<1	<1	<1	<1	1.1
CTM-29S	12-Jul-01	<2.5	<10	<1.3	<2.5	<1.3	<1.3	<2.5	240	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	NA
CTM-31S	15-May-01	<1	<2	<1	<1	<1	<1	18	5.1	<1	<1	<1	<1	<1	<1	<1
CTM-31S	24-May-01	<1	<2	<1	<1	<1	<1	22	1.9	<1	<1	<1	<1	<1	<1	<1
CTM-31S	28-Jun-01	<1	<2	<1	<1	<1	<1	21	4.8	<1	<1	<1	<1	<1	<1	NA
CTM-37S	28-Mar-01	<1	<2	<1	<1	<1	<1	2.8	<1	<1	<1	<1	<1	<1	<1	<1
CTM-37S	5-Apr-01	<1	<2	<1	<1	<1	<1	3.8	1.2	<1	<1	<1	<1	<1	<1	1.9
CTM-37S	12-Jul-01	<2.5	<10	<1.3	<2.5	<1.3	<1.3	<2.5	250	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	NA

NA - Not Analyzed

<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A
Table A-1a
Summary of Shallow Groundwater Monitoring Well Data Considered for Use In Risk Analysis

		Developed Shallow Groundwater Results (ug/L)														
Well	Date	cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	ETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
CTM-39S	6-Jun-01	<1	<2	<1	<1	<1	<1	13	<1	<1	<1	<1	<1	<1	<1	<1
CTM-39S	7-Jun-01	<1	<2	<1	<1	<1	<1	12	7.1	<1	<1	<1	<1	<1	<1	1.2
CTM-39S	25-Jun-01	<1	<2	<1	<1	<1	<1	13	6.8	<1	<1	<1	<1	<1	<1	NA
CTM-40S	6-Jun-01	<1	<2	<1	<1	<1	<1	1.5	4.8	<1	<1	<1	<1	<1	<1	<1
CTM-40S	7-Jun-01	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-40S	12-Jul-01	<2.5	<10	<1.3	<2.5	<1.3	<1.3	<2.5	220	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	NA
CTM-41S	12-Jun-01	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-41S	14-Jun-01	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-41S	10-Jul-01	<1	<4	<1	<1	<1	<1	<1	55	<1	<1	<1	<1	<1	<1	NA

NA - Not Analyzed
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Appendix A
Table A-1b
Summary of Grab Shallow Groundwater Data Considered for Use in Risk Analysis

			Grab Shallow Groundwater Results (ug/L)																			
Well	Depth	Date	1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene	cis-1,3-Dichloropropene
CTM-1S	37	27-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-2S	42	29-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2.3	<2	<1	<1
CTM-3S	44	27-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	3	<1
CTM-5S	47	28-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.4	<2	<1	<1
CTM-6S	35	20-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-7S	30	8-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-9S	52	3-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-11S	40	20-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	2.4	<1
CTM-13S	39	23-Mar-01	2.5	<1	<1	11	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-14S	7	21-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<4	<1	<1
CTM-15S	60	26-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-16S	26	15-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-19S	22	29-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-20S	22	15-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-21S	26	16-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-28S	32	30-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<4	<1	<1
CTM-29S	25	22-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-31S	41	4-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.1	<2	<1	<1
CTM-37S	30	21-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-39S	35	1-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1	<1
CTM-40S	126.5	5-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2.9	<2	<1	<1
CTM-41S	38	4-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.1	<2	<1	<1

<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A
Table A-1b
Summary of Grab Shallow Groundwater Data Considered for Use in Risk Analysis

Well	Depth	Date	Grab Shallow Groundwater Results (ug/L)													
			DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
CTM-1S	37	27-Mar-01	<2	<1	<1	<1	<1	5.6	<1	<1	<1	<1	<1	<1	<1	<1
CTM-2S	42	29-Mar-01	<2	<1	<1	<1	<1	9.9	<1	<1	<1	<1	<1	<1	<1	<1
CTM-3S	44	27-Mar-01	<2	<1	<1	<1	1.4	1.5	<1	<1	<1	<1	<1	<1	<1	<1
CTM-5S	47	28-Mar-01	<2	<1	<1	<1	<1	7.4	<1	<1	<1	<1	<1	<1	<1	<1
CTM-6S	35	20-Mar-01	<2	<1	<1	<1	<1	36	<1	<1	<1	<1	1.6	<1	<1	<1
CTM-7S	30	8-Mar-01	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-9S	52	3-May-01	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-11S	40	20-Mar-01	<2	<1	<1	<1	<1	3.8	<1	<1	<1	<1	<1	<1	<1	<1
CTM-13S	39	23-Mar-01	<2	<1	<1	<1	<1	34	<1	<1	<1	<1	<1	<1	<1	3.6
CTM-14S	7	21-Mar-01	<4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-15S	60	26-Mar-01	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-16S	26	15-Mar-01	<2	<1	<1	<1	<1	9.9	<1	<1	<1	<1	<1	<1	<1	<1
CTM-19S	22	29-Apr-01	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-20S	22	15-Mar-01	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-21S	26	16-Mar-01	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-28S	32	30-Mar-01	<4	<1	<1	<1	<1	60	<1	<1	<1	<1	<1	<1	<1	<1
CTM-29S	25	22-Mar-01	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-31S	41	4-May-01	<2	<1	<1	<1	<1	15	<1	<1	<1	<1	<1	<1	<1	<1
CTM-37S	30	21-Mar-01	<2	<1	<1	<1	<1	1.6	<1	<1	<1	<1	<1	<1	<1	<1
CTM-39S	35	1-Jun-01	<2	<1	<1	<1	<1	11	<1	<1	<1	<1	<1	<1	<1	<1
CTM-40S	126.5	5-Jun-01	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-41S	38	4-Jun-01	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

<1 - Indicates not detected at the indicated laboratory detection limit

Appendix
Table A-1c
Summary of Shallow Groundwater Monitoring Well Data Averages for Use in Calculating Exposure Concentrations

	Developed Shallow Groundwater Results (ug/L)																		
Well	1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene
3	1.2	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.9	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
4	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	2.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
18a	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
19	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
22	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	3.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
22a	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
23	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
25a	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	11.3	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
25b	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
25c	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
25d	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	6312	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
25e	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
25f	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
25g	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
40	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
65	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
66	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
67	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.8	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
68	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
69	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
71	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
73	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
74	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
75	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
76	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
76a	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	10	2.5
79f	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
79h	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
79k	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
97	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	7.1	0.5	0.5	0.5	0.5	NA	0.5	8.35	0.5	NA
98	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	8.3	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
99	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
101	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
103	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
104	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
106	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	3.875	0.5	NA
108	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
111	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
111a	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
114	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	30	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
115	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	48	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
118	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	62.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
118a	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	3.7	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA

NA - Not Analyzed
Non-detects shown as half the detection limit

Appendix A
Table A-1c
Summary of Shallow Groundwater Monitoring Well Data Averages for Use in Calculating Exposure Concentrations

Well	Developed Shallow Groundwater Results (ug/L)																		
	1,1,1-TRICHLOROETHANE	1,1,22-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene
118b	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	26.2	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
118c	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	8	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
118d	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	14.4	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
118e	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
118f	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
119	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
119a	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	621.1	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
119b	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	5.6	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
119c	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
122a	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
122b	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
122c	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
126a	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
126b	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	142.25	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133a	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133b	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133c	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133d	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133e	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	3	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133f	2.14	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	37.74	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133g	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133h	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	1262.8	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133i	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	75.75	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133j	3.58333333	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.583333	0.5	0.5	0.5	0.5	NA	0.5	0.766667	0.5	NA
133k	7.46	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.9	0.5	0.5	0.5	0.5	NA	0.5	1.02	0.5	NA
133l	5.825	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133m	1.46666667	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133n	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
133o	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	0.5	0.5	NA
CTM-1S	0.875	0.875	0.875	0.875	0.875	0.875	0.875	0.875	0.875	0.575	0.875	0.875	0.875	0.875	0.875	0.875	0.875	3	0.875
CTM-2S	0.875	0.875	0.875	0.875	0.875	0.875	0.875	0.875	0.875	0.575	0.875	0.875	0.875	0.875	0.875	0.875	2.8	3	0.875
CTM-3S	0.55	0.55	0I55	0.55	0.55	0.55	0.55	0.55	0.55	0.5	0.55	0.55	0.55	0.55	0.55	0.55	0.55	1.5	0.55
CTM-5S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.6	1.5	0.5
CTM-6S	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.55	0.75	0.75	0.75	0.75	0.75	0.75	0.75	2.333333	0.75
CTM-7S	0.875	0.875	0.875	0.875	0.875	5.625	0.875	0.875	5.625	0.575	0.875	0.875	0.875	0.875	0.875	0.875	0.875	3	0.875
CTM-9S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.1	1.333333	0.5
CTM-11S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2	3.1
CTM-13S	9.675	0.5	0.5	8.275	0.5	0.5	0.5	0.5	0.5	2.775	0.5	0.5	0.5	0.5	0.5	0.5	0.825	1	0.5
CTM-14S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5
CTM-15S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5
CTM-16S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5
CTM-18S	0.5	0.5	0.5	0.5	0.5	2.875	0.5	0.5	2.875	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5
CTM-19S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5

NA - Not Analyzed
Non-detects shown as half the detection limit

Appen

Table A-1c

Summary of Shallow Groundwater Monitoring Well Data Averages for Use in Calculating Exposure Concentrations

Well	Developed Shallow Groundwater Results (ug/L)																		
	1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene
CTM-20S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5
CTM-21S	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	2.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	17.33333	4.5
CTM-28S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.75	0.5
CTM-29S	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.55	0.75	0.75	0.75	0.75	0.75	0.75	0.75	2.333333	0.75
CTM-31S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2	1	0.5
CTM-37S	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.55	0.75	0.75	0.75	0.75	0.75	0.75	1.216667	2.333333	0.75
CTM-39S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5
CTM-40S	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.55	0.75	0.75	0.75	0.75	0.75	0.75	0.916667	2.333333	0.75
CTM-41S	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.9	1.333333	0.5

NA - Not Analyzed

Non-detects shown as half the detection limit

Appendix A
Table A-1c
Summary of Shallow Groundwater Monitoring Well Data Averages for Use In Calculating Exposure Concentrations

Well	Developed Shallow Groundwater Results (ug/L)															
	1,1,1-TRICHLOROETHANE	cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
3	1.2	NA	0.5	21.45	0.5	0.5	NA	0.5	340.7	NA	NA	0.5	0.5	0.5	0.5	689.6
4	0.5	NA	0.5	0.5	0.5	0.5	NA	3.3	42.2	NA	NA	0.5	1.6	0.5	0.5	11.2
5	0.5	NA	0.5	2.2	0.5	0.5	NA	2.3	2.3	NA	NA	0.5	0.5	25.3	0.5	7.9
18a	0.5	NA	0.5	1.2	0.5	0.5	NA	113.25	29.9	NA	NA	0.5	0.5	0.5	0.5	0.85
19	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
22	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	2.3
22a	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	8.6	NA	NA	0.5	0.5	0.5	0.5	0.5
23	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	48.5	NA	NA	0.5	0.5	0.5	0.5	0.5
25a	0.5	NA	0.5	25.1	0.5	3.7	NA	0.5	135.3	NA	NA	0.5	2.9	0.5	0.5	229.2
25b	0.5	NA	0.5	10.4	0.5	4.3	NA	0.5	180.9	NA	NA	0.5	0.5	0.5	0.5	39.7
25c	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	48.4	NA	NA	0.5	0.5	0.5	0.5	0.5
25d	0.5	NA	0.5	16.3	0.5	35.9	NA	0.5	79.2	NA	NA	0.5	0.5	0.5	0.5	123.3
25e	0.5	NA	0.5	1.6	0.5	0.5	NA	1.4	8.8	NA	NA	0.5	0.5	0.5	0.5	2.7
25f	0.5	NA	0.5	0.5	0.5	8758	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
25g	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	37.8	NA	NA	0.5	0.5	0.5	0.5	0.5
40	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
65	0.5	NA	0.5	0.5	0.5	8.4	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
66	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
67	0.5	NA	0.5	7.933333	0.5	0.5	NA	9.025	54	NA	NA	0.5	0.95	0.5	0.5	20.93333
68	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
69	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
71	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
73	0.5	NA	0.5	2.675	0.5	0.5	NA	11.275	19.55	NA	NA	0.5	0.5	0.5	0.5	6.7
74	0.5	NA	0.5	23.4	0.5	0.5	NA	28.64	97.775	NA	NA	0.5	0.9	0.5	0.5	50.425
75	0.5	NA	0.5	3.466667	0.5	0.5	NA	3.1	17.4	NA	NA	0.5	0.5	0.5	0.5	10.06667
76	0.5	NA	0.5	7.8	0.5	0.5	NA	0.5	36.3	NA	NA	0.5	0.5	0.5	0.5	20.3
76a	2.5	2.5	10	1.25	2.5	1.25	1.25	2.5	310	2.5	2.5	2.5	2.5	2.5	2.5	NA
79f	0.5	NA	0.5	4.5	0.5	0.5	NA	3.3	24.5	NA	NA	0.5	0.5	0.5	0.5	10.6
79h	0.5	NA	0.5	3.2	0.5	0.5	NA	2.3	14.5	NA	NA	0.5	0.5	0.5	0.5	7.5
79k	0.5	NA	0.5	3.2	0.5	0.5	NA	2.3	15.7	NA	NA	0.5	0.5	0.5	0.5	7.8
97	0.5	NA	0.5	1.55	0.5	0.5	NA	2	18.05	NA	NA	0.5	0.5	0.5	0.5	0.5
98	0.5	NA	0.5	0.5	0.5	0.5	NA	3.05	31.45	NA	NA	0.5	0.5	0.5	0.5	1.1
99	0.5	NA	0.5	0.5	0.5	0.5	NA	1.95	15.65	NA	NA	0.5	0.5	0.5	0.5	0.5
101	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
103	0.5	NA	0.5	1.05	0.5	0.5	NA	2.65	16.5	NA	NA	0.5	0.5	0.5	0.5	2.45
104	0.5	NA	0.5	0.766667	0.5	0.5	NA	9.7	30.76667	NA	NA	0.5	0.5	0.5	0.5	1.566667
106	0.5	NA	0.5	1.425	0.5	0.5	NA	3.425	22.85	NA	NA	0.5	0.5	0.5	0.5	3.75
108	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
111	NA	NA	NA	NA	NA	NA	NA	2.4	NA	NA	NA	NA	NA	NA	NA	NA
111a	NA	NA	NA	NA	NA	NA	NA	12.96667	NA	NA	NA	NA	NA	NA	NA	NA
114	0.5	NA	0.5	392	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	751
115	0.5	NA	0.5	1049	0.5	142	NA	0.5	1645	NA	NA	0.5	0.5	0.5	0.5	38013
118	0.5	NA	0.5	670	0.5	28.4	NA	0.5	542.8	NA	NA	0.5	0.5	0.5	0.5	1114.7
118a	0.5	NA	0.5	138.7	0.5	0.5	NA	0.5	281.8	NA	NA	0.5	0.5	0.5	0.5	0.5

NA - Not Analyzed
Non-detects shown as half the detection limit

Appen
Table A-1c
Summary of Shallow Groundwater Monitoring Well Data Averages for Use in Calculating Exposure Concentrations

Well	Developed Shallow Groundwater Results (ug/L)															
	1,1,1-TRICHLOROETHANE	cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
118b	0.5	NA	0.5	807.5	0.5	0.5	NA	0.5	207.8	NA	NA	0.5	0.5	0.5	0.5	506.2
118c	0.5	NA	0.5	731.9	0.5	0.5	NA	0.5	268.4	NA	NA	0.5	0.5	0.5	0.5	865.3
118d	0.5	NA	0.5	629.9	0.5	0.5	NA	0.5	66.8	NA	NA	0.5	0.5	0.5	0.5	246.5
118e	0.5	NA	0.5	63.5	0.5	0.5	NA	0.5	50.6	NA	NA	0.5	0.5	0.5	0.5	69.7
118f	0.5	NA	0.5	31.1	0.5	0.5	NA	0.5	19.8	NA	NA	0.5	0.5	0.5	0.5	34.9
119	0.5	NA	0.5	48.8	0.5	0.5	NA	0.5	39.7	NA	NA	0.5	0.5	0.5	0.5	55.9
119a	0.5	NA	0.5	67.1	0.5	139.9	NA	0.5	131	NA	NA	0.5	0.5	0.5	0.5	273.1
119b	0.5	NA	0.5	11.2	0.5	0.5	NA	0.5	8.7	NA	NA	0.5	0.5	0.5	0.5	14.9
119c	0.5	NA	0.5	16.7	0.5	0.5	NA	0.5	15.1	NA	NA	0.5	0.5	0.5	0.5	24.3
122a	0.5	NA	0.5	2.2	0.5	0.5	NA	4.05	5.65	NA	NA	0.5	0.5	0.5	0.5	6
122b	0.5	NA	0.5	1.35	0.5	0.5	NA	3.8	27.15	NA	NA	0.5	0.5	0.5	0.5	3.05
122c	0.5	NA	0.5	0.5	0.5	0.5	NA	1.4	3.2	NA	NA	0.5	0.5	0.5	0.5	0.5
126a	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	6.4	NA	NA	0.5	0.5	0.5	0.5	0.5
126b	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	9.5	NA	NA	0.5	0.5	0.5	0.5	0.5
133	0.5	NA	0.5	1.45	0.5	5.45	NA	17.85	237.4	NA	NA	0.5	0.5	0.5	0.5	213.55
133a	0.5	NA	0.5	0.5	0.5	0.5	NA	11.7	0.5	NA	NA	0.5	2	0.5	0.5	0.5
133b	0.5	NA	0.5	0.5	0.5	0.5	NA	5.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
133c	0.5	NA	0.5	0.5	0.5	0.5	NA	20	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
133d	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	810
133e	0.5	NA	0.5	0.5	0.5	0.5	NA	16.3	0.5	NA	NA	0.5	2.2	0.5	0.5	0.5
133f	2.14	NA	0.5	28.72	0.5	40.74	NA	111.72	26.66	NA	NA	0.5	7.56	0.5	0.5	52.06
133g	0.5	NA	0.5	0.5	0.5	0.5	NA	36.35	6.25	NA	NA	0.5	0.5	0.5	0.5	0.5
133h	0.5	NA	0.5	83.6	0.5	25	NA	233.6	1451.15	NA	NA	0.5	11.93333	0.5	0.5	1650.35
133i	0.5	NA	0.5	294.3	0.5	0.5	NA	1.3	479.95	NA	NA	0.5	0.5	0.5	0.5	200.8
133j	3.58333333	NA	0.5	4.516667	0.5	1.916667	NA	495.8	17.9	NA	NA	0.5	2.25	0.5	0.5	7.983333
133k	7.46	NA	0.5	1.84	0.5	0.5	NA	154.92	21.78	NA	NA	0.5	0.82	0.5	0.5	6.98
133l	5.825	NA	2.025	4.975	0.5	1.175	NA	91.25	23.8	NA	NA	0.5	0.975	0.5	0.5	16.5
133m	1.46666667	NA	0.5	0.8	0.5	3.5	NA	30.8	2.866667	NA	NA	0.5	1.233333	0.5	0.5	1.133333
133n	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
133o	0.5	NA	0.5	0.5	0.5	0.5	NA	0.5	0.5	NA	NA	0.5	0.5	0.5	0.5	0.5
CTM-1S	0.875	0.875	3	0.575	0.875	0.575	0.575	1.225	130.25	0.875	0.875	0.875	0.875	0.875	0.875	0.5
CTM-2S	0.875	0.875	3	0.575	0.875	0.575	0.575	8.7	161	0.875	0.875	0.875	0.875	0.875	0.875	1.1
CTM-3S	0.55	0.55	1.5	0.5	0.55	0.5	0.5	7.866667	72.16667	0.55	0.55	0.55	0.55	0.55	0.55	1.6
CTM-5S	0.5	0.5	1.5	0.5	0.5	0.5	0.5	19	39	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CTM-6S	0.75	0.75	2.333333	0.55	0.75	0.55	0.55	24.33333	52.96667	0.75	0.75	0.75	1.316667	0.75	0.75	1.45
CTM-7S	0.875	0.875	3	0.575	5.625	0.575	0.575	3.65	65.8	0.875	0.875	0.875	0.875	0.875	0.875	2.7
CTM-9S	0.5	0.5	1.333333	0.833333	0.5	0.5	0.933333	3.033333	12.33333	0.5	0.5	0.5	0.5	0.5	0.5	3.05
CTM-11S	0.5	0.5	2	0.5	0.5	9.8	0.5	7.1	46	0.5	0.5	0.5	2.3	0.5	0.5	NA
CTM-13S	9.675	0.5	1	1.125	0.5	0.5	0.75	15	2.225	0.5	0.5	0.5	0.5	0.5	0.5	3.4
CTM-14S	0.5	0.5	1	0.833333	0.5	0.5	0.9	1.133333	9.466667	0.5	0.5	0.5	0.5	0.5	0.5	2.4
CTM-15S	0.5	0.5	1	0.5	0.5	0.5	0.666667	1.233333	1.7	0.5	0.5	0.5	0.5	0.5	0.5	1.533333
CTM-16S	0.5	0.5	1	1.15	0.5	0.5	1.3	13	5.75	0.5	0.5	0.5	0.5	0.5	0.5	7.4
CTM-18S	0.5	0.5	1	0.5	2.875	0.5	0.625	3.225	4.15	0.5	0.5	0.5	0.5	0.5	0.5	1.533333
CTM-19S	0.5	0.5	1	0.5	0.5	0.5	0.5	0.733333	3.166667	0.5	0.5	0.5	0.5	0.5	0.5	0.5

NA - Not Analyzed
Non-detects shown as half the detection limit

Appendix A
Table A-1c
Summary of Shallow Groundwater Monitoring Well Data Averages for Use in Calculating Exposure Concentrations

Well	Developed Shallow Groundwater Results (ug/L)															
	1,1,1-TRICHLOROETHANE	cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
CTM-20S	0.5	0.5	1	0.5	0.5	0.5	0.5	1.35	1.65	0.5	0.5	0.5	0.5	0.5	0.5	1.65
CTM-21S	4.5	4.5	17.33333	2.5	4.5	2.5	2.5	5	467.4333	4.5	4.5	4.5	4.5	4.5	4.5	1.6
CTM-28S	0.5	0.5	1.75	0.5	0.5	0.5	0.5	82.5	37.275	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CTM-29S	0.75	0.75	2.333333	0.55	0.75	0.55	0.55	2.15	88.83333	0.75	0.75	0.75	0.75	0.75	0.75	0.8
CTM-31S	0.5	0.5	1	0.5	0.5	0.5	0.5	20.33333	3.933333	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CTM-37S	0.75	0.75	2.333333	0.55	0.75	0.55	0.55	2.616667	83.9	0.75	0.75	0.75	0.75	0.75	0.75	1.2
CTM-39S	0.5	0.5	1	0.5	0.5	0.5	0.5	12.66667	4.8	0.5	0.5	0.5	0.5	0.5	0.5	0.85
CTM-40S	0.75	0.75	2.333333	0.55	0.75	0.55	0.55	1.083333	75.1	0.75	0.75	0.75	0.75	0.75	0.75	0.5
CTM-41S	0.5	0.5	1.333333	0.5	0.5	0.5	0.5	0.5	18.66667	0.5	0.5	0.5	0.5	0.5	0.5	0.5

NA - Not Analyzed
Non-detects shown as half the detection limit

Appen

Table A-2a

Summary of Deep Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)																		
		1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene
3b	4-Feb-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
56b	20-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
59	25-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
60	20-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
60a	20-Jul-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.2	NA	NA
60a	19-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.3	NA	NA
60a	21-Sep-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.3	NA	NA
60a	4-Nov-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.2	NA	NA
60a	22-Nov-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.3	NA	NA
60a	20-Jan-00	2.2	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
60a	24-Jan-00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
60a	1-Mar-00	NA	NA	NA	NA	NA	NA	NA	NA	NA	5	NA	NA	NA	NA	NA	NA	NA	NA	NA
62	25-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
63	11-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.9	NA	NA
64	11-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
64a	11-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.4	NA	NA
64a	1-Sep-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.4	NA	NA
64a	22-Sep-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.3	NA	NA
64a	19-Nov-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.3	NA	NA
64a	20-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
64c	20-Jul-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.4	NA	NA
64c	19-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.4	NA	NA
64c	21-Sep-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.4	NA	NA
64c	26-Oct-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.3	NA	NA
64c	24-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
64d	11-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
64f	25-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
64g	19-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.3	NA	NA
64g	21-Sep-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
64g	26-Oct-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.3	NA	NA
64g	16-Nov-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.2	NA	NA
64g	20-Jan-00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
64g	24-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
64g	1-Mar-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
64h	11-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
64h	27-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
64i	20-Jul-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
64i	19-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
64i	21-Sep-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
64i	26-Oct-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	NA	NA	NA	NA
64i	24-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
64j	11-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
64j	27-Jan-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
64k	18-Feb-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
77	30-Nov-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
77	30-Aug-00	1.8	<1	<1	<1	NA	<1	<1	<1	<1	1.2	<1	<1	<1	<1	NA	<1	<1	<1	NA

NA - Not Analyzed

<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A
Table A-2a
Summary of Deep Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)																		
		1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene
82	21-Mar-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
82	12-May-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
82	21-Sep-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
84	12-May-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
86	6-Mar-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
102	26-Aug-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
102	26-May-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
105	8-Sep-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
105	18-Feb-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
105	26-May-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
107	12-Aug-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
107	18-Feb-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
107	16-Jun-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
109	16-Aug-99	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
109	19-Jun-00	<1	<1	<1	<1	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1	NA
CTM-4D	17-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	5.2	<2	<1
CTM-4D	19-Apr-01	<1	<1	<1	<1	<1	<20	<1	<1	<20	<1	<1	<1	<1	<1	<1	<1	5.3	<2	<1
CTM-4D	28-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	6.3	<2	<1
CTM-8D	26-Mar-01	<1	<1	<1	<1	<1	<20	<1	<1	<20	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-8D	5-Jul-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1.3	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<10	<2.5
CTM-10D	2-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-10D	10-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-10D	26-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-12D	11-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<4	<1
CTM-12D	10-Jul-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-17D	9-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-17D	10-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-17D	11-Jul-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<4	<1
CTM-22D	26-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-22D	3-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-22D	24-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.1	<2	<1
CTM-22D	11-Jul-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1.3	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<10	<2.5
CTM-23D	5-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-23D	21-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-23D	3-Jul-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-25D	13-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-25D	19-Apr-01	<1	<1	<1	<1	<1	<20	<1	<1	<20	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-25D	3-Jul-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<4	<1
CTM-27D	6-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-27D	10-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-27D	22-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-30D	13-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-30D	19-Apr-01	<1	<1	<1	<1	<1	<20	<1	<1	<20	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-30D	5-Jul-01	<1	<1	1.2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-33D	3-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1
CTM-33D	27-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	<1

NA - Not Analyzed

<1 - Indicates not detected at the indicated laboratory detection limit

Appe

Table A-2a

Summary of Deep Groundwater Monitoring Well Data Considered for Use In Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)																		
		1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene
CTM-37D	1-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	4	<1	<1
CTM-37D	7-Jun-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	3.9	<2	<1
CTM-37D	11-Jul-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1.3	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	3.4	<10	<2.5
CTM-38D	6-Jun-01	2.3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	3.1
CTM-38D	25-Jun-01	2.2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<2	3.6
SPA	11-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	2.9	NA	<0.2	<0.2	NA	NA	13.5	NA	NA
SPB	12-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
SPD	12-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.6	NA	NA
SPE	12-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
SPG	11-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
SPH	20-Jul-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
SPH	19-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.4	NA	NA
SPH	21-Sep-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
SPH	4-Nov-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.5	NA	NA
SPH	16-Nov-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	0.5	NA	NA
SPJ	9-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA
SPK	9-Aug-99	<0.2	NA	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.2	<0.2	NA	NA	<0.2	NA	NA

NA - Not Analyzed

<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A
Table A-2a
Summary of Deep Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)														
		cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	rans-1,2-Dichloroethene	rans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
3b	4-Feb-00	NA	<1	2.5	<1	<1	NA	<1	5.7	NA	NA	<1	<1	<1	<1	5.1
56b	20-Sep-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
59	25-Jan-00	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
60	20-Jan-00	NA	<1	<1	<1	<1	NA	16.1	<1	NA	NA	<1	<1	<1	<1	<1
60a	20-Jul-99	NA	<0.2	<0.2	NA	NA	NA	16.2	<0.2	NA	NA	<0.2	1.1	NA	<0.2	<0.2
60a	19-Aug-99	NA	<0.2	<0.2	NA	NA	NA	17.5	<0.2	NA	NA	<0.2	1.3	NA	<0.2	<0.2
60a	21-Sep-99	NA	<0.2	<0.2	NA	NA	NA	15.7	<0.2	NA	NA	<0.2	1.2	NA	<0.2	<0.2
60a	4-Nov-99	NA	<0.2	<0.2	NA	NA	NA	16.3	<0.2	NA	NA	<0.2	1.2	NA	<0.2	<0.2
60a	22-Nov-99	NA	<0.2	<0.2	NA	NA	NA	16.1	<0.2	NA	NA	<0.2	1.2	NA	<0.2	<0.2
60a	20-Jan-00	NA	<1	<1	<1	<1	NA	1.8	<1	NA	NA	<1	<1	<1	<1	<1
60a	24-Jan-00	NA	NA	NA	NA	NA	NA	14.1	NA	NA	NA	NA	NA	NA	NA	NA
60a	1-Mar-00	NA	NA	5.4	NA	NA	NA	14.9	1.7	NA	NA	NA	1.2	NA	NA	3.2
62	25-Jan-00	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
63	11-Aug-99	NA	<0.2	<0.2	NA	NA	NA	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
64	11-Aug-99	NA	<0.2	<0.2	NA	NA	NA	0.9	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
64a	11-Aug-99	NA	<0.2	<0.2	NA	NA	NA	2.4	<0.2	NA	NA	<0.2	3	NA	<0.2	<0.2
64a	1-Sep-99	NA	<0.2	<0.2	NA	NA	NA	2.3	<0.2	NA	NA	<0.2	2.6	NA	<0.2	<0.2
64a	22-Sep-99	NA	<0.2	<0.2	NA	NA	NA	2.1	<0.2	NA	NA	<0.2	2.4	NA	<0.2	<0.2
64a	19-Nov-99	NA	<0.2	<0.2	NA	NA	NA	1.9	<0.2	NA	NA	<0.2	2.4	NA	<0.2	<0.2
64a	20-Jan-00	NA	<1	<1	<1	<1	NA	15.4	<1	NA	NA	<1	<1	<1	<1	<1
64c	20-Jul-99	NA	<0.2	<0.2	NA	NA	NA	8	<0.2	NA	NA	<0.2	1.3	NA	<0.2	<0.2
64c	19-Aug-99	NA	<0.2	<0.2	NA	NA	NA	8	<0.2	NA	NA	<0.2	1.3	NA	<0.2	<0.2
64c	21-Sep-99	NA	<0.2	<0.2	NA	NA	NA	7.5	<0.2	NA	NA	<0.2	1.2	NA	<0.2	<0.2
64c	26-Oct-99	NA	<0.2	<0.2	NA	NA	NA	7.2	<0.2	NA	NA	<0.2	1.1	NA	<0.2	<0.2
64c	24-Jan-00	NA	<1	<1	<1	<1	NA	6.4	<1	NA	NA	<1	<1	<1	<1	<1
64d	11-Aug-99	NA	<0.2	<0.2	NA	NA	NA	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
64f	25-Jan-00	NA	<1	<1	<1	<1	NA	2.7	<1	NA	NA	<1	<1	<1	<1	<1
64g	19-Aug-99	NA	<0.2	<0.2	NA	NA	NA	16.4	<0.2	NA	NA	<0.2	2.1	NA	<0.2	<0.2
64g	21-Sep-99	NA	<0.2	<0.2	NA	NA	NA	14.5	<0.2	NA	NA	<0.2	1.5	NA	<0.2	<0.2
64g	26-Oct-99	NA	<0.2	<0.2	NA	NA	NA	14.9	<0.2	NA	NA	<0.2	1.5	NA	<0.2	<0.2
64g	16-Nov-99	NA	<0.2	<0.2	NA	NA	NA	13.3	<0.2	NA	NA	<0.2	1.3	NA	<0.2	<0.2
64g	20-Jan-00	NA	NA	NA	NA	NA	NA	1.4	NA	NA	NA	NA	2.1	NA	NA	NA
64g	24-Jan-00	NA	<1	<1	<1	<1	NA	14.1	<1	NA	NA	<1	NA	<1	<1	<1
64g	1-Mar-00	NA	<1	<1	<1	<1	NA	1.4	<1	NA	NA	<1	2	<1	<1	<1
64h	11-Aug-99	NA	<0.2	<0.2	NA	NA	NA	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
64h	27-Jan-00	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
64i	20-Jul-99	NA	<0.2	<0.2	NA	NA	NA	8.5	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
64i	19-Aug-99	NA	<0.2	<0.2	NA	NA	NA	8.5	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
64i	21-Sep-99	NA	<0.2	<0.2	NA	NA	NA	8.3	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
64i	26-Oct-99	NA	<0.2	<0.2	NA	NA	NA	8.2	<0.2	NA	NA	NA	<0.2	NA	<0.2	<0.2
64i	24-Jan-00	NA	<1	<1	<1	<1	NA	8.4	<1	NA	NA	<1	<1	<1	<1	<1
64j	11-Aug-99	NA	<0.2	<0.2	NA	NA	NA	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
64j	27-Jan-00	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
64k	18-Feb-00	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
77	30-Nov-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
77	30-Aug-00	NA	<1	9.1	<1	<1	NA	2.2	23.1	NA	NA	<1	<1	<1	<1	15.4

NA - Not Analyzed
<1 - Indicates not detected at the indicated laboratory detection limit

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Table A-2a

Summary of Deep Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)														
		cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	ETRACHLOROETHENE (PCE)	TOLUENE	rans-1,2-Dichloroethene	rans-1,3-Dichloropropene	TRIBOMOMETHANE	RICHLOROETHYLENE	RICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
82	21-Mar-00	NA	<1	<1	<1	<1	NA	3.4	4.5	NA	NA	<1	<1	<1	<1	<1
82	12-May-00	NA	<1	<1	<1	<1	NA	2.6	2.1	NA	NA	<1	<1	<1	<1	<1
82	21-Sep-00	NA	<1	<1	<1	<1	NA	4.7	<1	NA	NA	<1	<1	<1	<1	<1
84	12-May-00	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
86	6-Mar-00	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
102	26-Aug-99	NA	<1	<1	<1	<1	NA	<1	<1	NA	NA	<1	<1	<1	<1	<1
102	26-May-00	NA	<1	<1	<1	<1	NA	1.3	5.8	NA	NA	<1	<1	<1	<1	2
105	8-Sep-99	NA	<1	<1	<1	<1	NA	22.1	<1	NA	NA	<1	<1	<1	<1	<1
105	18-Feb-00	NA	<1	<1	<1	<1	NA	22.4	1.2	NA	NA	<1	<1	<1	<1	<1
105	26-May-00	NA	<1	<1	<1	<1	NA	19.8	14.9	NA	NA	<1	<1	<1	<1	1.9
107	12-Aug-99	NA	<1	<1	<1	<1	NA	57.2	<1	NA	NA	<1	5.9	<1	<1	<1
107	18-Feb-00	NA	<1	<1	<1	<1	NA	29.5	12.3	NA	NA	<1	4.1	<1	<1	<1
107	16-Jun-00	NA	<1	<1	<1	<1	NA	23.3	5.8	NA	NA	<1	3.3	<1	<1	1.3
109	16-Aug-99	NA	<1	<1	<1	<1	NA	1.8	<1	NA	NA	<1	<1	<1	<1	<1
109	19-Jun-00	NA	<1	<1	<1	<1	NA	2	1.9	NA	NA	<1	<1	<1	<1	2.6
CTM-4D	17-Apr-01	<1	<2	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	19-Apr-01	<1	<2	<1	<20	<1	<1	1.4	6	<1	<1	<1	<1	<1	<1	<1
CTM-4D	28-Jun-01	<1	<2	<1	<1	<1	<1	1.4	4.3	<1	<1	<1	<1	<1	<1	NA
CTM-8D	26-Mar-01	<1	<2	<1	<20	<1	<1	10	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	5-Jul-01	<2.5	<10	<1.3	<2.5	<1.3	<1.3	40	210	<2.5	<2.5	<2.5	2.6	<2.5	<2.5	NA
CTM-10D	2-May-01	<1	<2	<1	<1	<1	<1	41	1.8	<1	<1	<1	1.8	<1	<1	<1
CTM-10D	10-May-01	<1	<2	<1	<1	<1	<1	29	<1	<1	<1	<1	1.9	<1	<1	<1
CTM-10D	26-Jun-01	<1	<2	<1	<1	<1	<1	41	3.1	<1	<1	<1	2	<1	<1	NA
CTM-12D	11-May-01	<1	<4	<1	<1	<1	<1	1.2	1.2	<1	<1	<1	<1	<1	<1	<1
CTM-12D	10-Jul-01	<1	<2	<1	<1	<1	<1	1.4	47	<1	<1	<1	<1	<1	<1	NA
CTM-17D	9-Apr-01	<1	<2	<1	<1	<1	<1	18	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	10-Apr-01	<1	<2	<1	<1	<1	<1	15	8.3	<1	<1	<1	<1	<1	<1	1.4
CTM-17D	11-Jul-01	<1	<4	<1	<1	<1	<1	4.2	63	<1	<1	<1	<1	<1	<1	NA
CTM-22D	26-Apr-01	<1	<2	<1	<1	<1	<1	21	2.2	<1	<1	<1	<1	<1	<1	<1
CTM-22D	3-May-01	<1	<2	<1	<1	<1	<1	30	4.5	<1	<1	<1	<1	<1	<1	1.1
CTM-22D	24-May-01	<1	<2	<1	<1	<1	<1	23	3.1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	11-Jul-01	<2.5	<10	<1.3	<2.5	<1.3	<1.3	20	170	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	NA
CTM-23D	5-Apr-01	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.5
CTM-23D	21-May-01	<1	<2	<1	<1	<1	<1	<1	3.3	<1	<1	<1	<1	<1	<1	<1
CTM-23D	3-Jul-01	<1	<2	<1	<1	<1	<1	1	11	<1	<1	<1	<1	<1	<1	NA
CTM-25D	13-Apr-01	<1	<2	<1	<1	<1	<1	<1	1.7	<1	<1	<1	<1	<1	<1	<1
CTM-25D	19-Apr-01	<1	<2	<1	<20	<1	<1	<1	4.1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	3-Jul-01	<1	<4	<1	<1	<1	<1	<1	87	<1	<1	<1	<1	<1	<1	NA
CTM-27D	6-Apr-01	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	10-Apr-01	<1	<2	<1	<1	<1	<1	1.4	5.7	<1	<1	<1	<1	<1	<1	1.1
CTM-27D	22-Jun-01	<1	<2	<1	<1	<1	<1	<1	3.6	<1	<1	<1	<1	<1	<1	<1
CTM-30D	13-Apr-01	<1	<2	<1	<1	<1	<1	28	2	<1	<1	<1	<1	<1	<1	<1
CTM-30D	19-Apr-01	<1	<2	<1	<20	<1	<1	25	4.8	<1	<1	<1	<1	<1	<1	1.3
CTM-30D	5-Jul-01	<1	<2	<0.5	<1	<0.5	<0.5	25	21	<1	<1	<1	<1	<1	<1	NA
CTM-33D	3-May-01	<1	<2	<1	<1	<1	<1	2.8	4.9	<1	<1	<1	<1	<1	<1	<1
CTM-33D	27-Jun-01	<1	<2	<1	<1	<1	<1	1.8	1.3	<1	<1	<1	<1	<1	<1	NA

NA - Not Analyzed

<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A
Table A-2a
Summary of Deep Groundwater Monitoring Well Data Considered for Use in Risk Analysis

Well	Date	Developed Shallow Groundwater Results (ug/L)														
		cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	ETRACHLOROETHENE (PCE)	TOLUENE	rans-1,2-Dichloroethene	rans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
CTM-37D	1-Jun-01	<1	<1	<1	<1	<1	<1	3.1	1.2	<1	<1	<1	<1	<1	<1	<1
CTM-37D	7-Jun-01	<1	<2	<1	<1	<1	<1	1.8	3.9	<1	<1	<1	<1	<1	<1	<1
CTM-37D	11-Jul-01	<2.5	<10	<1.3	<2.5	<1.3	<1.3	<2.5	160	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	NA
CTM-38D	6-Jun-01	<1	<2	<1	<1	100	<1	49	<1	<1	<1	<1	2.1	<1	<1	<1
CTM-38D	25-Jun-01	<1	<2	<1	<1	95	<1	55	2.5	<1	<1	<1	2.4	<1	<1	NA
SPA	11-Aug-99	NA	<0.2	<0.2	NA	NA	NA	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
SPB	12-Aug-99	NA	<0.2	<0.2	NA	NA	NA	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
SPD	12-Aug-99	NA	<0.2	<0.2	NA	NA	NA	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
SPE	12-Aug-99	NA	<0.2	<0.2	NA	NA	NA	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
SPG	11-Aug-99	NA	<0.2	<0.2	NA	NA	NA	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
SPH	20-Jul-99	NA	<0.2	<0.2	NA	NA	NA	16.8	<0.2	NA	NA	<0.2	0.4	NA	<0.2	<0.2
SPH	19-Aug-99	NA	<0.2	<0.2	NA	NA	NA	17.8	<0.2	NA	NA	<0.2	0.5	NA	<0.2	<0.2
SPH	21-Sep-99	NA	<0.2	<0.2	NA	NA	NA	14.3	<0.2	NA	NA	<0.2	0.4	NA	<0.2	<0.2
SPH	4-Nov-99	NA	<0.2	<0.2	NA	NA	NA	16.6	<0.2	NA	NA	<0.2	0.4	NA	<0.2	<0.2
SPH	16-Nov-99	NA	<0.2	<0.2	NA	NA	NA	14.9	<0.2	NA	NA	<0.2	0.3	NA	<0.2	<0.2
SPJ	9-Aug-99	NA	<0.2	<0.2	NA	NA	NA	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2
SPK	9-Aug-99	NA	<0.2	<0.2	NA	NA	NA	<0.2	<0.2	NA	NA	<0.2	<0.2	NA	<0.2	<0.2

NA - Not Analyzed
<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A
Table A-2b
Summary of Grab Deep Groundwater Data Considered for Use in Risk Analysis

Well	Depth	Date	Grab Shallow Groundwater Results (ug/L)															
			1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE
CTM-4D	113	6-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	137	6-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	157	6-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	180	9-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	39	6-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	57	6-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	77	6-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	92	6-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	120	2-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	146	5-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	170	5-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	190	6-Mar-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-8D	210	6-Mar-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-8D	230	6-Mar-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-8D	255	6-Mar-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-8D	26	2-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	52	2-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	74	2-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	96	2-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-10D	103	23-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-10D	123	23-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-10D	243	25-Apr-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-10D	260	25-Apr-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-10D	283	25-Apr-01	<5	<5	<5	<5	<5	<5	<5	<5	<5	<2	<5	<5	<5	<5	<5	<5
CTM-10D	303	25-Apr-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-10D	320	25-Apr-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-10D	350	26-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-10D	63	23-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-10D	83	23-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	107	23-Mar-01	1.6	<1	<1	<1	<1	<1	<1	<1	<1	4.8	<1	<1	<1	<1	<1	<1
CTM-12D	125	23-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	2.3	<1	<1	<1	<1	<1	<1
CTM-12D	147	23-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.4	<1	<1	<1	<1	<1	<1
CTM-12D	165	26-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	182	26-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	197	26-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	217	26-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

NA - Not Analyzed
Non-detects shown as half the detection limit

Appendix A
Table A-2b
Summary of Grab Deep Groundwater Data Considered for Use in Risk Analysis

Well	Depth	Date	Grab Shallow Groundwater Results (ug/L)															
			1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE
CTM-12D	237	26-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	255	27-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	280	27-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	297	28-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	317	28-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	346	28-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	40	23-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1
CTM-12D	65	23-Mar-01	2.6	<1	<1	<1	<1	<1	<1	<1	<1	8.3	<1	<1	<1	<1	<1	<1
CTM-12D	86	23-Mar-01	2.4	<1	<1	<1	<1	<1	<1	<1	<1	7.5	<1	<1	<1	<1	<1	<1
CTM-17D	117	20-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	132	20-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	154	20-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	173	20-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	192	20-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	32	19-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	51	19-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	74	19-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	94	19-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	107	17-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	127	18-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	147	18-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	167	18-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	187	18-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	207	19-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	227	19-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	253	19-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	27	17-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	47	17-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	67	17-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	87	17-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	116.5	12-Mar-01	<5	<5	<5	<5	<5	<5	<5	<5	<5	<2	<5	<5	<5	<5	<5	<5
CTM-23D	136.5	12-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	15	9-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	160	12-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	180	12-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	36.5	9-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

NA - Not Analyzed
Non-detects shown as half the detection limit

Appendix A
Table A-2b
Summary of Grab Deep Groundwater Data Considered for Use in Risk Analysis

Well	Depth	Date	Grab Shallow Groundwater Results (ug/L)															
			1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE
CTM-23D	56.5	9-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	76.5	9-Mar-01	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-23D	96.5	9-Mar-01	<5	<5	<5	<5	<5	<5	<5	<5	<5	<2	<5	<5	<5	<5	<5	<5
CTM-25D	117	8-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	137	14-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	15	6-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	157	14-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	180	14-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	36	7-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	54	7-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	75	7-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	97	7-Mar-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	117	3-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	136	3-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	157	4-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	180	4-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	33	2-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	56	2-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	7	2-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	77	3-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	97	3-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	114	11-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	134	11-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	154	11-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	34	10-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	54	11-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	74	11-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	94	11-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	105	30-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	125	1-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	145	1-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	166	1-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	188	1-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	24	30-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	45	30-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	65	30-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

NA - Not Analyzed
Non-detects shown as half the detection limit

Appendix A
Table A-2b
Summary of Grab Deep Groundwater Data Considered for Use in Risk Analysis

			Grab Shallow Groundwater Results (ug/L)															
Well	Depth	Date	1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE
CTM-33D	85	30-Apr-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-37D	50	31-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-37D	70	31-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-37D	85	31-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-38D	33	29-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-38D	56	29-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-38D	75	29-May-01	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-38D	98	29-May-01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

NA - Not Analyzed
Non-detects shown as half the detection limit

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Table A-2b
Summary of Grab Deep Groundwater Data Considered for Use in Risk Analysis

Well	Depth	Date	Grab Shallow Groundwater Results (ug/L)																	
			CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene	cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
CTM-4D	113	6-Apr-01	2.2	<2	<1	<1	<2	<1	<1	<1	<1	5.9	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	137	6-Apr-01	2	<2	<1	<1	<2	<1	<1	<1	<1	3.6	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	157	6-Apr-01	1.4	<2	<1	<1	<2	<1	<1	<1	<1	1.8	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	180	9-Apr-01	1.5	<2	<1	<1	<2	<1	<1	<1	<1	1.2	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	39	6-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	5.5	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	57	6-Apr-01	<1	<2	3.5	<1	<2	<1	<1	<1	<1	10	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	77	6-Apr-01	<1	<2	1.7	<1	<2	<1	<1	<1	<1	14	<1	<1	<1	<1	<1	<1	<1	<1
CTM-4D	92	6-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	44	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	120	2-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	5.5	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	146	5-Mar-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	97	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	170	5-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	38	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	190	6-Mar-01	<2.5	<10	<2.5	<2.5	<10	<2.5	<2.5	<2.5	<2.5	31	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-8D	210	6-Mar-01	<2.5	<10	<2.5	<2.5	<10	<2.5	<2.5	<2.5	<2.5	31	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-8D	230	6-Mar-01	<2.5	<10	<2.5	<2.5	<10	<2.5	<2.5	<2.5	<2.5	23	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-8D	255	6-Mar-01	<2.5	<10	<2.5	<2.5	<10	<2.5	<2.5	<2.5	<2.5	20	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
CTM-8D	26	2-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	52	2-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	74	2-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	1.5	<1	<1	<1	<1	<1	<1	<1	<1
CTM-8D	96	2-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	5.4	<1	<1	<1	<1	<1	<1	<1	<1
CTM-10D	103	23-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-10D	123	23-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-10D	243	25-Apr-01	<2.5	<10	<2.5	<2.5	<10	<1	<2.5	<1	<1	14	<1	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1
CTM-10D	260	25-Apr-01	<2.5	<10	<2.5	<2.5	<10	<1	<2.5	<1	<1	15	<1	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1
CTM-10D	283	25-Apr-01	<5	<20	<5	<5	<20	<2	<5	<2	<2	18	<2	<5	<5	<5	<5	<5	<5	<2
CTM-10D	303	25-Apr-01	<2.5	<10	<2.5	<2.5	<10	<1	<2.5	<1	<1	22	<1	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1
CTM-10D	320	25-Apr-01	<2.5	<10	<2.5	<2.5	<10	<1	<2.5	<1	<1	27	<1	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1
CTM-10D	350	26-Apr-01	1.2	<4	<1	<1	<4	<1	<1	<1	<1	50	<1	<1	<1	<1	1.1	<1	<1	<1
CTM-10D	63	23-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-10D	83	23-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	107	23-Mar-01	<1	<2	12	<1	<2	<1	<1	130	<1	33	<1	<1	<1	<1	3.5	<1	<1	<1
CTM-12D	125	23-Mar-01	<1	<2	6.6	<1	<2	<1	<1	85	<1	19	<1	<1	<1	<1	1.9	<1	<1	<1
CTM-12D	147	23-Mar-01	<1	<2	4	<1	<2	<1	<1	55	<1	12	<1	<1	<1	<1	1.1	<1	<1	<1
CTM-12D	165	26-Mar-01	<1	<2	1.7	<1	<2	<1	<1	27	<1	6.2	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	182	26-Mar-01	<1	<2	1.7	<1	<2	<1	<1	25	<1	5.1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	197	26-Mar-01	<1	<2	1.3	<1	<2	<1	<1	22	<1	3.5	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	217	26-Mar-01	<1	<2	<1	<1	<2	<1	<1	18	<1	3.1	<1	<1	<1	<1	<1	<1	<1	<1

NA - Not Analyzed
Non-detects shown as half the detection limit

Appendix A
Table A-2b
Summary of Grab Deep Groundwater Data Considered for Use in Risk Analysis

Well	Depth	Date	Grab Shallow Groundwater Results (ug/L)																	
			CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene	cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
CTM-12D	237	26-Mar-01	<1	<4	<1	<1	<4	<1	<1	18	<1	5.1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	255	27-Mar-01	<1	<4	<1	<1	<4	<1	<1	11	<1	3.9	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	280	27-Mar-01	<1	<4	<1	<1	<4	<1	<1	8.6	<1	5.9	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	297	28-Mar-01	<1	<2	<1	<1	<2	<1	<1	5.4	<1	5.8	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	317	28-Mar-01	<1	<2	<1	<1	<2	<1	<1	1	<1	6	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	346	28-Mar-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	3.5	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	40	23-Mar-01	<1	<2	2.8	<1	<2	<1	<1	41	<1	8.8	<1	<1	<1	<1	<1	<1	<1	<1
CTM-12D	65	23-Mar-01	<1	<4	18	<1	<4	<1	<1	150	<1	55	<1	<1	<1	<1	5.4	<1	<1	<1
CTM-12D	86	23-Mar-01	<1	<2	16	<1	<2	<1	<1	140	<1	50	<1	<1	<1	<1	4.8	<1	<1	<1
CTM-17D	117	20-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	3.5	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	132	20-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	3.8	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	154	20-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	2.9	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	173	20-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	4.3	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	192	20-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	5	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	32	19-Mar-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	1.4	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	51	19-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	74	19-Mar-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	2.4	<1	<1	<1	<1	<1	<1	<1	<1
CTM-17D	94	19-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	3.2	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	107	17-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	127	18-Apr-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	147	18-Apr-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	167	18-Apr-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	187	18-Apr-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	2.7	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	207	19-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	7.7	<1	<1	<1	<1	2.6	<1	<1	<1
CTM-22D	227	19-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	6.2	<1	<1	<1	<1	2.1	<1	<1	<1
CTM-22D	253	19-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	3.4	<1	<1	<1	<1	1.1	<1	<1	<1
CTM-22D	27	17-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	47	17-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	67	17-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-22D	87	17-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	116.5	12-Mar-01	<5	<20	<5	<5	<20	<2	<5	<2	<2	440	<2	<5	<5	<5	<5	<5	<5	<2
CTM-23D	136.5	12-Mar-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	84	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	15	9-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	160	12-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	4.9	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	180	12-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	24	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	36.5	9-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	27	<1	<1	<1	<1	<1	<1	<1	<1

NA - Not Analyzed
Non-detects shown as half the detection limit

Appen

Table A-2b

Summary of Grab Deep Groundwater Data Considered for Use in Risk Analysis

Well	Depth	Date	Grab Shallow Groundwater Results (ug/L)																	
			CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene	cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
CTM-23D	56.5	9-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	21	<1	<1	<1	<1	<1	<1	<1	<1
CTM-23D	76.5	9-Mar-01	<2.5	<10	<2.5	<2.5	<10	<1	<2.5	<1	<1	100	<1	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<1
CTM-23D	96.5	9-Mar-01	<5	<20	<5	<5	<20	<2	<5	<2	<2	310	<2	<5	<5	<5	<5	<5	<5	<2
CTM-25D	117	8-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	1.6	<1	<1	<1	<1	<1	<1	<1
CTM-25D	137	14-Mar-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	15	6-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	157	14-Mar-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	180	14-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	36	7-Mar-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	54	7-Mar-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	75	7-Mar-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-25D	97	7-Mar-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	117	3-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	136	3-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	157	4-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	180	4-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	33	2-Apr-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	56	2-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	7	2-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	77	3-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-27D	97	3-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	114	11-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	1.7	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	134	11-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	1.6	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	154	11-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	1.6	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	34	10-Apr-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	154	11-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	74	11-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-30D	94	11-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	1.1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	105	30-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	1.7	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	125	1-May-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	2.6	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	145	1-May-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	2.3	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	166	1-May-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	2	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	188	1-May-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	1.8	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	24	30-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	8.4	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	45	30-Apr-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	5	<1	<1	<1	<1	<1	<1	<1	<1
CTM-33D	65	30-Apr-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	5.9	<1	<1	<1	<1	<1	<1	<1	<1

NA - Not Analyzed
Non-detects shown as half the detection limit

Appendix A
Table A-2b
Summary of Grab Deep Groundwater Data Considered for Use in Risk Analysis

Well	Depth	Date	Grab Shallow Groundwater Results (ug/L)																	
			CHLOROFORM	CHLOROMETHANE	cis-1,2-Dichloroethene	cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
CTM-33D	85	30-Apr-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	3.3	<1	<1	<1	<1	<1	<1	<1	<1
CTM-37D	50	31-May-01	1.1	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-37D	70	31-May-01	3.2	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-37D	85	31-May-01	2.3	<2	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CTM-38D	33	29-May-01	<1	<2	<1	<1	<2	<1	<1	<1	<1	13	<1	<1	<1	<1	<1	<1	<1	<1
CTM-38D	56	29-May-01	<1	<4	<1	<1	<4	<1	<1	<1	<1	11	<1	<1	<1	<1	<1	<1	<1	<1
CTM-38D	75	29-May-01	<1	<2	1.8	<1	<2	<1	<1	29	<1	26	<1	<1	<1	<1	1.3	<1	<1	<1
CTM-38D	98	29-May-01	<1	<4	1.5	<1	<4	<1	<1	25	<1	16	<1	<1	<1	<1	1	<1	<1	<1

NA - Not Analyzed
Non-detects shown as half the detection limit

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Table A-3a
Summary of All Soil Gas Data Considered for Use in Risk Analysis

Well	Date	Soil Gas Results (ug/L)																	
		1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM	CHLOROMETHANE
CTM-1S	27-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-1S Dup	27-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-2S	29-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-2S Dup	29-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.16	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-2S Dup 2	29-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.13	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-2S Dup 3	29-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-2S Dup 4	29-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-2S Dup 5	29-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-3S	27-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-3S Dup	27-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-5S	28-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-5S Dup	28-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-6S	20-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.25	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-6S Dup	20-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-7S	8-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-7S Dup	8-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-9S	3-May-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-9S Dup	3-May-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-9S Dup2	3-May-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-9S Dup3	3-May-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-9S Dup4	3-May-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-9S Dup5	3-May-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-14S	21-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-14S Dup	21-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-16S	15-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-16S Dup	15-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-19S	29-Apr-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-19S Dup	29-Apr-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-20S	15-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-20S Dup	15-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-21S	16-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.6
CTM-21S Dup	16-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CTM-28S	29-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
CTM-28S Dup	29-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A
Table A-3a
Summary of All Soil Gas Data Considered for Use in Risk Analysis

Well	Date	Soil Gas Results (ug/L)															
		cis-1,2-Dichloroethene	cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
CTM-1S	27-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	7.7	0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-1S Dup	27-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-2S	29-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-2S Dup	29-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-2S Dup 2	29-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	0.21	0.12	<0.2	<0.2	<0.2	<0.2	<0.2	NA	NA
CTM-2S Dup 3	29-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-2S Dup 4	29-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-2S Dup 5	29-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-3S	27-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-3S Dup	27-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-5S	28-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-5S Dup	28-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-6S	20-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	0.39	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.11
CTM-6S Dup	20-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-7S	8-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-7S Dup	8-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-9S	3-May-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-9S Dup	3-May-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-9S Dup2	3-May-01	<0.2	<0.2	<0.4	<0.1	<0.2	1.3	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-9S Dup3	3-May-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-9S Dup4	3-May-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-9S Dup5	3-May-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-14S	21-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-14S Dup	21-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-16S	15-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-16S Dup	15-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-19S	29-Apr-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-19S Dup	29-Apr-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-20S	15-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-20S Dup	15-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-21S	16-Mar-01	<0.2	<0.2	<0.6	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-21S Dup	16-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA
CTM-28S	29-Mar-01	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-28S Dup	29-Mar-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2	NA	NA	NA

<1 - Indicates not detected at the indicated laboratory detection limit

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Table A-3b
Summary of Soil Gas Data with Duplicates Resolved Considered for Use in Risk Analysis

Well	Date	Soil Gas Results (ug/L)																
		1,1,1-TRICHLOROETHANE	1,1,2,2-TETRACHLOROETHANE	1,1,2-TRICHLOROETHANE	1,1-DICHLOROETHANE	1,1-DICHLOROETHYLENE	1,2-DICHLOROBENZENE	1,2-DICHLOROETHANE	1,2-DICHLOROPROPANE	1,4-DICHLOROBENZENE	BENZENE	BROMODICHLOROMETHANE	BROMOMETHANE	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLORODIBROMOMETHANE	CHLOROETHANE	CHLOROFORM
CTM-1S	27-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-2S All	29-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.16	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-3S	27-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-5S	28-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-6S	20-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.25	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-7S	8-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-9S All	3-May-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-14S	21-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-16S	15-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-19S	29-Apr-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-20S	15-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-21S	16-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
CTM-28S	29-Mar-01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A

Table A-3b

Summary of Soil Gas Data with Duplicates Resolved Considered for Use in Risk Analysis

Well	Date			Soil Gas Results (ug/L)														
		CHLOROMETHANE	cis-1,2-Dichloroethene	cis-1,3-Dichloropropene	DICHLOROMETHANE	ETHYLBENZENE	M-DICHLOROBENZENE	MTBE	o-Xylene	TETRACHLOROETHENE (PCE)	TOLUENE	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	TRIBOMOMETHANE	TRICHLOROETHYLENE	TRICHLOROFLUOROMETHANE	Vinyl chloride	Xylenes
CTM-1S	27-Mar-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	7.7	0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-2S All	29-Mar-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	0.21	0.12	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-3S	27-Mar-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-5S	28-Mar-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-6S	20-Mar-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	0.39	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.11
CTM-7S	8-Mar-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-9S All	3-May-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	1.3	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-14S	21-Mar-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-16S	15-Mar-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-19S	29-Apr-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-20S	15-Mar-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-21S	16-Mar-01	<0.6	<0.2	<0.2	<0.6	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1
CTM-28S	29-Mar-01	<0.4	<0.2	<0.2	<0.4	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1

<1 - Indicates not detected at the indicated laboratory detection limit

Appendix A
Table A-4
Comparison of Soil Gas Reporting Limits to Risk-Based Screening Levels

Detected Chemical	Reporting Limits	Risk-Based Screening Level	Okay?
1,1,1-TRICHLOROETHANE	0.2 mg/m^3	8738 mg/m^3	OKAY
1,1,2,2-TETRACHLOROETHANE	0.2 mg/m^3	0.35 mg/m^3	OKAY
1,1,2-TRICHLOROETHANE	0.2 mg/m^3	1.26 mg/m^3	OKAY
1,1-DICHLOROETHANE	0.2 mg/m^3	4382 mg/m^3	OKAY
1,1-DICHLOROETHYLENE	0.2 mg/m^3	0.4 mg/m^3	OKAY
1,2-DICHLOROBENZENE	0.2 mg/m^3	1757 mg/m^3	OKAY
1,2-DICHLOROETHANE	0.2 mg/m^3	0.76 mg/m^3	OKAY
1,2-Dichloropropane	0.2 mg/m^3	35 mg/m^3	OKAY
1,4-DICHLOROBENZENE	0.2 mg/m^3	7039 mg/m^3	OKAY
BENZENE	0.1 mg/m^3	2.6 mg/m^3	OKAY
BROMODICHLOROMETHANE	0.2 mg/m^3	1.25 mg/m^3	OKAY
BROMOMETHANE	0.2 mg/m^3	44 mg/m^3	OKAY
CARBON TETRACHLORIDE	0.2 mg/m^3	1.36 mg/m^3	OKAY
CFC-11	0.2 mg/m^3	— mg/m^3	OKAY
CHLOROBENZENE	0.2 mg/m^3	175 mg/m^3	OKAY
CHLORODIBROMOMETHANE	0.2 mg/m^3	0.97 mg/m^3	OKAY
CHLOROETHANE	0.2 mg/m^3	246529 mg/m^3	OKAY
CHLOROFORM	0.2 mg/m^3	0.87 mg/m^3	OKAY
CHLOROMETHANE	0.4 mg/m^3	— mg/m^3	OKAY
cis-1,2-Dichloroethene	0.2 mg/m^3	307 mg/m^3	OKAY
cis-1,3-Dichloropropene	0.2 mg/m^3	5.2 mg/m^3	OKAY
DICHLOROMETHANE	0.4 mg/m^3	42.5 mg/m^3	OKAY
ETHYLBENZENE	0.1 mg/m^3	8761 mg/m^3	OKAY
M-DICHLOROBENZENE**	0.2 mg/m^3	7039 mg/m^3	OKAY
METHYLBENZENE	0.1 mg/m^3	3462 mg/m^3	OKAY
MTBE	0.1 mg/m^3	3.1 mg/m^3	OKAY
o-Xylene	0.1 mg/m^3	60561 mg/m^3	OKAY
TETRACHLOROETHENE (PCE)	0.2 mg/m^3	35 mg/m^3	OKAY
trans-1,2-Dichloroethene	0.2 mg/m^3	616 mg/m^3	OKAY
trans-1,3-Dichloropropene*	0.2 mg/m^3	5.2 mg/m^3	OKAY
TRIBOMOMETHANE	0.2 mg/m^3	20.5 mg/m^3	OKAY
TRICHLOROETHYLENE	0.2 mg/m^3	12 mg/m^3	OKAY
Vinyl chloride	0.2 mg/m^3	5 mg/m^3	OKAY
Xylenes	0.1 mg/m^3	60561 mg/m^3	OKAY

* - Value for cis-1,2-DCP is used
** - Value for cis-1,4-DCB is used
— - Not Available

Appendix B

Development of Site-Specific Screening Criteria for Selection of Chemicals of Potential Concern

Appendix B
Development of Site-Specific Screening Criteria for Selection of Chemicals of Potential Concern

This appendix presents the methods and assumptions used to develop site-specific screening criteria for the CTM Site. These screening criteria are used to select COPCs for groundwater and soil gas in Section 3. Site-specific screening criteria are developed using conservative exposure assumptions for potential exposure scenarios for the CTM site. Screening concentrations for groundwater and soil gas are based on a target cancer risk of 10^{-7} and a target hazard index (HI) of 0.1. Spreadsheets for all calculations are presented as an attachment to this appendix (to be included as part of the final document).

B-1 Screening Concentrations for Soil Gas

Risk-based screening levels for soil gas were developed using USEPA's subsurface to indoor air spreadsheet model (Windows™ - Excel) for the Johnson and Ettinger vapor intrusion model. The model (SLSCREEN.xls) estimates potential indoor air concentrations and risks associated with these concentrations from concentrations in soil gas by calculating flux of chemicals through a foundation. Although this particular spreadsheet does not run in a backwards mode (i.e. it does not back-calculate acceptable soil gas concentrations from acceptable indoor air concentrations), acceptable soil concentrations can be calculated by developing risk estimates associated with arbitrary soil gas concentrations, and then back-calculating soil gas concentrations corresponding with target risk levels in a separate spreadsheet. This approach was used here.

Exposure assumptions in the Johnson and Ettinger model assume residential exposures and are therefore conservative. Since residents have higher exposure durations and exposure frequencies than commercial/industrial workers, screening values based on residents are also protective of workers and it is not necessary to develop separate screening values for workers.

Model input parameters used were a combination of default and site-specific parameters. The following site specific assumption were used:

- Soil total porosity = 0.43
- Soil water-filled porosity = 0.3
- Soil gas sampling depth = 10 feet

Since site-specific physical parameter data for soils were not available, default values corresponding to common soil types similar to the soil types encountered in the site borings were used. Although the soil gas sampling depth ranged from 10 feet to 50 feet bgs, the soil gas sampling depth below grade was assumed to be 10 feet (300 cm) to provide a more conservative model. The depth below grade to the bottom of the enclosed space was assumed to be 6.5 feet (200 cm). The vadose zone soil type was assumed to be sandy clay. The vadose zone in the area where soil gas samples were collected consists of poorly sorted gravel, boulders, silt and clay and is characterized as consistently clay rich. Using a soil type assumed to represent a conservative average is therefore appropriate.

B-2. Screening Concentrations for Groundwater

Site –specific screening concentrations for groundwater are developed for a construction worker scenario. Construction workers are evaluated for incidental ingestion of groundwater, dermal contact with groundwater, and inhalation of ambient air. Exposure parameters for construction workers are presented in Section B-2.1. Section B-2.2 discusses how the volatilization of chemicals from groundwater into excavations is estimated

B-2.1 Exposure Assumptions

Exposure assumptions are summarized in Table B-1 and are discussed below. Several exposure assumptions for construction workers are based on professional judgement, since published guidance values for construction workers are limited.

Table B-1
Exposure Assumptions for Construction Workers

Exposure Parameter	***Exposure Pathway for which the Parameter is Used***	***Parameter Value***	***Source***
Inhalation Rate	Inhalation of Volatiles Released from Groundwater to Ambient Air	16.0 m^3/day	EPA 1997
Ingestion Rate	Incidental Ingestion of Groundwater	5 ml/day	Professional Judgment
Dermal Permeability Constant	Dermal Contact with Groundwater	Chemical Specific	EPA 1992
Exposure Time	Dermal Contact with Groundwater	1 hr/day	EPA 1989
Skin Surface Area	Dermal Contact with Groundwater	3,600 cm^2 (head, hands and Forearms)	EPA 1997
Body Weight	All	70 kg	EPA 1989
Exposure Frequency	All	250 days/year	Professional Judgment
Exposure Duration	All	1 year	Professional Judgment
Averaging Time for Carcinogens	All	25,550 days	EPA 1989
Averaging Time for Noncarcinogens	All	182 days	Professional Judgment

Inhalation Rate. USEPA (1997) presents inhalation rates for various levels of activity. Construction workers at the CTM study area are assumed to perform tasks associated with moderate activity for 4 hours per day and with heavy activity for another 4 hours. Inhalation rates for moderate and heavy activity are 1.5 and 2.5 m^3/hour, respectively (USEPA, 1997). The resulting inhalation rate for an 8-hour working day is 16 m^3/day. This value is used in the screening analysis.

Exposure Duration. Exposure duration is the number of years during which exposure is assumed to take place. For construction workers at the CTM study area, exposure duration during which direct contact with groundwater is considered possible, is assumed to be 1 year. Since the construction phase during which dewatering may be necessary is relatively short compared to the duration of an entire building project, this estimate is expected to be protective for a construction worker involved in multiple building projects at the CTM study area.

Exposure Frequency. Because an exposure duration of 1 year is assumed, exposure frequency is 250 days. This value is based on a 5-day workweek.

Body Weight. EPA (1989) recommends a body weight of 70 kg for adults. This value is used to evaluate future onsite construction workers.

Averaging Time. Carcinogenic exposures are averaged over 70 years (25,550 days) (EPA 1989). Averaging times for noncarcinogens are calculated by multiplying the exposure duration by 365 days/year (USEPA, 1989). Exposure duration for construction workers is 1 year; averaging time for exposure to noncarcinogens is therefore 365 days.

Incidental Groundwater Ingestion Rate. It is possible that construction workers involved in dewatering activities may incidentally ingest small quantities of water. Incidental ingestion of groundwater may occur, for example, if workers touch wet equipment such as hoses and then touch their hands to their lips. Incidentally ingested quantities of water are expected to be minute. Swimmers are thought to ingest no more than 50 milliliters (ml) of water per hour of swimming, and workers who might only have intermittent hand contact with groundwater could be expected to ingest only a small fraction of this amount. A conservative value of 5 ml per day is used.

Dermal Surface Area for Contact with Groundwater. Construction workers are assumed to contact contaminated groundwater with their head, hands, and forearms. This is a conservative assumption that is expected to be protective of construction workers. EPA (1989) recommends using average values for the skin surface area parameter. Fiftieth percentile values for adult skin surface area for head, hands, and forearms in adult males are 1,300, 990, and 1,310 cm^2, respectively (EPA 1997). The sum of these values, 3,600 cm^2, is used to evaluate dermal exposure to groundwater for construction workers.

Chemical-specific permeability constants used in the calculation of the chronic daily intake are shown on Table B-2.

Table B-2
Chemical-Specific Permeability Constants

COPCs	*Permeability Constants** (cm/hr)*
Carcinogenic VOCs	
1,2-Dichloroethane	5.30E-03
Benzene	2.10E-02
Chloroform	8.90E-03
Tetrachloroethene (PCE)	4.80E-02
Trichloroethylene	1.60E-02
Vinyl Chloride	7.30E-03
Dichloromethane	4.50E-03
Noncarcinogenic VOCs	
1,1-Dichloroethane	8.90E-03
1,1,1-Trichloroethane	1.70E-02
cis-1,2-Dichloroethene	1.00E-02
Ethylbenzene	7.40E-02
MTBE	2.57E-03
Toluene	4.50E-02
Xylenes	8.00E-02
CFC-11	1.70E-02

* Permeability Constants from USEPA, 1992
Dichloromethane = Methylene Chloride

Exposure Time for Dermal Contact with Groundwater.

Exposure time is a necessary parameter for evaluating dermal exposures with water. Construction workers are not expected to spend much time in dewatering activities. Exposure time for direct contact with groundwater during dewatering activities is assumed to be 1 hour. This assumption is based on professional judgement.

Dermal Permeability Constants.

Dermal permeability constants (PCs) are chemical specific and are obtained from EPA guidance (USEPA, 1992).

B-2.2 Methods Used to Estimate Chemical Transport between Groundwater and Ambient Air

For pathways associated with direct exposure to groundwater (e.g. incidental ingestion and dermal contact), chemical concentrations in groundwater are used to estimate risks. If indirect exposure to groundwater contaminants is evaluated (e.g. inhalation of volatiles released from groundwater into ambient air), it is necessary to estimate transport of chemicals from groundwater into the secondary exposure medium. Methods used to extrapolate between media are presented below.

Construction workers are evaluated for inhalation of ambient air. The ASTM (1998) RBCA methodology is used to estimate migration of volatiles to ambient air. The methodology is presented in the Standard Provisional Guidance for Risk-Based Corrective Action (RBCA, ASTM 1998). The equations presented in ASTM (1998) have been programmed into Excel spreadsheets by CDM and the Excel spreadsheets are used to interpolate between media. ASTM (1998) methods estimate volatilization of chemicals from groundwater into soil gas, Parameters that are be adjusted from default are discussed below. Except for depth to groundwater and windspeed, ASTM default parameters are used to estimate migration of contaminants into ambient air.

Depth to Groundwater. The average depth to ground in the CTM study area is 20 feet below ground surface (fbgs). This value is used instead of the default depth to groundwater parameter.

Windspeed. The default windspeed in the ASTM RBCA model is 5 miles/hour. To simulate the reduced airflow within an excavation, a windspeed of 1 mile per hour is used.

Risk-based Screening Calculation Tables for Groundwater

Ta

Risk-Based Screening Levels for Groundwater for the Construction Worker (Based on Inhalation of Volatiles Released to Ambient Air, Incidental Ingestion of Groundwater, and Dermal Contact with Groundwater)

Construction Worker - Risk-based Screening Levels for Groundwater (Inhalation of Volatiles Released from Groundwater to Ambient Air, Incidental Ingestion of Groundwater, Dermal Contact with Groundwater)

RBSL1 for carcinogens = [(TR x BW x AT) / (EF x ED)] / [(VFwamb x InR x SFI) + (IRgw x SFo) + (SA x PC x ET x CF1 x SFo)]

RBSL2 for noncarcinogens = [(TR x AT x BW)/ EF X ED)] x [(RfDI / InR X VF_{wamb}) + (RfDo/IRgw) + (RfDo / SA x PC x ET x CF1)]

COPCs	SF_inhal (mg/kg-day)$^{-1}$	SF_oral (mg/kg-day)$^{-1}$	Target Risk (unitless)	BW (kg)	AT (days)	InR (m^3/day)	IRgw (l/day)	ED (years)	EF (days/year)	SA (cm^2)	PC (cm/hr)	ET (hours/day)	CF1 (l/cm^3)	VFamb (mg/m^3-air)/(mg/l-H_2O)	GW RBSL (mg/l)	Solubility (mg/l)	GW RBSL (mg/l)	GW RBSL (ug/l)
Carcinogenic Exposure																		
VOCs																		
1,2-Dichloroethane	9.10E-02	9.10E-02	1.00E-07	70	25550	16	0.005	1	250	3600	5.30E-03	1	1.00E-03	8.98E-05	0.308	8690	0.308	308
Benzene	2.70E-02	5.50E-02	1.00E-07	70	25550	16	0.005	1	250	3600	2.10E-02	1	1.00E-03	2.13E-04	0.158	1750	0.158	158
Bromodichloromethane	6.20E-02	6.20E-02	1.00E-07	70	25550	16	0.005	1	250	3600	5.80E-03	1	1.00E-03	5.01E-05	0.432	6740	0.432	432
Chlorodibromomethane	8.40E-02	8.40E-02	1.00E-07	70	25550	16	0.005	1	250	3600	3.90E-03	1	1.00E-03	2.09E-05	0.440	2600	0.440	440
Chloroform	8.05E-02	6.10E-03	1.00E-07	70	25550	16	0.005	1	250	3600	8.90E-03	1	1.00E-03	1.38E-04	1.773	9640	1.773	1,773
Dichloromethane	1.60E-03	7.50E-03	1.00E-07	70	25550	16	0.005	1	250	3600	4.50E-03	1	1.00E-03	1.33E-04	4.405	13000	4.405	4,405
Tetrachloroethene (PCE)	2.03E-03	5.20E-02	1.00E-07	70	25550	16	0.005	1	250	3600	4.80E-02	1	1.00E-03	2.98E-04	0.08	200	0.08	77
Tribromomethane	3.90E-03	7.90E-03	1.00E-07	70	25550	16	0.005	1	250	3600	2.60E-03	1	1.00E-03	1.17E-05	6.266	3100	6.266	6,266
Trichloroethylene	6.00E-03	1.10E-02	1.00E-07	70	25550	16	0.005	1	250	3600	1.60E-02	1	1.00E-03	5.24E-04	0.97	1100	0.97	968
	RfD_inhal (mg/kg-day)	**RfD_oral (mg/kg-day)**																
Noncarcinogenic Exposure																		
VOCs																		
1,1,1-Trichloroethane	2.86E-01	2.00E-02	0.1	70	365	16	0.005	1	250	3600	1.70E-02	1	1.00E-03	3.28E-04	3.071	1330	3.07	3,071
1,1-Dichloroethane	1.43E-01	1.00E-01	0.1	70	365	16	0.005	1	250	3600	8.90E-03	1	1.00E-03	1.51E-04	26.385	5060	26.39	26,385
1,2-Dichloroethane	1.40E-03	3.00E-02	0.1	70	365	16	0.005	1	250	3600	5.30E-03	1	1.00E-03	8.98E-05	5.589	8690	5.59	5,589
Benzene	1.70E-03	3.00E-03	0.1	70	365	16	0.005	1	250	3600	2.10E-02	1	1.00E-03	2.13E-04	0.354	1750	0.35	354
Bromodichloromethane	2.00E-02	2.00E-02	0.1	70	365	16	0.005	1	250	3600	5.80E-03	1	1.00E-03	5.01E-05	7.661	6740	7.66	7,661
TRICHLOROFLUOROMETHAN	2.00E-01	3.00E-01	0.1	70	365	16	0.005	1	250	3600	1.70E-02	1	1.00E-03	3.17E-04	41.543	1100	41.54	41,543
Chlorodibromomethane	2.00E-02	2.00E-02	0.1	70	365	16	0.005	1	250	3600	3.90E-03	1	1.00E-03	2.09E-05	10.550	2600	10.55	10,550
Chloroform	8.60E-05	1.00E-02	0.1	70	365	16	0.005	1	250	3600	8.90E-03	1	1.00E-03	1.38E-04	0.348	9640	0.35	348
cis-1,2-Dichloroethene	1.00E-02	1.00E-02	0.1	70	365	16	0.005	1	250	3600	1.00E-02	1	1.00E-03	1.23E-04	2.378	800	2.38	2,378
Dichloromethane	8.60E-01	6.00E-02	0.1	70	365	16	0.005	1	250	3600	4.50E-03	1	1.00E-03	1.33E-04	28.723	13000	28.72	28,723
Ethylbenzene	2.86E-01	1.00E-01	0.1	70	365	18	0.005	1	250	3600	7.40E-02	1	1.00E-03	2.25E-04	3.748	169	3.75	3,748
Toluene	1.14E-01	2.00E-01	0.1	70	365	16	0.005	1	250	3600	4.50E-02	1	1.00E-03	2.27E-04	11.789	526	11.79	11,789
MTBE	8.57E-01	5.00E-03	0.1	70	365	16	0.005	1	250	3600	2.57E-03	1	1.00E-03	7.09E-05	3.585	48000	3.59	3,585
Tetrachloroethene (PCE)	1.40E-01	1.00E-02	0.1	70	365	16	0.005	1	250	3600	4.80E-02	1	1.00E-03	2.98E-04	0.574	200	0.57	574
Tribromomethane	2.00E-02	2.00E-02	0.1	70	365	16	0.005	1	250	3600	2.60E-03	1	1.00E-03	1.17E-05	14.050	3100	14.05	14,050
Trichloroethylene	6.00E-03	8.00E-03	0.1	70	365	16	0.005	1	250	3600	1.60E-02	1	1.00E-03	5.24E-04	0.864	1100	0.86	864
Xylenes	2.00E-01	2.00E+00	0.1	70	365	16	0.005	1	250	3600	8.00E-02	1	1.00E-03	2.10E-04	62.580	175	62.58	62,580
Vinyl Chloride	2.86E-02	3.00E-03	0.1	70	365	16	0.005	1	250	3600	7.30E-03	1	1.00E-03	6.66E-04	0.946	2760	0.95	946

▨ - Indicates oral toxicity criteria was used

Table
Summary of Risk-Based Screening Levels for Groundwater for CTM

Risk-Based Screening Levels for Groundwater (mg/L)			
Receptor	Construction Worker [1]		
Preliminary COPCs	Carcinogenic Risk-Based Screening Level [2]	Noncarcinogenic Risk-Based Screening Level [3]	Risk-Based Screening Level
1,2-Dichloroethane	308	5,589	308
Benzene	158	354	158
Chloroform	1,773	348	348
Tetrachloroethene (PCE)	77	574	77
Trichloroethylene	968	864	864
Bromodichloromethane	432	7,661	432
Chlorodibromomethane	440	10,550	440
Dichloromethane	4,405	28,723	4,405
Tribromomethane	6,266	14,050	6,266
1,1-Dichloroethane	#N/A	26,385	26,385
1,1,1-Trichloroethane	#N/A	3,071	3,071
cis-1,2-Dichloroethene	#N/A	2,378	2,378
Ethylbenzene	#N/A	3,748	3,748
MTBE	#N/A	3,585	3,585
Toluene	#N/A	11,789	11,789
Xylenes	#N/A	62,580	62,580
TRICHLOROFLUOROMETHANE	#N/A	41,543	41,543

[1] Preliminary Action Level is based on direct contact with groundwater (incidental ingestion and dermal contact) and inhalation of volatiles released to ambient air from groundwater)

[2] Carcinogenic Risk-Based Screening Levels Based on Target Risk of 10^{-7}

[3] Noncarcinogenic Risk-Based Screening Levels Based on Hazard Index of 0.1

#N/A = Not available

Risk-based Screening Calculation Tables for Soil Gas

DATA EN HEET

SG-SCREEN
Version 1.0; 03/01

Soil Gas Concentration Data

ENTER Chemical CAS No. (numbers only, no dashes)	**ENTER** Soil gas conc., C_g ($\mu g/m^3$)	OR	**ENTER** Soil gas conc., C_g (ppmv)	Chemical
127184	1.00E+03			Tetrachloroethylene

MORE ↓

ENTER Depth below grade to bottom of enclosed space floor, L_F (15 or 200 cm)	**ENTER** Soil gas sampling depth below grade, L_s (cm)	**ENTER** Average soil temperature, T_S (°C)	**ENTER** Vadose zone SCS soil type (used to estimate soil vapor permeability)	OR	**ENTER** User-defined vadose zone soil vapor permeability, k_v (cm^2)
200	300	10	SC		

MORE ↓

ENTER Vadose zone soil dry bulk density, ρ_b^A (g/cm^3)	**ENTER** Vadose zone soil total porosity, n^V (unitless)	**ENTER** Vadose zone soil water-filled porosity, θ_w^V (cm^3/cm^3)
1.5	0.43	0.3

MORE ↓

ENTER Averaging time for carcinogens, AT_C (yrs)	**ENTER** Averaging time for noncarcinogens, AT_{NC} (yrs)	**ENTER** Exposure duration, ED (yrs)	**ENTER** Exposure frequency, EF (days/yr)
70	30	30	350

END

CHEMICAL PROPERTIES SHEET

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H (atm-m^3/mol)	Henry's law constant reference temperature, T_R (°C)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B (°K)	Critical temperature, T_C (°K)	Unit risk factor, URF ($\mu g/m^3$)$^{-1}$	Reference conc., RfC (mg/m^3)	Molecular weight, MW (g/mol)
7.20E-02	8.20E-06	1.84E-02	25	8,288	394.40	620.20	5.8E-07	0.0E+00	165.83

END

INTERMEDIATE C ATIONS SHEET

Source-building separation, L_T (cm)	Vadose zone soil air-filled porosity, θ_a^V (cm^3/cm^3)	Vadose zone effective total fluid saturation, S_{te} (cm^3/cm^3)	Vadose zone soil intrinsic permeability, k_i (cm^2)	Vadose zone soil relative air permeability, k_{rg} (cm^2)	Vadose zone soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Soil gas conc. ($\mu g/m^3$)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
100	0.130	0.585	1.74E-09	0.634	1.11E-09	3,844	1.00E+03	5.63E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} ($atm\text{-}m^3/mol$)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Vadose zone effective diffusion coefficient, D^{eff}_V (cm^2/s)	Diffusion path length, L_d (cm)
1.69E+06	2.27E-04	200	9,553	7.83E-03	3.37E-01	1.75E-04	4.39E-04	100

Convection path length, L_p (cm)	Source vapor conc., C_{source} ($\mu g/m^3$)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ ($\mu g/m^3$)
200	1.00E+03	0.10	7.34E-01	4.39E-04	3.84E+02	2.36E+28	1.19E-05	1.19E-02

Unit risk factor, URF ($(\mu g/m^3)^{-1}$)	Reference conc., RfC (mg/m^3)
5.8E-07	NA

END

RESULTS SHEET

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
2.8E-09	NA

MESSAGE SUMMARY BELOW:

END

DATA EN IEET

SG-SCREEN
Version 1.0; 03/01

Soil Gas Concentration Data

ENTER Chemical CAS No. (numbers only, no dashes)	**ENTER** Soil gas conc., C_g (μg/m^3)	OR	**ENTER** Soil gas conc., C_g (ppmv)	Chemical
71432	1.00E+03			Benzene

MORE ↓

ENTER Depth below grade to bottom of enclosed space floor, L_F (15 or 200 cm)	**ENTER** Soil gas sampling depth below grade, L_s (cm)	**ENTER** Average soil temperature, T_S (^oC)	**ENTER** Vadose zone SCS soil type (used to estimate soil vapor permeability)	OR	**ENTER** User-defined vadose zone soil vapor permeability, k_v (cm^2)
200	300	10	SC		

MORE ↓

ENTER Vadose zone soil dry bulk density, ρ_b^A (g/cm^3)	**ENTER** Vadose zone soil total porosity, n^V (unitless)	**ENTER** Vadose zone soil water-filled porosity, θ_w^V (cm^3/cm^3)
1.5	0.43	0.3

MORE ↓

ENTER Averaging time for carcinogens, AT_C (yrs)	**ENTER** Averaging time for noncarcinogens, AT_{NC} (yrs)	**ENTER** Exposure duration, ED (yrs)	**ENTER** Exposure frequency, EF (days/yr)
70	30	30	350

END

CHEMICAL PR TIES SHEET

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($atm\text{-}m^3/mol$)	Henry's law constant reference temperature, T_R (°C)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B (°K)	Critical temperature, T_C (°K)	Unit risk factor, URF ($(\mu g/m^3)^{-1}$)	Reference conc., RfC (mg/m^3)	Molecular weight, MW (g/mol)
8.80E-02	9.80E-06	5.56E-03	25	7,342	353.24	562.16	7.8E-06	0.0E+00	78.11

END

INTERMEDIATE CALCULATIONS SHEET

Source-building separation, L_T (cm)	Vadose zone soil air-filled porosity, θ_a^V (cm³/cm³)	Vadose zone effective total fluid saturation, S_{te} (cm³/cm³)	Vadose zone soil intrinsic permeability, k_i (cm²)	Vadose zone soil relative air permeability, k_{rg} (cm²)	Vadose zone soil effective vapor permeability, k_v (cm²)	Floor-wall seam perimeter, X_{crack} (cm)	Soil gas conc. (μg/m³)	Bldg. ventilation rate, $Q_{building}$ (cm³/s)
100	0.130	0.585	1.74E-09	0.634	1.11E-09	3,844	1.00E+03	5.63E+04

Area of enclosed space below grade, A_B (cm²)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m³/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Vadose zone effective diffusion coefficient, D^{eff}_V (cm²/s)	Diffusion path length, L_d (cm)
1.69E+06	2.27E-04	200	8,122	2.69E-03	1.16E-01	1.75E-04	5.42E-04	100

Convection path length, L_p (cm)	Source vapor conc., C_{source} (μg/m³)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm³/s)	Crack effective diffusion coefficient, D^{crack} (cm²/s)	Area of crack, A_{crack} (cm²)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (μg/m³)
200	1.00E+03	0.10	7.34E-01	5.42E-04	3.84E+02	9.61E+22	1.21E-05	1.21E-02

Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m³)
7.8E-06	NA

END

RESUL HEET

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
3.9E-08	NA

MESSAGE SUMMARY BELOW:

END

DATA SHEET

SG-SCREEN
Version 1.0; 03/01

Soil Gas Concentration Data

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Soil gas conc., C_g ($\mu g/m^3$)		ENTER Soil gas conc., C_g (ppmv)	Chemical
		OR		
107062	1.00E+03			1,2-Dichloroethane

MORE ↓

ENTER Depth below grade to bottom of enclosed space floor, L_F (15 or 200 cm)	ENTER Soil gas sampling depth below grade, L_s (cm)	ENTER Average soil temperature, T_S (°C)	ENTER Vadose zone SCS soil type (used to estimate soil vapor permeability)		ENTER User-defined vadose zone soil vapor permeability, k_v (cm^2)
				OR	
200	300	10	SC		

MORE ↓

ENTER Vadose zone soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Vadose zone soil total porosity, n^V (unitless)	ENTER Vadose zone soil water-filled porosity, θ_w^V (cm^3/cm^3)
1.5	0.43	0.3

MORE ↓

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)
70	30	30	350

END

CHEMICAL PROPERTIES SHEET

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($atm\text{-}m^3/mol$)	Henry's law constant reference temperature, T_R (°C)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B (°K)	Critical temperature, T_C (°K)	Unit risk factor, URF ($(\mu g/m^3)^{-1}$)	Reference conc., RfC (mg/m^3)	Molecular weight, MW (g/mol)
1.04E-01	9.90E-06	9.78E-04	25	7,643	356.65	561.00	2.6E-05	0.0E+00	98.96

END

INTERMEDIATE C[illegible]LATIONS SHEET

Source-building separation, L_T (cm)	Vadose zone soil air-filled porosity, θ_a^V (cm^3/cm^3)	Vadose zone effective total fluid saturation, S_{te} (cm^3/cm^3)	Vadose zone soil intrinsic permeability, k_i (cm^2)	Vadose zone soil relative air permeability, k_{rg} (cm^2)	Vadose zone soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Soil gas conc. (μg/m^3)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
100	0.130	0.585	1.74E-09	0.634	1.11E-09	3,844	1.00E+03	5.63E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Vadose zone effective diffusion coefficient, D^{eff}_V (cm^2/s)	Diffusion path length, L_d (cm)
1.69E+06	2.27E-04	200	8,522	4.56E-04	1.96E-02	1.75E-04	6.80E-04	100

Convection path length, L_p (cm)	Source vapor conc., C_{source} (μg/m^3)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (μg/m^3)
200	1.00E+03	0.10	7.34E-01	6.80E-04	3.84E+02	2.05E+18	1.22E-05	1.22E-02

Unit risk factor, URF (μg/m^3)$^{-1}$	Reference conc., RfC (mg/m^3)
2.6E-05	NA

END

RESULT EET

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
1.3E-07	NA

MESSAGE SUMMARY BELOW:

END

DATA E HEET

SG-SCREEN
Version 1.0; 03/01

Soil Gas Concentration Data

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Soil gas conc., C_g ($\mu g/m^3$)		ENTER Soil gas conc., C_g (ppmv)	Chemical
		OR		
95476	1.00E+03			o-Xylene

MORE ↓

ENTER Depth below grade to bottom of enclosed space floor, L_F (15 or 200 cm)	ENTER Soil gas sampling depth below grade, L_s (cm)	ENTER Average soil temperature, T_S (°C)	ENTER Vadose zone SCS soil type (used to estimate soil vapor permeability)		ENTER User-defined vadose zone soil vapor permeability, k_v (cm^2)
				OR	
200	300	10	SC		

MORE ↓

ENTER Vadose zone soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Vadose zone soil total porosity, n^V (unitless)	ENTER Vadose zone soil water-filled porosity, θ_w^V (cm^3/cm^3)
1.5	0.43	0.3

MORE ↓

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)
70	30	30	350

END

CHEMICAL PR[illegible]IES SHEET

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H (atm-m^3/mol)	Henry's law constant reference temperature, T_R (°C)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B (°K)	Critical temperature, T_C (°K)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)	Molecular weight, MW (g/mol)
8.70E-02	1.00E-05	5.20E-03	25	8,661	417.60	630.30	0.0E+00	7.0E+00	106.17

END

INTERMEDIATE CA LATIONS SHEET

Source-building separation, L_T (cm)	Vadose zone soil air-filled porosity, θ_a^V (cm^3/cm^3)	Vadose zone effective total fluid saturation, S_{te} (cm^3/cm^3)	Vadose zone soil intrinsic permeability, k_i (cm^2)	Vadose zone soil relative air permeability, k_{rg} (cm^2)	Vadose zone soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Soil gas conc. (μg/m^3)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
100	0.130	0.585	1.74E-09	0.634	1.11E-09	3,844	1.00E+03	5.63E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Vadose zone effective diffusion coefficient, D^{eff}_V (cm^2/s)	Diffusion path length, L_d (cm)
1.69E+06	2.27E-04	200	10,404	2.05E-03	8.83E-02	1.75E-04	5.38E-04	100

Convection path length, L_p (cm)	Source vapor conc., C_{source} (μg/m^3)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, exp(Pe^f) (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (μg/m^3)
200	1.00E+03	0.10	7.34E-01	5.38E-04	3.84E+02	1.32E+23	1.21E-05	1.21E-02

Unit risk factor, URF (μg/m^3)$^{-1}$	Reference conc., RfC (mg/m^3)
NA	7.0E+00

END

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	1.7E-06

MESSAGE SUMMARY BELOW:

MESSAGE: Risk/HQ or risk-based soil concentration is based on a route-to-route extrapolation.

END

DATA EN HEET

SG-SCREEN
Version 1.0; 03/01

Soil Gas Concentration Data

ENTER Chemical CAS No. (numbers only, no dashes)	**ENTER** Soil gas conc., C_g ($\mu g/m^3$)	OR	**ENTER** Soil gas conc., C_g (ppmv)	Chemical
108883	1.00E+03			**Toluene**

MORE ↓

ENTER Depth below grade to bottom of enclosed space floor, L_F (15 or 200 cm)	**ENTER** Soil gas sampling depth below grade, L_s (cm)	**ENTER** Average soil temperature, T_S (°C)	**ENTER** Vadose zone SCS soil type (used to estimate soil vapor permeability)	OR	**ENTER** User-defined vadose zone soil vapor permeability, k_v (cm^2)
200	300	10	sc		

MORE ↓

ENTER Vadose zone soil dry bulk density, ρ_b^A (g/cm^3)	**ENTER** Vadose zone soil total porosity, n^V (unitless)	**ENTER** Vadose zone soil water-filled porosity, θ_w^V (cm^3/cm^3)
1.5	0.43	0.3

MORE ↓

ENTER Averaging time for carcinogens, AT_C (yrs)	**ENTER** Averaging time for noncarcinogens, AT_{NC} (yrs)	**ENTER** Exposure duration, ED (yrs)	**ENTER** Exposure frequency, EF (days/yr)
70	30	30	350

END

CHEMICAL PROPERTIES SHEET

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($atm\text{-}m^3/mol$)	Henry's law constant reference temperature, T_R (°C)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B (°K)	Critical temperature, T_C (°K)	Unit risk factor, URF ($(\mu g/m^3)^{-1}$)	Reference conc., RfC (mg/m^3)	Molecular weight, MW (g/mol)
8.70E-02	8.60E-06	6.63E-03	25	7,930	383.78	591.79	0.0E+00	4.0E-01	92.14

END

INTERMEDIATE CALCULATIONS SHEET

Source-building separation, L_T (cm)	Vadose zone soil air-filled porosity, θ_a^V (cm^3/cm^3)	Vadose zone effective total fluid saturation, S_{te} (cm^3/cm^3)	Vadose zone soil intrinsic permeability, k_i (cm^2)	Vadose zone soil relative air permeability, k_{rg} (cm^2)	Vadose zone soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Soil gas conc. (μg/m^3)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
100	0.130	0.585	1.74E-09	0.634	1.11E-09	3,844	1.00E+03	5.63E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Vadose zone effective diffusion coefficient, D^{eff}_V (cm^2/s)	Diffusion path length, L_d (cm)
1.69E+06	2.27E-04	200	9,154	2.92E-03	1.26E-01	1.75E-04	5.34E-04	100

Convection path length, L_p (cm)	Source vapor conc., C_{source} (μg/m^3)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (μg/m^3)
200	1.00E+03	0.10	7.34E-01	5.34E-04	3.84E+02	2.05E+23	1.20E-05	1.20E-02

Unit risk factor, URF (μg/m^3)$^{-1}$	Reference conc., RfC (mg/m^3)
NA	4.0E-01

END

RESULTS SHEET

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	2.9E-05

MESSAGE SUMMARY BELOW:

END

DATA EN HEET

SG-SCREEN
Version 1.0; 03/01

Soil Gas Concentration Data

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Soil gas conc., C_g (μg/m^3)	OR	ENTER Soil gas conc., C_g (ppmv)	Chemical
75014	1.00E+03			Vinyl chloride (chloroethene)

MORE ↓

ENTER Depth below grade to bottom of enclosed space floor, L_F (15 or 200 cm)	ENTER Soil gas sampling depth below grade, L_s (cm)	ENTER Average soil temperature, T_S (°C)	ENTER Vadose zone SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined vadose zone soil vapor permeability, k_v (cm^2)
200	300	10	SC		

MORE ↓

ENTER Vadose zone soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Vadose zone soil total porosity, n^V (unitless)	ENTER Vadose zone soil water-filled porosity, θ_w^V (cm^3/cm^3)
1.5	0.43	0.3

MORE ↓

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)
70	30	30	350

END

CHEMICAL PROPERTIES SHEET

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($atm\text{-}m^3/mol$)	Henry's law constant reference temperature, T_R (°C)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B (°K)	Critical temperature, T_C (°K)	Unit risk factor, URF ($(\mu g/m^3)^{-1}$)	Reference conc., RfC (mg/m^3)	Molecular weight, MW (g/mol)
1.06E-01	1.23E-05	2.71E-02	25	5,250	259.25	432.00	4.4E-06	1.0E-01	62.50

END

INTERMEDIATE CA ATIONS SHEET

Source-building separation, L_T (cm)	Vadose zone soil air-filled porosity, θ_a^V (cm^3/cm^3)	Vadose zone effective total fluid saturation, S_{te} (cm^3/cm^3)	Vadose zone soil intrinsic permeability, k_i (cm^2)	Vadose zone soil relative air permeability, k_{rg} (cm^2)	Vadose zone soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Soil gas conc. (μg/m^3)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
100	0.130	0.585	1.74E-09	0.634	1.11E-09	3,844	1.00E+03	5.63E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Vadose zone effective diffusion coefficient, D^{eff}_V (cm^2/s)	Diffusion path length, L_d (cm)
1.69E+06	2.27E-04	200	5,000	1.73E-02	7.46E-01	1.75E-04	6.44E-04	100

Convection path length, L_p (cm)	Source vapor conc., C_{source} (μg/m^3)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, exp(Pe^f) (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (μg/m^3)
200	1.00E+03	0.10	7.34E-01	6.44E-04	3.84E+02	2.13E+19	1.22E-05	1.22E-02

Unit risk factor, URF (μg/m^3)$^{-1}$	Reference conc., RfC (mg/m^3)
4.4E-06	1.0E-01

END

RESULTS SHEET

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
2.2E-08	1.2E-04

MESSAGE SUMMARY BELOW:

END

Summary Table

Calculation of Risk Based Screening Concentrations for Chemicals Detected in Soil Gas
Central Truckee Meadows

Detected Chemical	Soil Gas Concentration used in J&E Model (ug/m^3)	Estimated Cancer Risk	Estimated Hazard Index	Risk-based soil gas concentration based on 10^{-7} cancer risk or HI of 0.1 (ug/m^3)	Risk-based soil gas concentration based on 10^{-7} cancer risk or HI of 0.1 (mg/m^3)
Benzene	1000	3.87E-08	NA	2,587	2.6
[a] Methylbenzene	1000	NA	2.89E-05	3,462,768	3,463
[b] MTBE	1000	NA	NA	3,100	3.10
Tetrachloroethene (PCE)	1000	2.83E-09	NA	35,394	35
Xylenes	1000	NA	1.65E-06	60,561,142	60,561
Vinyl Chloride	1000	2.21E-08	1.17E-04	4,532	5

[a] Methylbenzene is a synonym for toluene. The value for toluene is used here.

[b] A value for this compound cannot be calculated, because toxicity criteria are not available in the model. The EPA Region 9 PRG value for ambient air is used as a substitute.

Soil Properties Lookup Table

SCS Soil Type	K_s (cm/h)	α (1/cm)	N (unitless)	M (unitless)	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	Mean Grain Diameter (cm)
C	0.61	0.01496	1.253	0.2019	0.459	0.098	0.0092
CL	0.34	0.01581	1.416	0.2938	0.442	0.079	0.016
L	0.50	0.01112	1.472	0.3207	0.399	0.061	0.020
LS	4.38	0.03475	1.746	0.4273	0.390	0.049	0.040
S	26.78	0.03524	3.177	0.6852	0.375	0.053	0.044
SC	0.47	0.03342	1.208	0.1722	0.385	0.117	0.025
SCL	0.55	0.02109	1.330	0.2481	0.384	0.063	0.029
SI	1.82	0.00658	1.679	0.4044	0.489	0.050	0.0046
SIC	0.40	0.01622	1.321	0.2430	0.481	0.111	0.0039
SICL	0.46	0.00839	1.521	0.3425	0.482	0.090	0.0056
SIL	0.76	0.00506	1.663	0.3987	0.439	0.065	0.011
SL	1.60	0.02667	1.449	0.3099	0.387	0.039	0.030

Chemical Properties Lookup Table

CAS No.	Chemical	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Pure component water solubility, S (mg/L)	Henry's law constant H' (unitless)	Henry's law constant at reference temperature, H (atm-m^3/mol)	Henry's law constant reference temperature, T_R (°C)	Normal boiling point, T_B (°K)	Critical temperature, T_C (°K)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Unit risk factor, URF (μg/m^3)$^{-1}$	Reference conc., RfC (mg/m^3)	Molecular weight, MW (g/mol)
50293	DDT	2.63E+06	1.37E-02	4.95E-06	2.50E-02	3.32E-04	8.10E-06	25	533.15	720.75	22,000	9.7E-05	0.0E+00	354.49
50328	Benzo(a)pyrene	1.02E+06	4.30E-02	9.00E-06	1.62E-03	4.63E-05	1.13E-06	25	715.90	969.27	19,000	2.1E-03	0.0E+00	252.32
51285	2,4-Dinitrophenol	1.02E-02	2.73E-02	9.06E-06	2.79E+03	1.82E-05	4.44E-07	25	605.28	827.85	25,000	0.0E+00	7.0E-03	184.11
53703	Dibenz(a,h)anthracene	3.80E+06	2.02E-02	5.18E-06	2.49E-03	6.03E-07	1.47E-08	25	743.24	990.41	29,995	2.1E-03	0.0E+00	278.36
56235	Carbon tetrachloride	1.74E+02	7.80E-02	8.80E-06	7.93E+02	1.25E+00	3.05E-02	25	349.90	556.60	7,127	1.5E-05	0.0E+00	153.82
56553	Benzo(a)anthracene	3.98E+05	5.10E-02	9.00E-06	9.40E-03	1.37E-04	3.34E-06	25	708.15	1004.79	16,000	2.1E-04	0.0E+00	228.30
57749	Chlordane	1.20E+05	1.18E-02	4.37E-06	5.60E-02	1.99E-03	4.85E-05	25	624.24	885.73	14,000	1.0E-04	7.0E-04	409.78
58899	gamma-HCH (Lindane)	1.07E+03	1.42E-02	7.34E-06	6.80E+00	5.74E-04	1.40E-05	25	596.55	839.36	15,000	3.7E-04	0.0E+00	290.83
60571	Dieldrin	2.14E+04	1.25E-02	4.74E-06	1.95E-01	6.19E-04	1.51E-05	25	613.32	842.25	17,000	4.6E-03	0.0E+00	380.91
65850	Benzoic Acid	5.76E-01	5.36E-02	7.97E-06	3.50E+03	6.31E-05	1.54E-06	25	720.00	751.00	12,094	0.0E+00	1.4E+01	122.12
67641	Acetone	5.75E-01	1.24E-01	1.14E-05	1.00E+06	1.59E-03	3.88E-05	25	329.20	508.10	6,955	0.0E+00	3.5E-01	58.08
67663	Chloroform	3.98E+01	1.04E-01	1.00E-05	7.92E+03	1.50E-01	3.66E-03	25	334.32	536.40	6,988	2.3E-05	0.0E+00	119.38
67721	Hexachloroethane	1.78E+03	2.50E-03	6.80E-06	5.00E+01	1.59E-01	3.88E-03	25	458.00	695.00	9,510	4.0E-06	0.0E+00	236.74
71363	Butanol	6.92E+00	8.00E-02	9.30E-06	7.40E+04	3.61E-04	8.80E-06	25	390.88	563.05	10,346	0.0E+00	3.5E-01	74.12
71432	Benzene	5.89E+01	8.80E-02	9.80E-06	1.75E+03	2.28E-01	5.56E-03	25	353.24	562.16	7,342	7.8E-06	0.0E+00	78.11
71556	1,1,1-Trichloroethane	1.10E+02	7.80E-02	8.80E-06	1.33E+03	7.05E-01	1.72E-02	25	347.24	545.00	7,136	0.0E+00	1.0E+00	133.41
72208	Endrin	1.23E+04	1.25E-02	4.74E-06	2.50E-01	3.08E-04	7.51E-06	25	718.15	986.20	15,000	0.0E+00	1.1E-03	380.91
72435	Methoxychlor	9.77E+04	1.56E-02	4.46E-06	4.50E-02	6.48E-04	1.58E-05	25	651.02	848.49	16,000	0.0E+00	1.8E-02	345.66
72548	DDD	1.00E+06	1.69E-02	4.76E-06	9.00E-02	1.64E-04	4.00E-06	25	639.90	863.77	17,000	6.9E-05	0.0E+00	320.05
72559	DDE	4.47E+06	1.44E-02	5.87E-06	1.20E-01	8.61E-04	2.10E-05	25	636.44	860.38	15,000	9.7E-05	0.0E+00	318.03
74839	Methyl bromide	1.05E+01	7.28E-02	1.21E-05	1.52E+04	2.56E-01	6.24E-03	25	276.71	467.00	5,714	0.0E+00	5.0E-03	94.94
75014	Vinyl chloride (chloroethene)	1.86E+01	1.06E-01	1.23E-05	2.76E+03	1.11E+00	2.71E-02	25	259.25	432.00	5,250	4.4E-06	1.0E-01	62.50
75092	Methylene chloride	1.17E+01	1.01E-01	1.17E-05	1.30E+04	8.98E-02	2.19E-03	25	313.00	510.00	6,706	4.7E-07	3.0E+00	84.93
75150	Carbon disulfide	4.57E+01	1.04E-01	1.00E-05	1.19E+03	1.24E+00	3.02E-02	25	319.00	552.00	6,391	0.0E+00	7.0E-01	76.13
75252	Bromoform	8.71E+01	1.49E-02	1.03E-05	3.10E+03	2.19E-02	5.34E-04	25	422.35	696.00	9,479	1.1E-06	0.0E+00	252.73
75274	Bromodichloromethane	5.50E+01	2.98E-02	1.06E-05	6.74E+03	6.56E-02	1.60E-03	25	363.15	585.85	7,800	1.8E-05	0.0E+00	163.83
75343	1,1-Dichloroethane	3.16E+01	7.42E-02	1.05E-05	5.06E+03	2.30E-01	5.61E-03	25	330.55	523.00	6,895	0.0E+00	5.0E-01	98.96
75354	1,1-Dichloroethylene	5.89E+01	9.00E-02	1.04E-05	2.25E+03	1.07E+00	2.61E-02	25	304.75	576.05	6,247	5.0E-05	0.0E+00	96.94
76448	Heptachlor	1.41E+06	1.12E-02	5.69E-06	1.80E-01	4.47E-02	1.09E-03	25	603.69	846.31	13,000	1.3E-03	0.0E+00	373.32
77474	Hexachlorocyclopentadiene	2.00E+05	1.61E-02	7.21E-06	1.80E+00	1.11E+00	2.71E-02	25	512.15	746.00	10,931	0.0E+00	7.0E-05	272.77
78591	Isophorone	4.68E+01	6.23E-02	6.76E-06	1.20E+04	2.72E-04	6.63E-06	25	488.35	715.00	10,271	2.7E-07	0.0E+00	138.21
78875	1,2-Dichloropropane	4.37E+01	7.82E-02	8.73E-06	2.80E+03	1.15E-01	2.80E-03	25	369.52	572.00	7,590	0.0E+00	4.0E-03	112.99
79005	1,1,2-Trichloroethane	5.01E+01	7.80E-02	8.80E-06	4.42E+03	3.74E-02	9.12E-04	25	386.15	602.00	8,322	1.6E-05	0.0E+00	133.41
79016	Trichloroethylene	1.66E+02	7.90E-02	9.10E-06	1.10E+03	4.22E-01	1.03E-02	25	360.36	544.20	7,505	1.7E-06	0.0E+00	131.39
79345	1,1,2,2-Tetrachloroethane	9.33E+01	7.10E-02	7.90E-06	2.97E+03	1.41E-02	3.44E-04	25	419.60	661.15	8,996	5.8E-05	0.0E+00	167.85
83329	Acenaphthene	7.08E+03	4.21E-02	7.69E-06	4.24E+00	6.36E-03	1.55E-04	25	550.54	803.15	12,155	0.0E+00	2.1E-01	154.21
84662	Diethylphthalate	2.88E+02	2.56E-02	6.35E-06	1.08E+03	1.85E-05	4.51E-07	25	567.15	757.00	13,733	0.0E+00	2.8E+00	222.24
84742	Di-n-butyl phthalate	3.39E+04	4.38E-02	7.86E-06	1.12E+01	3.85E-08	9.39E-10	25	613.15	798.67	14,751	0.0E+00	3.5E-01	278.35
85687	Butyl benzyl phthalate	5.75E+04	1.74E-02	4.83E-06	2.69E+00	5.17E-05	1.26E-06	25	660.60	839.68	14,000	0.0E+00	7.0E-01	312.37
86306	N-Nitrosodiphenylamine	1.29E+03	3.12E-02	6.35E-06	3.51E+01	2.05E-04	5.00E-06	25	632.28	890.45	7,300	1.4E-06	0.0E+00	198.23
86737	Fluorene	1.38E+04	3.63E-02	7.88E-06	1.98E+00	2.61E-03	6.37E-05	25	570.44	870.00	12,666	0.0E+00	1.4E-01	166.22
86748	Carbazole	3.39E+03	3.90E-02	7.03E-06	7.48E+00	6.26E-07	1.53E-08	25	627.87	899.00	13,977	5.7E-06	0.0E+00	167.21
87683	Hexachloro-1,3-butadiene	5.37E+04	5.61E-02	6.16E-06	3.23E+00	3.34E-01	8.15E-03	25	486.15	738.00	10,206	2.2E-05	0.0E+00	260.76
87865	Pentachlorophenol	5.92E+02	5.60E-02	6.10E-06	1.95E+03	1.00E-06	2.44E-08	25	582.15	813.20	16,109	3.4E-05	0.0E+00	266.34

88062	2,4,6-Trichlorophenol	3.81E+02	3.18E-02	6.25E-06	8.00E+02	3.19E-04	7.78E-06	25	519.15	749.03	12,000	3.1E-06	0.0E+00	197.45
91203	Naphthalene	2.00E+03	5.90E-02	7.50E-06	3.10E+01	1.98E-02	4.83E-04	25	491.14	748.40	10,373	0.0E+00	3.0E-03	128.18
91941	3,3-Dichlorobenzidine	7.24E+02	1.94E-02	6.74E-06	3.11E+00	1.64E-07	4.00E-09	25	560.26	754.03	20,000	1.3E-04	0.0E+00	253.13
95476	o-Xylene	3.63E+02	8.70E-02	1.00E-05	1.78E+02	2.13E-01	5.20E-03	25	417.60	630.30	8,661	0.0E+00	7.0E+00	106.17
95487	2-Methylphenol (o-cresol)	9.12E+01	7.40E-02	8.30E-06	2.60E+04	4.92E-05	1.20E-06	25	464.19	697.60	10,800	0.0E+00	1.8E-01	108.14
95501	1,2-Dichlorobenzene	6.17E+02	6.90E-02	7.90E-06	1.56E+02	7.79E-02	1.90E-03	25	453.57	705.00	9,700	0.0E+00	2.0E-01	147.00
95578	2-Chlorophenol	3.88E+02	5.01E-02	9.46E-06	2.20E+04	1.60E-02	3.90E-04	25	447.53	675.00	9,572	0.0E+00	1.8E-02	128.56
95954	2,4,5-Trichlorophenol	1.60E+03	2.91E-02	7.03E-06	1.20E+03	1.78E-04	4.34E-06	25	526.15	759.13	11,000	0.0E+00	3.5E-01	197.45
98953	Nitrobenzene	6.46E+01	7.60E-02	8.60E-06	2.09E+03	9.84E-04	2.40E-05	25	483.95	719.00	10,566	0.0E+00	2.0E-03	123.11
100414	Ethylbenzene	3.63E+02	7.50E-02	7.80E-06	1.69E+02	3.23E-01	7.88E-03	25	409.34	617.20	8,501	0.0E+00	1.0E+00	106.17
100425	Styrene	7.76E+02	7.10E-02	8.00E-06	3.10E+02	1.13E-01	2.76E-03	25	418.31	636.00	8,737	0.0E+00	1.0E+00	104.15
105679	2,4-Dimethylphenol	2.09E+02	5.84E-02	8.69E-06	7.87E+03	8.20E-05	2.00E-06	25	484.13	707.60	11,329	0.0E+00	7.0E-02	122.17
106423	p-Xylene	3.89E+02	7.69E-02	8.44E-06	1.85E+02	3.14E-01	7.66E-03	26	411.52	616.20	8,525	0.0E+00	7.0E+00	106.17
106467	1,4-Dichlorobenzene	6.17E+02	6.90E-02	7.90E-06	7.38E+01	9.96E-02	2.43E-03	25	447.21	684.75	9,271	0.0E+00	8.0E-01	147.00
106478	p-Chloroaniline	6.61E+01	4.83E-02	1.01E-05	5.30E+03	1.36E-05	3.32E-07	25	503.65	754.00	11,689	0.0E+00	1.4E-02	127.57
107062	1,2-Dichloroethane	1.74E+01	1.04E-01	9.90E-06	8.52E+03	4.01E-02	9.78E-04	25	356.65	561.00	7,643	2.6E-05	0.0E+00	98.96
108054	Vinyl acetate	5.25E+00	8.50E-02	9.20E-06	2.00E+04	2.10E-02	5.12E-04	25	345.65	519.13	7,800	0.0E+00	2.0E-01	86.09
108383	m-Xylene	4.07E+02	7.00E-02	7.80E-06	1.61E+02	3.01E-01	7.34E-03	25	412.27	617.05	8,523	0.0E+00	7.0E+00	106.17
108883	Toluene	1.82E+02	8.70E-02	8.60E-06	5.26E+02	2.72E-01	6.63E-03	25	383.78	591.79	7,930	0.0E+00	4.0E-01	92.14
108907	Chlorobenzene	2.19E+02	7.30E-02	8.70E-06	4.72E+02	1.52E-01	3.71E-03	25	404.87	632.40	8,410	0.0E+00	2.0E-02	112.56
108952	Phenol	2.88E+01	8.20E-02	9.10E-06	8.28E+04	1.63E-05	3.98E-07	25	455.02	694.20	10,920	0.0E+00	2.1E+00	94.11
111444	Bis(2-chloroethyl)ether	1.55E+01	6.92E-02	7.53E-06	1.72E+04	7.38E-04	1.80E-05	25	451.15	659.79	10,803	3.3E-04	0.0E+00	143.11
115297	Endosulfan	2.14E+03	1.15E-02	4.55E-06	5.10E-01	4.59E-04	1.12E-05	25	674.43	942.94	14,000	0.0E+00	2.1E-02	406.92
117817	Bis(2-ethylhexyl)phthalate	1.51E+07	3.51E-02	3.66E-06	3.40E-01	4.18E-06	1.02E-07	25	657.15	806.00	15,999	4.0E-06	0.0E+00	390.57
117840	Di-n-octyl phthalate	8.32E+07	1.51E-02	3.58E-06	2.00E-02	2.74E-03	6.68E-05	25	704.09	862.22	14,000	0.0E+00	7.0E-02	390.57
118741	Hexachlorobenzene	5.50E+04	5.42E-02	5.91E-06	6.20E+00	5.41E-02	1.32E-03	25	582.55	825.00	14,447	4.6E-04	0.0E+00	284.78
120127	Anthracene	2.95E+04	3.24E-02	7.74E-06	4.34E-02	2.67E-03	6.51E-05	25	615.18	873.00	13,121	0.0E+00	1.1E+00	178.24
120821	1,2,4-Trichlorobenzene	1.78E+03	3.00E-02	8.23E-06	3.00E+02	5.82E-02	1.42E-03	25	486.15	725.00	10,471	0.0E+00	2.0E-01	181,45
120832	2,4-Dichlorophenol	1.47E+02	3.46E-02	8.77E-06	4.50E+03	1.30E-04	3.17E-06	25	482.15	708.17	15,000	0.0E+00	1.1E-02	163.00
121142	2,4-Dinitrotoluene	9.55E+01	2.03E-01	7.06E-06	2.70E+02	3.80E-06	9.27E-08	25	590.00	814.00	13,467	1.9E-04	0.0E+00	182.14
124481	Chlorodibromomethane	6.31E+01	1.96E-02	1.05E-05	2.60E+03	3.21E-02	7.83E-04	25	416.14	678.20	5,900	2.4E-05	0.0E+00	208.28
127184	Tetrachloroethylene	1.55E+02	7.20E-02	8.20E-06	2.00E+02	7.54E-01	1.84E-02	25	394.40	620.20	8,288	5.8E-07	0.0E+00	165.83
129000	Pyrene	1.05E+05	2.72E-02	7.24E-06	1.35E-01	4.51E-04	1.10E-05	25	667.95	936.00	14,370	0.0E+00	1.1E-01	202.26
156592	cis-1,2-Dichloroethylene	3.55E+01	7.36E-02	1.13E-05	3.50E+03	1.67E-01	4.07E-03	25	333.65	544.00	7,192	0.0E+00	3.5E-02	96.94
156605	trans-1,2-Dichloroethylene	5.25E+01	7.07E-02	1.19E-05	6.30E+03	3.85E-01	9.39E-03	25	320.85	516.50	6,717	0.0E+00	7.0E-02	96.94
193395	Indeno(1,2,3-cd)pyrene	3.47E+06	1.90E-02	5.66E-06	2.20E-05	6.56E-05	1.60E-06	25	809.15	1078.24	19,000	2.1E-04	0.0E+00	276.34
205992	Benzo(b)fluoranthene	1.23E+06	2.26E-02	5.56E-06	1.50E-03	4.55E-03	1.11E-04	25	715.90	969.27	17,000	2.1E-04	0.0E+00	252.32
206440	Fluoranthene	1.07E+05	3.02E-02	6.35E-06	2.06E-01	6.60E-04	1.61E-05	25	655.95	905.00	13,815	0.0E+00	1.4E-01	202.26
207089	Benzo(k)fluoranthene	1.23E+06	2.26E-02	5.56E-06	8.00E-04	3.40E-05	8.29E-07	25	753.15	1019.70	18,000	2.1E-05	0.0E+00	252.32
218019	Chrysene	3.98E+05	2.48E-02	6.21E-06	1.60E-03	3.88E-03	9.46E-05	25	714.15	979.00	16,455	2.1E-06	0.0E+00	228.30
309002	Aldrin	2.45E+06	1.32E-02	4.86E-06	1.80E-01	6.97E-03	1.70E-04	25	603.01	839.37	15,000	4.9E-03	0.0E+00	364.92
319846	alpha-HCH (alpha-BHC)	1.23E+03	1.42E-02	7.34E-06	2.00E+00	4.35E-04	1.06E-05	25	596.55	839.36	15,000	1.8E-03	0.0E+00	290.83
319857	beta-HCH (beta-BHC)	1.26E+03	1.42E-02	7.34E-06	2.40E-01	3.05E-05	7.44E-07	25	596.55	839.36	19,000	5.3E-04	0.0E+00	290.83
542756	1,3-Dichloropropene	4.57E+01	6.26E-02	1.00E-05	2.80E+03	7.26E-01	1.77E-02	25	381.15	587.38	7,900	4.0E-06	2.0E-02	110.97
606202	2,6-Dinitrotoluene	6.92E+01	3.27E-02	7.26E-06	1.82E+02	3.06E-05	7.46E-07	25	558.00	770.00	12,938	1.9E-04	0.0E+00	182.14
621647	N-Nitrosodi-n-propylamine	2.40E+01	5.45E-02	8.17E-06	9.89E+03	9.23E-05	2.25E-06	25	509.60	746.87	6,100	2.0E-03	0.0E+00	130.19
1024573	Heptachlor epoxide	8.32E+04	1.32E-02	4.23E-06	2.00E-01	3.90E-04	9.51E-06	25	613.96	848.76	16,000	2.6E-03	0.0E+00	389.32
7439976	Mercury (elemental)	5.20E+01	3.07E-02	6.30E-06	5.62E-02	4.67E-01	1.14E-02	25	629.88	1750.00	14,127	0.0E+00	3.0E-04	200.59
8001352	Toxaphene	2.57E+05	1.16E-02	4.34E-06	7.40E-01	2.46E-04	6.00E-06	25	657.15	873.31	15,000	3.2E-04	0.0E+00	413.81

Appendix C

Risk Assessment Equations

Appendix C
Risk Assessment Equations

C.1 Cancer Risks

Target risk levels in the range of 10^{-6} to 10^{-4} are generally considered acceptable by the EPA (1990). To evaluate potential risks from exposure to carcinogens, the chronic daily intake is multiplied by a cancer slope factor to develop upper range incremental lifetime cancer risks. The cancer risks are summed for the exposure pathways discussed in Section 2 (inhalation of volatilization of groundwater, dermal contact with groundwater, and ingestion of groundwater) to determine a total incremental lifetime cancer risk for exposure to groundwater at the site. The cancer risks for groundwater was calculated using the following EPA equation (EPA 1989):

$$Risk_{gw} = \frac{C_{gw}xEFxED}{BWxAT}x\ \{[SF_{o}xIR]+[SF_{o}xSAxPCxETxCF]+[SF_{i}xVF_{amb}xInR]\}$$

Where: Risk_{gw} = Cancer Risk for groundwater pathway

SF_o = Oral Cancer Slope Factor $(\text{mg/kg-day})^{-1}$

SF_i = Infalation Cancer Slope Factor $(\text{mg/kg-day})^{-1}$

C_{gw} = Concentration in groundwater (mg/kg)

EF = Absorption Factor (days/year)

ED = Exposure duration (years)

ET = Exposure time (hours)

BW = Body weight (kg)

AT = Averaging time (days)

IR = Ingestion rate (l/day)

InR = Inhalation rate (m^3/day)

VF_{amb} = Volatilization factor ((mg/m^3-air)/(mg/l-H_2O))

CF = Conversion factor (l/cm^3)

SA = Surface area (cm^2)

PC = Permeability Coefficient (cm/hr)

The following values were used to represent a construction worker:

- an incidental groundwater ingestion rate of 5 ml/day
- an averaging time of 70 years
- an exposure frequency of 250 days/year
- an exposure duration of 1 year
- an exposure time of 1 hour/day
- a body weight of 70 kg
- 3,600 cm^2 of skin surface area exposed

C.2 Noncarcinogenic Risks

To evaluate noncancer health effects, estimated chemical exposures are compared to RfDs to determine if exposures are within a range that is likely to cause adverse health effects. The ratio of exposure to toxicity for a single chemical is called a hazard quotient (HQ) and is calculated as follows:

$$HQ_{gw} = \frac{CDI}{RfD_o}$$

Where: HQ_{gw} = Hazard quotient for groundwater pathway

CDI = Chronic Daily Intake (mg/kg-day)

RfD = Reference Dose (mg/kg-day)

The HQ is based on the assumption that there is a level of daily exposure (RfD) below which it is unlikely that even sensitive populations will experience adverse health effects. If the CDI exceeds the RfD (i.e., CDI/RfD > 1), a potential for adverse health effects may exist.

The HI is a summation of HQs for a particular pathway or from several pathways. If the HI exceeds 1, further evaluation is required. Summation of HQs may overestimate risks since chemicals may affect a variety of different organs or systems within the body. Chemicals affecting different organs or systems may act independently, and it is not appropriate to add HQs for such chemicals. Thus, if the HI for a pathway or a combination of pathways is 1 or above, HIs will be further evaluated by grouping together those chemicals that may affect the same organ.

The hazard index is calculated using the following EPA equation:

$$HI_{gw} = \frac{C_{gw}xEFxED}{BWxAT}x\left\{\frac{IR}{RfDo}+\frac{SAxPCxETxCF}{RfDo}+\frac{VF_{amb}xInR}{RfDi}\right\}$$

Where:

HI_{gw} = Hazard index for groundwater pathway

RfD_o = Oral Reference Dose (mg/kg-day)

RfD_i = Inhalation Reference Dose (mg/kg-day)

C_{gw} = Concentration in groundwater (mg/kg)

EF = Absorption Factor (days/year)

ED = Exposure duration (years)

ET = Exposure time (hours)

BW = Body weight (kg)

AT = Averaging time (days)

IR = Ingestion rate (l/day)

InR = Inhalation rate (m^3/day)

VF_{amb} = Volatilization factor ((mg/m^3-air)/(mg/l-H_2O))

CF = Conversion factor (l/cm^3)

SA = Surface area (cm^2)

PC = Permeability Coefficient (cm/hr)

The following values were used to represent a construction worker:

- an incidental groundwater ingestion rate of 5 ml/day
- an averaging time of 70 years
- an exposure frequency of 250 days/year
- an exposure duration of 1 year
- an exposure time of 1 hour/day

- a body weight of 70 kg
- 3,600 cm^2 of skin surface area exposed

Risk Analysis Calculation Table

Table
Site-Specific Risk Calculation for Groundwater for the Construction Worker
(Based on Incidental Ingestion of and Dermal Contact with Shallow Groundwater)

Site Specific Construction Worker - Risk Calculation for Groundwater (Incidental Ingestion of Groundwater, Dermal Contact with Groundwater)
CANCER1 for carcinogens = [(Cgw x EF x ED)/(BW x AT)] + (IRgw x SFo) + (SA x PC x ET x CF1 x SFo)]
NONCANCER2 for noncarcinogens = [(Cgw x EF X ED)/(BW x AT)] x [(Irgw/RfDo) + (SA x PC x ET x CF1/RfDo)]

COPCs	SF_oral	BW	AT	IRgw	ED	EF	SA	PC	ET	CF1	GW Risk by Area							
	(mg/kg-day)$^{-1}$	(kg)	(days)	(l/day)	(years)	(days/year)	(cm^2)	(cm/hr)	(hours/day)	(l/cm^3)	A	B	C	D	E	F	G	H
Carcinogenic Exposure																		
VOCs																		
Benzene	5.50E-02	70	25550	0.005	1	250	3600	2.10E-02	1	1.00E-03	ND	ND	5.14E-09	7.82E-07	ND	3.91E-06	3.85E-07	3.87E-08
Tetrachloroethene (PCE)	5.20E-02	70	25550	0.005	1	250	3600	4.80E-02	1	1.00E-03	1.46E-07	1.12E-08	2.76E-08	6.82E-07	5.23E-09	3.70E-08	4.81E-09	6.46E-09
										Total	**1.E-07**	**1.E-08**	**3.E-08**	**1.E-06**	**5.E-09**	**4.E-06**	**4.E-07**	**5.E-08**
	RfD_oral (mg/kg-day)																	
Noncarcinogenic Exposure																		
VOCs																		
Benzene	3.00E-03	70	385	0.005	1	250	3600	2.10E-02	1	1.00E-03	ND	ND	0.002	0.3	ND	1.7	0.16	0.016
MTBE	5.00E-03	70	365	0.005	1	250	3600	2.57E-03	1	1.00E-03	0.0002	ND	ND	0.001	ND	0.2	0.004	0.0008
Tetrachloroethene (PCE)	1.00E-02	70	365	0.005	1	250	3600	4.80E-02	1	1.00E-03	0.020	0.002	0.004	0.09	0.0007	0.005	0.0006	0.0009
										Total	**0.02**	**0.002**	**0.006**	**0.4**	**0.0007**	**2**	**0.2**	**0.02**

Appendix D

Toxicity Profiles

1,1,1-Trichloroethane
1.2-Dichloroethane (1,2-DCA)
1,2-Dichloroethene
Benzene
Chloroform
Ethylbenzene
Methyl-tert-Butyl-Ether (MTBE)
Methylene Chloride
Tetrachloroethene (PCE)
Trichloroethene (TCE)
Toluene
Vinyl Chloride
Xylenes

1,1,1-Trichloroethane

Introduction

1,1,1-trichloroethane is a colorless liquid with a sweet yet sharp characteristic odor. It is a manmade chemical that does not occur naturally.

Toxicokinetics

1,1,1-trichloroethane is readily absorbed gastrointestinally, dermally, and through the lungs. Studies in rats and mice indicate that 1,1,1-trichloroethane and its metabolites are widely distributed throughout the body following absorption (RTI 1987). Following exposure most of the inhaled dose is rapidly excreted in expired air. Most of the remaining absorbed portion is excreted in the urine as trichloroethanol and trichloroacetic acid (ATSDR 1990).

Qualitative Description of Health Effects

The most notable effects of 1,1,1-trichloroethane in humans and animals are central nervous system depression, including anesthesia at very high concentrations and impairment of coordination, equilibrium, and judgement at lower concentrations (350 ppm and above); cardiovascular effects, including premature ventricular contractions, decreased blood pressure, and sensitation to epinephrine-induced arrhythmia and adverse effects on the lungs, liver, and kidneys. Irritation of the skin and mucous membranes resulting from exposure to 1,1,1-trichloroethane has also been reported (ATSDR 1990).

Quantitative Description of Health Effects

There are no reported human data or animal studies that have demonstrated carcinogenicity of 1,1,1-trichloroethane. Therefore, EPA has classified 1,1,1-trichloroethane as a Group D carcinogen (not classifiable as to human carcinogenicity).

An oral Reference Dose (RfD) of 9 x 10^{-2} mg/kg-day was derived from a 6-month inhalation study in guinea pigs, which indicated no adverse effects in growth at a dose of 90 mg/kg-day (EPA 1989). An uncertainty factor of 1,000 was used to address the extrapolation of results to humans. The RfD has been withdrawn from the Integrated Risk Information System (IRIS) and is currently under review. A new value of 0.035 mg/kg-day is cited in Smith (1996). EPA-NCEA Regional Support provisional value is 0.02 mg/kg-day (1998). A Reference Concentration (RfC) for inhalation was also calculated (EPA 1989). The RfC (0.29 mg/kg-day) has also been withdrawn from IRIS.

A final drinking water maximum contaminant level (MCL) of 200 µg/L has been established for 1,1,1-trichloroethane (EPA 1994).

Summary of 1,1,1-Trichloroethane Criteria

EPA Carcinogen Classification	Group D	EPA 2001
Oral RfD	0.02 mg/kg-day	EPA 1998
Inhalation RfC (withdrawn)	0.29 mg/kg-day	EPA 1998
Final MCL	200 µg/L	

References

ATSDR (Agency for Toxic Substances and Disease Registry). 1990. *Draft Toxicological Profile for 1,1,1-Trichloroethane.*

EPA (U.S. Environmental Protection Agency). 1989. *Health Effects Assessment Summary Tables. Fourth Quarter*. Environmental Criteria and Assessment Office.

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________. 1994. *Integrated Risk Information System (IRIS).*

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RTI (Research Triangle Institute). 1987. *Absorption, Disposition, Metabolites, and Excretion of 1,1,1-Trichloroethane (TCEN).* RTI-213/311T-3662. Prepared for the National Institute of Environmental Health by Research Triangle Institute.

1,2-Dichloroethane (1,2-DCA)

Introduction

1,2-Dichloroethane (1,2-DCA) is a man-made, colorless, oily liquid. It is principally used as an intermediate in the manufacture of ethylene glycol, diaminoethylene, polyvinyl chloride, nylon, rubber, viscose rayon, and various plastics. It is used as a dry-cleaning agent, a pickling agent, and has various uses in the production of cosmetics, in photography, and in water softening. It is also an agricultural fumigant used for postharvest grains in orchards and in mushroom houses. 1,2-DCA is being replaced as a solvent and degreaser by less toxic compounds. The major releases to the environment occur during production of other products.

Toxicokinetics

Data on the pharmacokinetics of 1,2-DCA in humans are limited, but data from animal studies suggest that the chemical is rapidly adsorbed following oral and inhalation exposure and after dermal contact with the liquid form of the compound (EPA 1985). Reitz, et al. (1982) reported that a 150 mg/kg bw oral dose of radio-labeled 1,2-DCA given to rats was completely absorbed 48 hours after administration, and Spreafico, et al. (1978, 1979, 1980) reported 78 percent absorption in rats given a single oral dose of 25 mg/kg bw 1,2-DCA in a water vehicle. Absorption rates of inhaled 1,2-DCA have not been quantified, but because the chemical has a moderately high vapor pressure (80 mm Hg at 25 degrees C) and a high blood-air partition coefficient (19.5), pulmonary absorption is probably rapid and complete (EPA 1984). Dermal absorption of 1,2-dichloroethane following vapor exposure is negligible, but direct skin application studies in mice (Tsuruta 1975, 1977) and guinea pigs (Jakobson, et al. 1983) indicate that percutaneous absorption following direct liquid contact can be substantial and is linearly related to exposure duration.

After peroral or pulmonary absorption, 1,2-DCA is distributed to all body tissues. The substance readily passes the blood-brain and placental barriers (EPA 1985). In rats, the highest tissue concentrations following acute exposure are reached in the adipose tissue, followed by the blood and liver (Spreafico, et al. 1978, 1977, 1980).

Studies in mice (Yllner 1971) and rats (Reitz, et al. 1980, 1982) indicate that 1,2-DCA is extensively metabolized, and the liver is the primary site of metabolic activity (EPA 1985). 1,2-dichloroethane is metabolized to 2-chloroacetaldehyde, S-(2-chloroethyl)-glutathione, and other putative reactive metabolites capable of covalent binding to cellular macromolecles (EPA 1985). Metabolism appears to be dose related; percent metabolized decreases as dose increases (Yllner 1971; Reitz, et al. 1980). Elimination of unmetabolized 1,2-DCA is almost exclusively through the lungs (EPA 1985).

Qualitative Description of Health Effects

Carcinogenicity

No epidemiological data are available to evaluate the carcinogenicity of 1,2-DCA in humans. Several chronic bioassays of 1,2-DCA have been conducted in animals and some of these are outlined below.

In a study sponsored by the National Cancer Institute (NCI), groups of 50 male and 50 female 9-week-old Osborne-Mendel rats were administered technical grade 1,2-DCA (99 percent pure) in corn oil by gavage 5 days/week for 78 weeks (NCI 1978). Surviving animals were observed for up to 32 weeks following termination of treatment. The time-weighted average doses were 95 and 47 mg/kg bw/day for high- and low-dose males and females. A group of 20 male and 20 female rats received corn oil alone and were used as matched vehicle controls, and an additional group of 60 male and 60 female rats received corn oil and were used as pooled vehicle controls. (The group of matched vehicle controls was not considered in the statistical analyses of tumor incidences). Mortality was increased in the high-dose group; all high-dose females were dead by week 15 of the observation period. All treated and control animals were histologically examined. A statistically significant increase in total number of tumors in high-dose females was observed when compared with pooled controls. Additionally, statistically significant increases in the incidence of squamous-cell carcinomas of the forestomach in high-dose male rats and mammary gland adenocarcinomas in high-dose female rats were observed. Low-dose males and females showed higher incidences of hemangiosarcomas than high-dose animals. There was a statistically significant positive trend in the incidence of hemangiosarcomas in male and female rats as compared with pooled vehicle controls.

In a second oral-dose study sponsored by NCI (1978), groups of 50 male and 50 female 5-week-old B6C3F1 mice were administered technical grade (99 percent pure) 1,2-5 in corn oil by gavage 5 days/week for 78 weeks, followed by a 12-week (females) or 13-week (males) period without treatment. The time-weighted doses were 195 and 299 mg/kg bw/day for high-dose males and females, respectively, and 97 and 149 mg/kg bw/day for low-dose males and females, respectively. A group of 60 male and 60 female mice received corn oil alone and served as pooled vehicle controls. Of the high-dose animals, 42 percent of the males survived until the end of the study, and 72 percent of the females died between weeks 60 and 80. In the low-dose group, 48 percent of the males survived more than 74 weeks, and 68 percent of the females survived until the end of the study. In the vehicle control groups, 55 percent of the males and 80 percent of the females survived until the end of the study. When compared with controls, the number of animals with tumors and the total number of tumors were significantly greater in both male and female high-dose mice and also in low-dose female mice.

Mutagenicity

1,2-DCA has been shown to cause gene mutations in bacteria, plants, Drosophila, and cultured Chinese hamster ovary cells (EPA 1985). The majority of in vitro tests have reported marginal positive responses without metabolic activation and stronger positive responses with exogenous hepatic metabolic activation, indicating that 1,2-DCA maybe mutagenic by itself but that metabolites are more potent mutagens. In addition, 1,2-DCA also has been observed to cause meiotic chromosomal nondisjunction in Drosophila and to alkylate DNA in several somatic tissues in the rat (EPA 1985).

Teratogenicity/Reproductive Effects

Available data suggest that 1,2-DCA does not adversely affect reproductive or developmental processes in experimental animals except at maternally toxic levels (EPA 1985). However, data are limited, and additional experimental and epidemiological studies are needed to conclusively demonstrate that this compound is not a human teratogen and does not produce adverse reproductive effects.

Chronic Toxicity

Data on chronic toxicity of 1,2-DCA in humans are primarily limited to foreign case reports and health surveys. Repeated exposure to 1,2-DCA vapor in the work place has been reported to result in anorexia, nausea, vomiting, weakness and fatigue, nervousness, epigastric pain, and irritation of the respiratory tract and eyes (EPA 1984, 1985). Kozik (1957) reported that workers in the Russian aircraft industry who were exposed for at least 4 years to approximately 10- to 15-ppm 1,2-DCA experienced increased incidences of gastrointestinal disease, liver and gallbladder disease, and diseases of the muscles, tendons, and ganglia. Cetnarowicz (1959) reported dizziness, fatigue, drowsiness, nausea, and epigastric pain in Polish oil refinery workers exposed to 1,2-DCA concentrations between 10 and 200 ppm for an unspecified period of time.

Chronic studies in animals also have revealed toxic effects following inhalation exposure. Spencer, et al. (1951) exposed 8 guinea pigs of both sexes, 1 female and 2 male rabbits, and 2 male monkeys to 1,2-DCA vapor at concentrations of 400 and 100 ppm for 7 hours/day, 5 days/week for 6 months. In addition, 15 rats of both sexes and 8 guinea pigs of both sexes were similarly exposed to 200-ppm 1,2-DCA for 151 and 180 seven-hour periods, respectively. Exposure to 200-ppm 1,2-DCA caused parenchymatous degeneration of the liver in guinea pigs. Severe toxic effects were found in all animals exposed to the 400-ppm concentration, but no toxic effects were observed in any animals exposed to the 100-ppm concentration.

Heppel, et al. (1946) observed increased mortality and/or significant pathological changes in various organs of rats, rabbits, and guinea pigs exposed to 1,000 or 400 ppm of 1,2-DCA 7 hours/day for 5 days/week but not in animals similarly exposed to concentrations of 100 ppm.

No pertinent data on chronic oral toxicity of 1,2-DCA in humans were located in the available literature, and limited reports of chronic oral exposure in laboratory animals were available. In the NCI (1978) bioassay previously discussed, groups of 50 male and 50 female Osborne-Mendel rats were treated by gavage with time-weighed average (TWA) 1,2-DCA concentrations of 45 or 74 mg/kg bw/day, respectively, for 78 weeks and observed for up to an additional 32 weeks. Groups of 50 male and 50 female B6C3F1 mice were treated by gavage with TWA doses of 195 or 97 mg/kg bw/day (male) or 299 or 149 mg/kg bw/day (female) 1,2-DCA for 78 weeks, followed by a 12- to 13-week observation period. No significant dose-related body weight depression in rats of either sex was noted, but there was increased mortality, particularly in high-dose groups. Mean body weight depression was noted as early as week 15 of the study in high-dose female mice but not in high- or low-dose males or low-dose females.

In a chronic feeding study, rats received diets containing 1,2-DCA at concentrations of 0, 250, or 500 mg/kg fed for 2 years (Alumot, et al. 1976). No biochemical or histopathological abnormalities attributable to 1,2-DCA were observed. However, there was a widespread incidence of chronic respiratory disease and low survival rates. A lack of detailed data prevents establishment of the actual dose administered.

Acute Toxicity

Effects of acute inhalation exposure in humans are similar to those observed in humans following chronic work-time exposure and include irritation of mucous membranes and the respiratory tract and central nervous system depression (EPA 1985). Death may occur as a result of respiratory and circulatory failure. Pathological examinations typically show congestion, degeneration, necrosis, and hemorrhagic lesions of most internal organs, including the liver, kidney, spleen, lungs, and respiratory and gastrointestinal tracts (EPA 1985). Adverse effects caused by less extreme exposures were generally associated with the gastrointestinal and nervous systems.

Quantitative Description of Health Effects

1,2-DCA has been classified as a Group B2 carcinogen a probable human carcinogen (EPA 1994). This category applies to agents for which inadequate evidence of carcinogenicity from human studies and sufficient evidence of carcinogenicity from animal studies exists.

EPA (1985a) derived a cancer slope factor for ingestion of 1,2-DCA based on the incidence of hemangiosarcomas in Osborne-Mendel male rats observed in the NCI (1978) gavage study outlined previously. The final time-weighted average doses in male and female rats were 95 and 47 mg/kg-day for the high- and low-dose groups, respectively. Animals were observed for up to 32 additional weeks before sacrifice. Based on the hemangiosarcoma response in male rats using a time-to-death adjustment and an adjusted dose derived from the metabolism/kinetic evaluation, EPA used the multistage model to estimate an upperbound carcinogenic slope factor of 9.1×10^{-2} $(mg/kg\text{-}day)^{-1}$ for ingestion of 1,2-DCA. The inhalation carcinogenic slope factor is also 9.1×10^{-2} $(mg/kg\text{-}day)^{-1}$.

EPA (1980) also based the ambient water quality criterion for 1,2-DCA on the incidence of hemangiosarcomas observed in male rats in the NCI (1978) study previously discussed. However, because a somewhat different approach was used, a cancer potency factor of 3.7×10^{-2} (mg/kg-day)$^{-1}$ was derived. The resulting water concentration to keep the lifetime excess cancer risk below 10^{-6} was 0.94 µg/L. This value assumes ingestion of contaminated water and aquatic organisms (e.g., fish) from the contaminated water. Without consumption of contaminated aquatic organisms, a lifetime cancer risk of 10^{-6} would be associated with ingestion of water containing 0.95 µg/L of 1,2-DCA.

EPA Office of Drinking Water established a maximum contaminant level (MCL) of 5 µg/L (EPA 1993). The maximum contaminant level goal (MCLG) is 0 µg/L. MCLGs are zero for all carcinogens. The EPA Office of Drinking Water also developed a longer-term health advisory (HA) for 1,2-DCA based upon results of two chronic inhalation studies (Heppel, et al. 1946; Spencer, et al. 1951) and one subchronic inhalation study (Hoffmann, et al. 1971) in which various animal species were exposed to 1,2-DCA. In these studies, exposure to air containing 100-ppm 1,2-DCA for 6 to 7 hours/day, 5 days/week for up to 8 months resulted in no mortality and no adverse effects on behavior, growth, organ function, or blood chemistry. Similar exposures to 400 to 500 ppm 1,2-DCA resulted in high mortality and various pathological effects (Heppel, et al. 1946). The 100-ppm level (405 mg/m^3) was used as the no-observable-adverse-effect level (NOAEL) for the determination of the HA. The HAs derived for a 10-kg child consuming 1 liter of water per day and for a 70-kg adult consuming 2 liters of water per day are 740 µg/L and 2, µg/L, respectively.

Summary of Criteria

Criterion	Value	Source
EPA carcinogen classification oral and inhalation	Group B2	EPA 1994
Oral carcinogenic slope factor	9.1×10^{-2} (mg/kg-day)$^{-1}$	EPA 2001
Inhalation carcinogenic slope factor	9.1×10^{-2} (mg/kg-day)$^{-1}$	EPA 2001
Oral Reference Dose	0.03 mg/kg-day	EPA 1998
Longer-Term HA		
Child	740 µg/L	EPA 1994
Adult	2,600 µg/L	EPA 1994
Final MCL	5 µg/L	EPA 1994
Final MCLG	0 µg/L	EPA 1994
AWQC (Water and Fish Consumption)	0.94 µg/L	EPA 1994

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1,2-Dichloroethene

Introduction

1,2-dichloroethene is a highly flammable, colorless liquid that is commonly used in the production of chemical mixtures and solvents. The chemical is a mixture of two isomers, *cis*- and *trans*-1,2-dichloroethene, with the proportion of each isomer depending upon the manufacturer's specifications.

1,2-dichloroethene enters the environment by release from chemical factories, by leaching or evaporation from landfills, from chemical spills, from the burning of vinyl-containing objects, and from breakdown of tetra- and trichloroethene.

1,2-dichloroethene volatilizes rapidly from soil and surface water and is therefore not persistent in these media. Leaching of 1,2-dichloroethene through soil commonly results in the contamination of groundwater. Removal of the chemical from the atmosphere occurs predominantly via photochemical reactions in the troposphere. Removal of 1,2-dichloroethene in soil occurs predominantly by anaerobic microbial degradation.

The following information has been summarized from ATSDR 1990 and EPA 1995a.

Toxicokinetics

Both *trans*- and *cis*-1,2-dichloroethene isomers are readily absorbed via the lung in animals (Filser and Bolt 1979) and humans (Lehmann and Schmidt-Kehl 1936). No information is available regarding absorption following dermal or oral exposure.

1,2-dichloroethene is metabolized to dichloroethanol and dichloroacetic acid (Borse, et al. 1975). The *cis*-isomer is metabolized at a faster rate than the *trans*- isomer (Costa and Ivanetich 1982).

No information is available concerning the excretion of 1,2-dichloroethene after exposure by oral, dermal, or inhalation exposure.

Qualitative Description of Health Effects

Acute/Chronic Toxicity

Inhalation of a high concentration of 1,2-dichloroethene has resulted in death in at least one case (Hamilton 1934). Inhalation of 1,2-dichloroethene has also been associated with nausea, drowsiness, fatigue, increased intracranial pressure, and ocular irritation in humans.

In animal studies perturbations in the humoral immune system and lung effects have been observed following inhalation of *trans*-1,2-dichloroethene. Immune system effects include suppressed spleen cell antibody production against sheep erythrocytes in rats (Shopp, et al. 1985) and fatty degeneration of liver Kupffer cells (Freundt, et al.

1977). Kupffer cells are phagocytic macrophages involved in protecting the systemic circulation from gastrointestinal bacteria. Effects to the lung include pulmonary capillary hyperemia, alveolar septal distention, and pulmonary edema in rats (Freundt, et al. 1977). Fibrous swelling of the myocardium and hyperemia of the heart are also observed in rats following inhalation of *trans*-1,2-dichloroethene (Freundt, et al. 1977).

No information is available regarding toxicity of 1,2-dichloroethene in humans following oral or dermal exposure.

Ingestion of acute doses of more than 1,000 mg/kg were lethal to mice and rats (Barnes, et al. 1985; Hayes, et al. 1987). Liver pathological effects similar to those caused by inhalation exposure have been observed following ingestion of *trans*-1,2-dichloroethene (Freundt, et al. 1977). Near-lethal doses were needed to elicit these effects, however.

Evidence from *in vivo* tests indicate that *cis*-1,2-dichloroethene is mutagenic, but the *trans*-1,2-dichloroethene isomer is not (Cerna and Kypenova 1977).

Quantitative Description of Health Effects

The *cis*- and *trans*-1,2-dichloroethene isomers have been classified as Group D carcinogens. For chemicals in this category, no data regarding carcinogenicity in humans exists, and the evidence for carcinogenicity in animals is inadequate.

The oral RfD for *trans*-1,2-dichloroethene is 2 x 10^{-2} mg/kg-day (EPA 1995a). The RfD is based on a study by Barnes, et al. (1985) in which male mice were exposed to *trans*-1,2-dichloroethene in drinking water for 90 days. Administered doses were 17, 175, or 387 mg/kg-day. Significant increases in serum alkaline phosphatase levels were observed at doses of 175 and 387 mg of 1,2-dichloroethene per kg/day. At doses of 17 mg of *trans*-1,2-dichloroethene per kg/day, no changes in serum alkaline phosphatase levels were observed. An uncertainty factor of 1,000 was applied to the RfD to allow for uncertainty in the extrapolation of dose levels from laboratory animals to humans, uncertainty in the threshold for sensitive humans, and uncertainty in the effect of duration when extrapolating from subchronic to chronic exposure (EPA 1995a). The RfD is based on the NOAEL of 17 mg/kg-day.

The RfD for *cis*-1,2-dichloroethene was based on a study by McCauley, et al. (no date, as cited in EPA 1991), in which rats were exposed to daily doses of 32 mg/kg of *cis*-1,2-dichloroethene by gavage for 90 days. The effects of concern were decreased hematocrit and hemoglobin levels (EPA 1991). The RfD of 1 x 10^{-2} mg/kg-day is currently under review by EPA and is subject to change (EPA 1994).

The maximum contaminant levels (MCLs) for *trans*- and *cis*-1,2-dichloroethene are 100 µg/L and 700 µg/L, respectively (EPA 1995b). The maximum contaminant level goals (MCLGs) are equal to the MCLs.

Summary of 1,2-Dichloroethene Criteria

Criterion	Value	Source
trans-1,2-Dichloroethene		
EPA Carcinogen Classification	Group D	EPA 1995a
Oral RfD	2×10^{-2} mg/kg-day	EPA 1995a
MCL/MCLG	100 µg/L	EPA 1995b
cis-1,2-Dichloroethene		
EPA Carcinogenic Classification	Group D	EPA 1995a
Oral RfD (under review)	1×10^{-2} mg/kg-day	EPA 1994
MCL/MCLG	70 µg/L	EPA 1995b

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Benzene

Introduction

Benzene is a volatile, colorless, flammable liquid aromatic hydrocarbon that has a characteristic odor. It is a chemical intermediate in the synthesis of compounds such as styrene, synthetic rubber, and phenol, and it is used as an additive to gasoline to increase the octane. Information in this toxicity profile has been summarized from the Agency for Toxic Substances and Disease Registry (ATSDR) profile on benzene[1] and other sources, as indicated.

Potential for Human Exposure

Releases to the Environment

Benzene is released to the environment by both natural and man-made sources; however, natural sources account for only a very small part of benzene releases. Major sources of atmospheric releases include vehicle exhaust emissions, evaporative gasoline fumes, emissions from vehicle refueling (i.e., service stations), and industrial emissions. In 1984, motor vehicle exhaust accounted for almost 80% of total emissions in California.[2] Other sources of atmospheric benzene include cigarette smoke and the exhaled breath of smokers, landfill emissions, off-gassing from particle board, and emissions from structural fires. Benzene is released to soils and water from industrial discharges, landfill leachate, and gasoline leaks from underground storage tanks.[3]

Environmental Fate

Benzene is water-soluble and highly volatile. Atmospheric benzene is removed primarily through chemical degradation. Due to its water-solubility, some benzene is removed from the atmosphere in rainwater. Benzene in soil and water is removed through volatilization, photooxidation, and biodegradation.

Environmental Levels

Air: Benzene is ubiquitous in the atmosphere. It has been detected in outdoor air samples from rural and urban areas and in indoor air. Results of the U.S. Environmental Protection Agency (EPA) Total Exposure Assessment Methodology (TEAM) studies in the 1980s indicated that exposure to benzene in water, food, and beverages is insignificant; more than 99% of total personal exposure to benzene was through inhalation of benzene in the air.[4] Wilson et al.[5]

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[1] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene*. Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

[2] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene*. Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

[3] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene*. Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

[4] Wallace, L. Environmental Exposure to Benzene: An Update. *Environmental Health Perspectives* 104(6): 1129-1136. 1996.

[5] Wilson, A.L., S.D. Colome, and Y. Tian. California Residential Indoor Air Quality Study. Volume 1: Methodology and Descriptive Statistics. Irvine, CA: Integrated Environmental Services. 1993.

measured indoor and outdoor 48-hour average benzene concentrations at 161 homes throughout much of California. Indoor mean concentrations were 8.3 micrograms per meter cubed (:g/m^3) compared to 6.1 :g/m^3 outdoors.[6]

Twenty-four hour average benzene levels have been measured every twelfth day at about 20 sites throughout California since 1986 by the California Air Resources Board (CARB).[7] From 1986 to 1992, statewide annual average benzene concentrations ranged from 9 to 6 :g/m^3. For the years 1989 to 1992, the average concentration was 7 :g/m^3. In 1993 and 1994, the statewide annual average values dropped to 4 :g/m^3. The decline appears to be due to one or more of several factors: a) the 50% reduction in hydrocarbon emissions mandated for new cars; b) the Stage II vapor recovery controls recently in effect; and c) a reduction in benzene content in gasoline down to the 1% mandated in the 1990 Clean Air Act Amendments. Analysis of the California database indicates seasonal variation in benzene concentrations, with winter values about twice summer values. This may be due to changes in the blend of gasoline or to increased likelihood of inversions during the winter.

The South Coast Air Quality Management District (SCAQMD)[8] characterized in-vehicle benzene exposure for Los Angeles commuters in summer and winter seasons. In-vehicle benzene exposure averaged 40 :g/m^3 for commuters during rush hour, approximately 5 times greater than concentrations at a fixed outdoor site. Benzene concentration in the gasoline used was not measured; benzene content in gasoline has been reduced from 2 or 3% to 1% since this study was conducted. Smaller studies conducted more recently in North Caroline and New Jersey-New York have also shown increased benzene concentrations while driving.[9] These later studies showed lower in-vehicle exposures, but outdoor concentrations were also less, so the ratio of personal exposure to outdoor concentration continued to range from 5 to 10. Decreased concentrations could be due to the difference in location or could reflect reductions of benzene in gasoline.[10]

The primary source of benzene exposure for cigarette smokers is mainstream cigarette smoke.[11] A typical smoker takes in roughly 2 milligrams (mg) of benzene per day; about 1.8 mg is delivered by mainstream smoke.[12] A typical nonsmoker inhales about 0.2 mg benzene per day.[13] The majority of benzene exposure for nonsmokers is from automotive exhaust or

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[6] Wilson, A.L., S.D. Colome, and Y. Tian. California Residential Indoor Air Quality Study. Volume 1: Methodology and Descriptive Statistics. Irvine, CA: Integrated Environmental Services. 1993.

[7] Wallace, L. Environmental Exposure to Benzene: An Update. *Environmental Health Perspectives* 104(6): 1129-1136. 1996.

[8] South Coast Air Quality Management District. In-vehicle Characterization Study in the South Coast Air Basin, Los Angeles. 1989.

[9] Wallace, L. Environmental Exposure to Benzene: An Update. *Environmental Health Perspectives* 104(6): 1129-1136. 1996.

[10] Wallace, L. Environmental Exposure to Benzene: An Update. *Environmental Health Perspectives* 104(6): 1129-1136. 1996.

[11] Wallace, L., E. Pellizzari, T. Hartwell, K. Perritt, and R. Ziegenfus. Exposures to Benzene and Other Volatile Organic Compounds from Active and Passive Smoking. *Arch Environ. Health* 42: 272-279. 1987.

[12] South Coast Air Quality Management District. In-vehicle Characterization Study in the South Coast Air Basin, Los Angeles. 1989.

[13] South Coast Air Quality Management District. In-vehicle Characterization Study in the South Coast Air Basin, Los Angeles. 1989.

gasoline vapor emissions. This includes most outdoor air benzene exposure, indoor exposures due to intrusion of evaporative gasoline fumes from attached garages, and personal activities such as driving.[14] About 10% of nonsmoker exposure comes from environmental tobacco smoke exposures at home or work. Smokers have an average benzene body burden of about 6 to 10 times that of nonsmokers.[15]

Water: A number of studies have reported finding benzene at concentrations of 5 nanograms per liter (ng/L) in surface water and well water.[16,17] Assuming ingestion of 2 liters of water daily, this corresponds to a daily intake of 10 ng benzene. This is only 5% of the average daily intake for nonsmokers of 200 ng from air. Studies of benzene exposure while showering in water contaminated by a gasoline spill indicated that 20-minute exposure to volatilized benzene while showering was on the same order of magnitude as a full days exposure to benzene for a typical nonsmoker.[18,] A smoker would still get the majority of exposure through smoking.

Soil and Sediment: Benzene levels ranging from <2 to 191 parts per billion (ppb) were recorded in the vicinity of five industrial facilities using or producing benzene.[19] Data from EPA's Storage and Retrieval (STORET) database (1980 - 1982) showed that benzene had been positively detected in sediment samples taken at 9% of 355 observation stations with a median level of < 5 ppb.[20]

Other Environmental Media: The TEAM study concluded that food and beverages contained minimal concentrations of benzene. Recent studies have confirmed the results of the TEAM study. A U.S. Food and Drug Administration (FDA) study analyzed more than 50 foods for benzene. Most foods contained less than 2 nanograms per gram (ng/g) parts per billion by weight (ppbw).[21] Exceptions included strawberry preserves (38 ng/g), taco sauces (9 and 22 ng/g), duck sauce (7 ng/g), and barbecue sauce (5 ng/g).

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[14] South Coast Air Quality Management District. In-vehicle Characterization Study in the South Coast Air Basin, Los Angeles. 1989.

[15] South Coast Air Quality Management District. In-vehicle Characterization Study in the South Coast Air Basin, Los Angeles. 1989.

[16] Wallace, L. Environmental Exposure to Benzene: An Update. *Environmental Health Perspectives* 104(6): 1129-1136. 1996.

[17] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene.* Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

[18] Wallace, L. Environmental Exposure to Benzene: An Update. *Environmental Health Perspectives* 104(6): 1129-1136. 1996.

[19] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene.* Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

[20] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene.* Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

[21] Wallace, L. Environmental Exposure to Benzene: An Update. *Environmental Health Perspectives* 104(6): 1129-1136. 1996.

Toxicokinetics

Benzene is readily absorbed into the body via ingestion and inhalation. Dermal absorption is somewhat slower. It is stored in the bone marrow, liver, kidney, and body fat. The body metabolizes benzene through several pathways; some of the metabolites formed (i.e., hydroquinone, phenol, and muconic dialdehyde) can produce hematotoxic effects. Following inhalation exposure to benzene, the majority of the compound is excreted unchanged in exhaled air.[22] Absorbed benzene is excreted primarily in the urine following metabolism; some benzene may be accumulated in the body.[23]

Qualitative Description of Health Effects

Carcinogenicity

Many case studies have described a causal relationship between exposure to benzene (concentrations unspecified) by inhalation (either alone or in combination with other chemicals) and leukemia in humans[24,25.] Most cases were acute myelogenous leukemia, although some were monocytic, erythroblastic, or lymphocytic. Various hematological disorders other than leukemia have also been reported; these include pancytopenia (reduction in the number of red blood cells, white blood cells, and platelets) and aplastic anemia (cessation of bone marrow function).[26]

A series of epidemiological studies, both cohort and case-control, showed statistically significant associations between leukemia and occupational exposure (concentration unspecified) to benzene.[27,28,29,30] These results have been replicated in a number of countries and in different industries.[31]

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[22] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene*. Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

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[24] International Agency for Research on Cancer. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Volume 27: Some Aromatic Amines, Anthraquinones and Nitroso Compounds, and Inorganic Fluorides Used in Drinking-Water and Dental Preparations. World Health Organization, Lyon, France. 1982.

[25] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene*. Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

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[31] International Agency for Research on Cancer. IARC Monographs on the Evaluation of the Carcinogenic Risk of

The carcinogenicity of benzene has been evaluated in rats and mice by various routes of exposure (inhalation, oral, dermal, subcutaneous). Oral exposure to benzene has been associated with increased incidences of zymbal gland and mammary gland carcinomas, oral cavity carcinomas, and lymphomas.[32,33,34] Inhalation exposure to benzene has been associated with thymic and nonthymic lymphoma, hematopoietic neoplasms, zymbal gland carcinomas, carcinomas of the oral and nasal cavities, and other malignant tumors.[35,36,37] Leukemia has been observed in studies in which benzene was administered by subcutaneous injection; however, these studies were limited by lack of controls and high incidences of leukemia in untreated controls.[38]

Mutagenicity

Benzene does not induce gene mutations in bacterial systems and has not been found to be a point mutagen in mammalian cells. However, benzene did induce cytogenetic abnormalities in mammalian cells in vitro (chromosomal aberrations and sister-chromatid exchanges). Several studies demonstrate that benzene exposure of laboratory animals in vivo leads to chromosomal aberrations in bone marrow cells. There is a clear correlation between exposure to benzene and the appearance of chromosomal aberrations in the bone marrow and in peripheral lymphocytes of individuals exposed to high levels of benzene (more than 100 parts per million [ppm]).[39] Examination of workers occupationally exposed to benzene shows increased incidence of lymphocytes with unstable chromosomal aberrations. Additional case studies also support the chromosomal damaging effects of benzene.[40]

Chemicals to Humans. Volume 27: Some Aromatic Amines, Anthraquinones and Nitroso Compounds, and Inorganic Fluorides Used in Drinking-Water and Dental Preparations. World Health Organization, Lyon, France. 1982.

[32] National Toxicology Program. *Toxicology and Carcinogenesis Studies of Benzene (CAS No. 71-43-2) in F344/N Rats and B6C3F1 Mice (Gavage Studies).* Technical Report Series No 289. NIH Publication No. 86-2545. 1985.

[33] U.S. Environmental Protection Agency. *Integrated Risk Information System (IRIS).* Benzene. Online; Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office. Cincinnati, Ohio. 2000.

[34] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene.* Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

[35] Cronkite, E.P., R.T. Drew, T. Inone, and J.E. Bullis. Benzene Hematotoxicity and Leukemogenesis. *Am. J. Ind. Med.* 7:447-456. 1985.

[36] Snyder, C.A., B.D Goldstein, A.R. Sellakumar, I. Bromberg, S. Laskin, and R.E. Albert. The Inhalation Toxicology of Benzene: Incidence of Hematopoietic Neoplasms and Hematotoxicity in AKR/J and C57BL/6J Mice. *Toxicol. Appl. Pharmacol.* 54:323-331. 1980.

[37] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene.* Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

[38] International Agency for Research on Cancer. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Volume 27: Some Aromatic Amines, Anthraquinones and Nitroso Compounds, and Inorganic Fluorides Used in Drinking-Water and Dental Preparations. World Health Organization, Lyon, France. 1982.

[39] International Agency for Research on Cancer. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Volume 27: Some Aromatic Amines, Anthraquinones and Nitroso Compounds, and Inorganic Fluorides Used in Drinking-Water and Dental Preparations. World Health Organization, Lyon, France. 1982.

[40] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene.* Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR.

Teratogenicity/Reproductive Effects

Data suggest that occupational exposure to benzene may impair reproduction in women, however, findings are inconclusive because the studies are limited.[41] Inhalation experiments conducted in rats, mice, guinea pigs, and rabbits suggest that benzene is not teratogenic at doses that are fetotoxic and embryolethal.[42] Studies with pregnant animals indicate that inhalation exposure to benzene may have adverse effects on the developing fetus, including low birth weight, delayed bone formation, and bone marrow damage.[43] Animal experiments in rats, guinea pigs, and rabbits suggest that exposure to benzene vapors may damage the testicles and ovaries.[44]

Acute/Chronic Effects

The toxic effects of benzene vapors in humans exposed occupationally and in experimental animals include central nervous system effects, hematological effects, and effects on the immune system.[45]

In humans, acute inhalation of benzene concentrations ranging from 300 to 3,000 ppm produces central nervous system effects that include dizziness, drowsiness, headache, vertigo, tremor, delirium, and coma.[46] Acute exposure (5 to 10 minutes) to higher concentrations of benzene vapor (10,000 to 20,000 ppm) can result in death.[47] In cases not resulting in death, individuals exhibited symptoms similar to those reported for lower exposures, such as headaches, nausea, staggering, paralysis, convulsions, and coma.[48] Death is usually the result of respiratory or cardiac failure.[49] In laboratory animals, acute exposures to high concentrations of benzene vapors cause depression of the central nervous system.[50]

1995.

[41] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene*. Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

[42] International Agency for Research on Cancer. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Volume 27: Some Aromatic Amines, Anthraquinones and Nitroso Compounds, and Inorganic Fluorides Used in Drinking-Water and Dental Preparations. World Health Organization, Lyon, France. 1982.

[43] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene*. Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

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[47] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene*. Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

[48] Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene*. Prepared by Clement International Corporation for U.S. Department of Health and Human Services, Public Health Service, ATSDR. 1995.

[49] National Academy of Science. *Health Effects of Benzene: A Review Committee on Toxicology, Assembly of Life*

Chronic human exposure to benzene vapors can cause a continuum of changes in the circulatory blood elements and bone marrow precursors.[51] Leukopenia, thrombocytopenia, anemia, or combinations of these all occur. In early stages of such blood dyscrasias, effects appear to be reversible. Exposure for longer periods of time may lead to pancytopenia or aplastic anemia, which are irreversible.[52]

Leukopenia is the most commonly observed effect of chronic benzene exposure in laboratory animals. Longer exposure periods may lead to pancytopenia and general bone marrow depression.[53]

Immune system depression by benzene is well known. Depression of serum antibodies (IgG and IgA) in workers exposed occupationally to benzene (exposure concentration unspecified) has been reported.[54] However, the workers were exposed to multiple solvents making it difficult to conclude that benzene exposure alone was responsible for the adverse effects noted. Cellular immunity is also impacted by benzene exposure; workers exposed chronically to benzene vapors had reduced leukocytes and lymphocytes.[55] It has been demonstrated that administration of benzene to mice inhibits the function of B- and T-lymphocytes tested in vitro.[56] These observations, as well as the well-known ability of benzene to depress leukocytes, may explain why benzene-exposed individuals readily succumb to infection and the terminal event in severe benzene toxicity is often overwhelming infection.[57]

Quantitative Description of Health Effects

Applying EPA's criteria for evaluating the overall weight of evidence of carcinogenicity to humans[58], benzene has been classified in Group A-Human Carcinogen.[59] Epidemiological

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Sciences. National Research Council, Washington, DC. 1976.

[50] U.S. Environmental Protection Agency. Draft Health Advisory for Benzene. Office of Drinking Water, Washington, DC. September 30, 1985.

[51] U.S. Environmental Protection Agency. Draft Health Advisory for Benzene. Office of Drinking Water, Washington, DC. September 30, 1985.

[52] International Agency for Research on Cancer. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Volume 27: Some Aromatic Amines, Anthraquinones and Nitroso Compounds, and Inorganic Fluorides Used in Drinking-Water and Dental Preparations. World Health Organization, Lyon, France. 1982.

[53] U.S. Environmental Protection Agency. National Primary Drinking Water Regulations; Volatile Synthetic Organic Chemicals, Final Rule. *Fed. Reg.* 50:46,880-46,901. November 13, 1985.

[54] U.S. Environmental Protection Agency. National Primary Drinking Water Regulations; Volatile Synthetic Organic Chemicals, Final Rule. *Fed. Reg.* 50:46,880-46,901. November 13, 1985.

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[56] International Agency for Research on Cancer. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Volume 27: Some Aromatic Amines, Anthraquinones and Nitroso Compounds, and Inorganic Fluorides Used in Drinking-Water and Dental Preparations. World Health Organization, Lyon, France. 1982.

[57] International Agency for Research on Cancer. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Volume 27: Some Aromatic Amines, Anthraquinones and Nitroso Compounds, and Inorganic Fluorides Used in Drinking-Water and Dental Preparations. World Health Organization, Lyon, France. 1982.

[58] U.S. Environmental Protection Agency. Evaluation of the Potential Carcinogenicity of Benzene (71-43-2). Prepared by Carcinogen Assessment Group for the Office of Response. Washington, DC. OHEA-C-073-29.

studies indicating increased incidence of nonlymphocytic leukemia from occupational exposure, increased incidence of neoplasia in rats and mice exposed by inhalation and gavage, and supporting data form the basis for this classification.[60]

The EPA Carcinogen Assessment Group (CAG) calculated an oral cancer slope factor for benzene derived from human epidemiological studies[61,62,63] in which significantly increased incidences of leukemia were observed for workers exposed to benzene principally by inhalation.[64,65] EPA proposed a "single best judgment" estimate of 2.9×10^{-2} (mg/kg-day)$^{-1}$ [66] A drinking water ingestion unit risk estimate of 8.3×10^{-7} (:g/L)$^{-1}$ was derived by EPA based upon human occupational exposure.[67,68] The concentration in water corresponding to a 10^{-6} excess lifetime cancer risk is 1 :g/L (EPA 2000). Risk estimates based on animal gavage studies are about 5 times higher than those derived from human data. Pharmacokinetic data that could impact the risk assessment are currently being evaluated.

EPA derived an inhalation unit risk of 8.3×10^{-6} (:g/m^3)$^{-1}$ based on the human epidemiological studies used to calculate an oral cancer slope factor (Ott, et al. 1978; Rinsky, et al. 1981; and Wong, et al. 1983). EPA provided an inhalation cancer slope factor of 2.9×10^{-2} (mg/kg-day)$^{-1}$ in its Integrated Risk Information System (IRIS) database (EPA 2000).

California Environmental Protection Agency (Cal EPA) has developed an oral and inhalation cancer potency factor for benzene of 1.0×10^{-2} (mg/kg-day)$^{-1}$. Cal EPA has also developed an inhalation unit risk value of 2.9×10^{-5} (:g/m^3)$^{-1}$.

EPA (1985d, 1996) promulgated a final drinking water maximum contaminant level goal (MCLG) of zero because benzene is a human carcinogen. A drinking water maximum

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1986.

[59] U.S. Environmental Protection Agency. *Integrated Risk Information System (IRIS)*. Benzene. Online; Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office. Cincinnati, Ohio. 2000.

[60] EPA (U.S. Environmental Protection Agency). *Integrated Risk Information System (IRIS)*. Benzene. Online; Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office. Cincinnati, Ohio. 2000.

[61] Ott, M.G., J.C. Townsend, W.A. Fishbeck, and R.A. Langner. Mortality Among Individuals Occupationally Exposed to Benzene. *Arch. Environ. Health*. 33:3-10. 1978.

[62] Rinsky, R.A., A.B Smith, R. Hornung, T.G. Filloon, R.J. Young, A.H. Okun, and P.J. Longdrigan. Benzene and Leukemia: An Epidemiologic Risk Assessment. *N. Eng. J. Med*. 316:1,044-1,050. 1987.

[63] Wong, O. An Industry-Wide Mortality Study of Chemical Workers Occupationally Exposed to Benzene. Prepared for the Chemical Manufacturers Association by Environmental Health Associates, Oakland, California. 1983.

[64] U.S. Environmental Protection Agency. Evaluation of the Potential Carcinogenicity of Benzene (71-43-2). Prepared by Carcinogen Assessment Group for the Office of Response. Washington, DC. OHEA-C-073-29. 1986.

[65] U.S. Environmental Protection Agency. *Integrated Risk Information System (IRIS)*. Benzene. Online; Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office. Cincinnati, Ohio. 2000.

[66] U.S. Environmental Protection Agency. *Integrated Risk Information System (IRIS)*. Benzene. Online; Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office. Cincinnati, Ohio. 2000.

[67] U.S. Environmental Protection Agency. *Ambient Water Quality Criteria for Benzene*. Environmental Criteria and Assessment Office, Cincinnati, Ohio. EPA 40/5-80-0018. NTIS PB 81-117293. 1980.

[68] U.S. Environmental Protection Agency. *Health Effects Assessment for Benzene*. Environmental Criteria and Assessment Office. Cincinnati, Ohio. EPA 540/1-86-037. September, 1984.

contaminant level (MCL) of 5 :g/L was finalized in 1987. MCLGs consider only health effects whereas MCLs consider analytical limitations, treatability, occurrence and cost, as well as health effects.

The EPA Office of Drinking Water developed a 1-day and 10-day health advisory (HA) of 200 :g/L for children (EPA 1996). These HAs were based on an inhalation study in which 103 mg/m^3 caused depressed white blood cell counts within two weeks. A dose of 96 mg/m^3 had no effects after two weeks (EPA 1985b). Health advisories for longer exposure periods were not developed because of the potent carcinogenic response of benzene (EPA 1985b).

Neither a reference dose (RfD) nor concentration (RfC) are available for benzene.

The American Conference of Governmental Industrial Hygienists (ACGIH 1995) has recommended an 8-hour time-weighted average threshold limit value of 10 ppm (32 mg/m^3) for occupational exposure to benzene. It was also specified that benzene should not be employed when substitute materials are available. The OSHA national regulation for occupational exposure is an 8-hour time weighted average of 1 ppm.

Summary of Benzene Criteria

Criteria	Value	Source
EPA carcinogen classification	Group A	EPA 2001
Oral cancer slope factor	5.5×10^{-2} (mg/kg-day)$^{-1}$	EPA 2001
Inhalation cancer slope factor	2.7×10^{-2} (mg/kg-day)$^{-1}$	EPA 2001
Final MCLG	0	EPA 1996
Final MCL	5 :g/L	EPA 1996
1-day and 10-day HA	200 :g/L	EPA 1996
Ambient Water Quality Criteria (Water and Fish Consumption)	0.66 :g/L	EPA 1986b

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Chloroform

Introduction

Chloroform is a clear, colorless liquid that occurs naturally and is also manufactured. The majority of manufactured chloroform is used to produce fluorocarbon-22, a refrigerant. Chloroform is also used as a solvent, fumigant, dry cleaning agent, intermediate in the preparation of dyes and pesticides, in fire extinguishers, and as an extraction and purification solvent. The primary sources through which chloroform is released to the environment are pulp and paper mills, chemical manufacturing plants, pharmaceutical manufacturing plants, chlorinated wastewater from sewage treatment plants, and chlorinated drinking water.

Toxicokinetics

Chloroform, a trihalomethane, is rapidly absorbed through the respiratory tract and gastrointestinal tract in humans and experimental animals. Dermal absorption from contact of the skin with liquid chloroform can also occur. Following inhalation or ingestion, the highest chloroform concentrations are found in tissues with high lipid contents (i.e., liver and kidneys). Elimination of chloroform is through exhalation of the unchanged compound and the primary metabolite, CO_2. The inorganic chlorine generated from chloroform metabolism is excreted through the urine (EPA 1985).

Qualitative Description of Health Effects

Carcinogenicity

Available data regarding carcinogenicity of chloroform in humans are inadequate. Several studies of populations consuming chlorinated drinking water show small significant increases in the risk of rectal, bladder, or colon cancer (EPA 1995a). However, even though chloroform was the major chlorinated organic chemical present in the drinking water, many other suspected carcinogens were also present.

Data regarding carcinogenicity of chloroform in laboratory animals is considered sufficient by EPA (1993a). Chloroform has been reported to induce renal epithelial tumors in Osborne-Mendel rats, hepatocellular carcinomas in male and female B6C3F1 mice, kidney tumors in male ICI mice, and hepatomas in female strain A mice and NCL mice (EPA 1985).

Mutagenicity

The mutagenicity of chloroform was examined in a number of tests including the *Salmonella*/microsome test, the *Drosophila* sex-linked recessive lethal test, and the micronucleus test in mice. The results of bacterial tests on chloroform were predominantly negative. However, many of the results are inconclusive because of inadequacies in the experimental protocols, including inadequate evidence that chloroform was activated or metabolized by the activation system used and the possibility that the primary reactive metabolite of chloroform, phosgene, may not have reached the bacterial DNA (EPA 1985). Results in eucaryotic test systems were primarily negative but also inconclusive.

Teratogenicity/Reproductive Effects

A number of studies indicate that chloroform can cause adverse effects in pregnancy maintenance, delays in fetal development, and fetal abnormalities in experimental animals (EPA 1985). Schwetz, et al. (1974) exposed female Sprague-Dawley rats via inhalation 7 hours/day to 30, 100, or 300 ppm reagent grade chloroform on days six to 15 of gestation. The investigators reported a significant increase in the number of resorptions at 300 ppm and an apparent decrease in conception rate. At 100 ppm, incidences of acardia (absence of tail), short tail, imperforate anus, subcutaneous edema, missing ribs, and delayed ossification of sternebrae were increased. Schwetz, et al. (1974) also reported maternal toxicity at the 100 and 300 ppm levels.

Acute/Chronic Toxicity

In humans, acute exposure to chloroform may result in death caused by ventricular fibrillation. Chloroform's use as an anesthetic may lead to delayed death attributable to liver necrosis. Exposure to chloroform may cause irritation to the skin, eyes, and gastrointestinal tract. Chronic exposure may lead to hepatic, renal, and cardiac effects, and central nervous system depression (EPA 1984b, 1985).

In experimental animals, inhalation and oral exposure to chloroform have been reported to result in systemic toxic effects. Torkelson, et al. (1976) exposed a number of species of rats via inhalation to chloroform for five days/week for six months. Exposure to 25 ppm chloroform for up to seven hours/day resulted in histopathological changes in the liver and kidneys (lobular granular degeneration and focal necrosis of the liver and cloudy swelling of the kidneys) in male but not female rats.

Roe, et al. (1979) noted severe renal changes and an increased incidence of renal tumors but no liver effects in Swiss mice exposed by gavage to 60 mg/kg-day chloroform, six days/week for 80 weeks.

Quantitative Description of Health Effects

Based on EPA's proposed guidelines for carcinogen risk assessment (EPA 1984a), chloroform has been classified in Group B2 – Probable Human Carcinogen (EPA 1985). This category applies to agents for which there is sufficient animal evidence and inadequate human evidence of carcinogenicity.

The oral cancer slope factor for chloroform is 6.1×10^{-3} $(mg/kg\text{-}day)^{-1}$ and is based on the increased incidence of renal tumors in rats receiving chloroform in drinking water (EPA 1995a). In this study, Osborne-Mendel rats received 0, 200, 400, 900, or 1,800 mg chloroform/L for 104 weeks. A significant increase in renal tumors was observed only in high-dose males (Jorgenson, et al. 1985). Dose-response data on male rats with renal tumors was used in the linearized multistage model to estimate the oral slope factor.

The inhalation slope factor for chloroform is based on the results of a National Cancer Institute bioassay in mice (NCI 1976). Groups of 50 male and female B6C3F1 mice were treated by gavage five times/week for 78 weeks with chloroform in corn oil. The male and female mice received average treatments of 138 or 277 mg/kg-day and 238 or 477 mg/kg-day, respectively, five times/week for 78 weeks. The mice were sacrificed after 92 or 93 weeks. The induction of hepatocellular carcinomas was significantly increased in both the male (1/18, 18/50, 44/50) and female mice (0/20, 36/45, 39/41) (control, low dose, and high dose, respectively, for both sexes). The carcinogenic slope factor for inhalation of chloroform was obtained by taking the geometric mean of the individual carcinogenic potencies calculated from the liver tumor data for males and females. Using the linearized multistage model and appropriate scaling factors, an inhalation carcinogenic slope factor of 8.1×10^{-2} $(\text{mg/kg-day})^{-1}$ was derived.

It should be noted that current research indicates that application of the linearized multistage model may not be appropriate for extrapolation of cancer risks from chloroform exposure (Larson, et al. 1994). Chloroform-induced tumorigenesis is secondary to cell necrosis and subsequent regeneration, and is dependent on a dose of sufficient magnitude and duration to cause cell damage. It is, therefore, likely that the current slope factor approach overestimates human carcinogenic risks from exposure to chloroform at low doses. In addition, data based on gavage administration of chloroform may also overestimate risks from chloroform exposure. Larson, et al. (1994) showed that administration of chloroform in drinking water was much less effective in producing cellular damage in the livers of B6C3F1 mice than similar doses of chloroform administered via gavage in corn oil. The inhalation slope factor for chloroform may, therefore, greatly overestimate carcinogenic risks for human receptors.

EPA has derived a verified RfD for oral exposure to chloroform (EPA 1986) based on a chronic oral bioassay in dogs (Heywood, et al. 1979). In this study, beagle dogs were administered chloroform at doses of 15 or 30 mg/kg-day in a toothpaste base for six days/week for 7.5 years. Fatty nodules of altered hepatocytes were observed that appeared to be treatment-related but not dose-dependent. The dose of 15 mg/kg-day was considered to be a lowest observed effect level (LOEL), and the RfD was calculated to be 0.01 mg/kg-day.

The safe drinking water maximum contaminant level (MCL) for total trihalomethanes is 100 μg/L (EPA 1995b). Under the regulation, chloroform is one of the four trihalomethanes whose combined concentrations must not exceed this value. The maximum contaminant level goal (MCLG) for trihalomethanes is zero (EPA 1995b). Only health effects are considered in the development of MCLGs. In addition to health effects, other factors, such as technical feasibility and costs, are considered in developing MCLs (EPA 1978).

EPA (1980) used the incidence of hepatocellular carcinomas in female B6C3F1 mice reported in the NCI (1976) bioassay as the basis of an AWQC for chloroform. The incidences of this tumor type in the female mice were fitted to the linearized multistage model, and extrapolation into the low dose range gave 0.19 µg/L as the concentration of chloroform in water estimated to be associated with a lifetime risk of cancer of 10^{-6}.

Summary of Chloroform Criteria

Criteria	Value	Source
EPA carcinogen classification	Group B2	EPA 2001
Oral cancer slope factor	6.1×10^{-3} (mg/kg-day)$^{-1}$	EPA 2001
Inhalation cancer slope factor	8.05×10^{-2} (mg/kg-day)$^{-1}$	EPA 2001
RfD	0.01 mg/kg-day	EPA 2001
MCL (total trihalomethanes)	100 µg/L	EPA 1995b
MCLG	0	EPA 1995b
AWQC (Water and Fish Consumption)	0.19 µg/L	EPA 1980

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Ethylbenzene

Introduction

Ethylbenzene is a clear, colorless, flammable liquid found in gasoline. It is used as a solvent and in the manufacture of styrene and acetophenone. Ethylbenzene is also a constituent of asphalt and naphtha.

Pharmacokinetics

Ethylbenzene absorbed via inhalation was found to be distributed throughout the body in rats. However, the highest levels were detected in the kidney, lung, adipose tissue, digestive tract, and liver (Chin, et al. 1980). Data regarding the absorption of ethylbenzene from the gastrointestinal tract following oral ingestion were not located in the available literature.

In humans this compound is rapidly metabolized to form, primarily, mandelic acid, and phenylglyoxylic acid. These two metabolites account for 64 percent and 25 percent, respectively, of the absorbed dose. Most of the inhaled dose is eliminated in the urine within 24 hours after termination of exposure (EPA 1984).

Qualitative Description of Health Effects

Ethylbenzene is characterized as being an irritant to the skin and is slightly irritating to the mucous membranes. No systemic effects can be expected at levels producing skin and eye irritation. The acute toxicity of ethylbenzene is considered to be low. In human volunteers, an 8-hour inhalation exposure to 100 ppm produced no adverse effects. This level was increased to an unspecified level. Effects observed included sleepiness, fatigue, headache, and mild eye and respiratory tract irritation (EPA 1987).

In guinea pigs, exposure to 10,000 ppm has been fatal within a matter of minutes. Death was preceded by vertigo, unsteadiness, and ataxia. Examination of dead animals showed intense congestion and edema of the lungs and generalized visceral hyperemia. A chronic inhalation study produced no effects in several animal species tested, except for liver effects in animals exposed to 400 ppm for six months. Liver and kidney effects were observed in rats receiving 408 to 680 mg of ethylbenzene per kilogram of body weight per day for six months (EPA 1987).

Ethylbenzene was not mutagenic in Salmonella typhimurium or Saccharomyces cerevisiae test strains, with and without metabolic activation. At the highest dose tested, ethylbenzene had a minimal effect on induction of sister chromatid exchange after a 48-hour treatment of whole blood lymphocytes in vitro. Ethylbenzene did not elicit a positive mutagenic response in Drosophila, yeast cells, or rat liver epithelial cells (EPA 1987).

Quantitative Description of Health Effects

There are no animal or human carcinogenicity data available. Therefore, EPA has assigned ethylbenzene a weight-of-evidence classification of D: not classifiable as to human carcinogenicity (EPA 1992).

EPA has derived an oral RfD based on an oral bioassay in rats. Female rats were given ethylbenzene five days/week for 26 weeks at doses of 0, 13.6, 136, 408, or 680 mg/kg-day by gavage. Parameters measured were growth, mortality, appearance, behavior, hematologic, blood urea nitrogen concentrations, and organ and body weights. Histopathological changes were observed in the liver and kidney at the LOAEL of 408 mg/kg-day (Wolf, et al. 1956 in EPA 1995a). The NOAEL of 136 was adjusted by an uncertainty factor of 1,000, resulting in a RfD of 1 x 10^{-1} mg/kg-day.

EPA has also derived an inhalation RfC based on developmental effects in ethylbenzene exposed rabbits. New Zealand rabbits were exposed 6 to 7 hours/day, seven days/week during gestation days one through 24 of gestation. Exposure concentrations were 0, 434, or 4,342 mg/m^3. Ethylbenzene did not elicit embryotoxicity, fetotoxicity, or teratogenicity at either exposure level (Andrew, et al. 1981 in EPA 1992). Therefore, the 434 mg/m^3 was deemed the NOAEL as well as the NOAEL human equivalent concentration (HEC). An uncertainty factor of 300 was applied (10 for intraspecies variability, 3 for interspecies conversion, and 10 to adjust for the absence of multigenerational reproductive and chronic studies), resulting in a RfC of 1 mg/m^3 (EPA 1995a).

EPA (1980b) has established an ambient water quality criterion (AWQC) of 1.4 mg/L for the protection of human health from the toxic properties of ethylbenzene ingested through water and contaminated aquatic organisms.

The American Conference of Governmental Industrial Hygienists (ACGIH 1986) has recommended a time-weighted average threshold limit value of 100 ppm (435 mg/m^3) for occupational exposure to ethylbenzene.

Summary of (Toxicity) Criteria for Ethylbenzene

Criteria	Value	Source
EPA Carcinogen Classification	D	EPA 2001
Reference Dose (RfD)	1 x 10^{-1} mg/kg-day, oral	EPA 2001
Reference Concentration (RfC)	1 mg/m^3	EPA 2001
Drinking Water Health Advisory:		
30 mg/L, one day - 10 kg child		EPA 1995b
3 mg/L, 10 day - 10 kg child		EPA 1995b
1 mg/L, long-term - 10 kg child		EPA 1995b
3 mg/L, long-term - 70 kg adult		EPA 1995b
0.7 mg/L, lifetime		EPA 1995b
MCL 0.7 mg/L, final		EPA 1995b
MCLG 0.7 mg/L, final		EPA 1995b
SMCL 0.03 mg/L, proposed		EPA 1995a
Ambient Water Quality Criteria		
1.4 mg/L, consumption of fish and water		EPA 1995a
3.28 mg/L, consumption of fish only		EPA 1995a
ACGIH TLV-TWA: 100 ppm (434 mg/m^3)		ACGIH 1990

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Methyl-tert-Butyl-Ether (MTBE)

Introduction

Methyl-tert-butyl ether (MTBE) is a colorless, flammable liquid with a disagreeable odor. It is a synthetic chemical create by the mixing of isobutylene and methanol. MTBE has been used as an octane booster in gasoline since the 1980s and is used to make other chemicals and for a medicine to dissolve gall stones.

Toxicokinetics

MTBE is readily absorbed gastrointestinally and through the lungs. It can be absorbed dermally, but that pathway occurs more slowly. Following exposure most of the inhaled dose is rapidly excreted in expired air. The portion that is not immediately breathed out is converted into butyl alcohol, methyl alcohol, formaldehyde, formic acid, and carbon dioxide. These chemicals are then excreted in expired air or through urine. In general, MTBE does not stay in the organs of the body and the majority of its breakdown products leave the body within 1 to 2 days after exposure (ATSDR 1996).

Qualitative Description of Health Effects

The most notable effects of MTBE in humans and animals are to the central nervous system. Possible symptoms include headaches, nausea, dizziness, irritation of the nose or throat, feelings of spaciness or confusion, and minor liver damage. Irritation of the skin and mucous membranes resulting from exposure to MTBE has also been reported for animals (ATSDR 1996).

Quantitative Description of Health Effects

There are no reported human data or animal studies that have demonstrated carcinogenicity of MTBE. Therefore, MTBE is classified as a Group D carcinogen (not classifiable as to human carcinogenicity).

An inhalation Reference Concentration (RfC) of 3 mg/m^3 was derived from a 24-month inhalation study in 100 Fischer 344 rats. The study indicated no adverse effects at a dose of 403 ppm for 6 hours/day, 5 days/week for 24 months (Chun,et al. 1992). An uncertainty factor of 10 was applied to account for sensitive human populations and an additional uncertainty factor of 3 for the interspecies extrapolation. Confidence in the RfC is medium to high. The NOAEL level determined in Chun et. al. (1992) chronic study is supported by a two-generation reproduction study (Neeper-Bradley, 1991) of Sprague- Dawley rats.

A drinking water maximum contaminant level (MCL) of 13 µg/L has been established for MTBE (CalEPA 2001).

Summary of 1,1,1-Trichloroethane Criteria

EPA Carcinogen Classification	Group D	EPA 2001
Oral RfD	Not Available	EPA 2001
Inhalation RfC	3 mg/m^3	EPA 2001
Final MCL	13 µg/L	CalEPA 2001

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Methylene Chloride

Introduction

Methylene chloride (dichloromethane) is predominantly used as a solvent. It is a colorless, volatile chemical with a mild sweet odor. Approximately 85 percent of methylene chloride consumed in the United States is lost directly to the environment, largely by evaporation to the atmosphere.

Toxicokinetics

Methylene chloride is readily absorbed into the blood via the gastrointestinal tract. Methylene chloride is also absorbed via inhalation, with the amount absorbed increasing in direct proportion to the concentration in inspired air, the duration of exposure, and physical activity. No data regarding dermal absorption are available. Methylene chloride is highly soluble in water and lipids, and is therefore probably distributed throughout all body fluids and tissues. It is known to readily cross the blood-brain barrier. Methylene chloride is metabolized by the liver to carbon dioxide or carbon monoxide with formaldehyde and formic acid formed as intermediates. Carbon monoxide is eliminated along with carbon dioxide from the lung (EPA 1985a).

Qualitative Description of Health Effects

Acute human exposure to methylene chloride may result in irritation of eyes, skin, and respiratory tract; central nervous system depression; elevated carboxyhemoglobin levels; and circulatory system disorders that may be fatal. Chronic exposure of animals may produce renal and hepatic toxicity. There is limited evidence of genotoxicity in rodents (EPA 1980).

Carcinogenicity

There have been several chronic studies in which methylene chloride was administered to experimental animals either orally or by inhalation. There is clear evidence for carcinogenicity in the inhalation studies. However, there is only suggestive evidence of a treatment-associated increase in combined hepatocellular carcinomas and neoplastic nodules provided in drinking water studies (EPA 1985a,b).

Mutagenicity

Methylene chloride has been found positive for mutagenicity in the Ames assay without the need for metabolic activation. Results in other tests of genotoxicity were largely negative; those for transformation were mixed. An *in vivo* screening test for carcinogenicity, induction of lung adenomas in strain A mice, gave suggestive positive results for methylene chloride (EPA 1980).

Quantitative Description of Health Effects

EPA has classified methylene chloride in Group B2 - Probable Human Carcinogen for exposures from ingestion and inhalation.

The carcinogenic slope factor for exposure by inhalation is based on the results of a National Toxicology Program (NTP) inhalation bioassay (NTP 1985). In the NTP bioassay, groups of 50 male and 50 female F344/N rats and B6C3F$_1$ mice were exposed by inhalation 6 hours a day, 5 days a week) for 102 weeks at concentrations ranging from 1,000 to 4,000 ppm of methylene chloride. Incidences of alveolar/bronchiolar or hepatocellular adenomas or carcinomas in female mice were 5/50, 36/48, and 46/47 for the 0, 2,000, and 4,000 ppm groups, respectively. These doses correspond to 0, 1,582, and 3,164 mg/kg-day, respectively. Doses and incidence rates were fitted to the multistate model using the program GLOBAL83 (Howe 1983). After using a correction factor for the difference in the surface area-to-volume ratios between mice and humans, the upper 95th percentile estimate of the carcinogenic potency was 4.7×10^{-7} ($\mu g/m^3)^{-1}$.

EPA (1985b) calculated a cancer slope factor for exposure to methylene chloride by ingestion based on the results of the NTP (1985) inhalation bioassay and on an ingestion bioassay conducted by the National Coffee Association (NCA 1983). Using appropriate dose-conversion procedures, a slope factor of 2.6×10^{-3} (mg/kg-day)$^{-1}$ was calculated using the results of the NTP (1985) inhalation bioassy. In the NCA (1983) study, groups of from 50 to 200 B6C3F$_1$ mice received methylene chloride in drinking water for 24 months at doses of approximately 0, 60, 125, 185, and 250 mg/kg-day. Significant increases in the incidence of hepatocellular adenomas and/or carcinomas were reported for male mice in the 125 mg/kg-day and 185 mg/kg-day groups, and a borderline significant increase in incidence of these hepatocellular lesions was reported in the 250 mg/kg-day group. Using the incidence of hepatocellular adenomas and carcinomas in male mice (24/125, 51/200, 30/100, 31/99, and 35/125 for the control, 60, 125, 185, and 250 mg/kg-day groups, respectively) and the appropriate dose-conversion procedures, a cancer slope factor of 1.21×10^{-2} (mg/kg-day)$^{-1}$ was calculated. EPA recommended use of the mean result of the two studies (7.5×10^{-3} (mg/kg-day)$^{-1}$) as the cancer slope factor for oral exposure to methylene chloride.

A reference dose (RfD) of 0.06 mg/kg-day for noncarcinogenic effects of methylene chloride following oral exposure has been developed by EPA (1986). The RfD was derived from a 2-year rat drinking water bioassay (NCA 1983) that identified no-observed-effects-levels (NOELS) of 5.85 and 6.47 mg/kg-day for male and female rats, respectively. Liver toxicity was the observed effect, and lowest-observed-effect levels (LOELS) of 52.58 and 58.32 mg/kg-day were reported for males and females, respectively. The study was given a high confidence rating by EPA (1986) because a large number of animals of both sexes in four dose groups were tested. Many effects were monitored and a good dose-severity relationship was observed.

EPA established an ambient water quality criterion of 0.19 µg/L for methylene chloride, (EPA 1992) and a maximum contaminant level (MCL) of 0.005 mg/L (EPA 1993).

Summary of Criteria

Criterion	Value	Source
EPA carcinogen classification oral and inhalation	Group B2	EPA 1992
Oral carcinogenic slope factor	7.5×10^{-3} (mg/kg-day)$^{-1}$	EPA 2001
Inhalation carcinogenic slope factor	1.6×10^{-3} (mg/kg-day)$^{-1}$	EPA 2001
Risk Reference Dose (for noncarcinogenic effects)	0.06 mg/kg-day	EPA 2001
AWQC	1.9×10^{-1} µg/L	EPA 1992
Proposed MCL	0.005 mg/L	EPA 1992

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Tetrachloroethene (PCE)

Introduction

Tetrachloroethene (PCE) is a volatile, colorless, nonflammable liquid. It has widespread use as a solvent in dry cleaning operations, metal degreasing, and as a paint remover.

Toxicokinetics

Tetrachloroethene is readily absorbed through the lungs (IARC 1979) and to some extent from the gastrointestinal tract (EPA 1985a). Tetrachloroethene vapors and liquid can be absorbed through the skin (rate and extent unspecified) (EPA 1985a). Only small amounts of tetrachloroethene (less than 4 percent of the absorbed dose) are metabolized in humans (IARC 1979). The metabolic pathways of tetrachloroethene are saturable and may involve an epoxide intermediate (IARC 1979). Urinary metabolic products include trichloroethanol, trichloroacetic acid, and unidentified chlorinated products, but represent only a small percentage of the absorbed dose (IARC 1979). Elimination of tetrachloroethene has been reported to be primarily via the lungs (IARC 1979).

Qualitative Description of Health Effects

Carcinogenicity

In a National Cancer Institute bioassay (1977), a high incidence of hepatocellular carcinoma was observed in both sexes of B6C3F1 mice administered tetrachloroethene in corn oil by gavage five days per week for 78 weeks. Time-weighted average doses were 536 and 1,072 mg/kg-day in males and 386 and 772 mg/kg-day in females. No conclusions concerning the effects on Osborne-Mendel rats administered 471 to 949 mg/kg-day by gavage could be made because of high mortality rates and other technical flaws (NCI 1977).

NTP has reported the results of inhalation studies concerning carcinogenicity of tetrachloroethene. There was some evidence of carcinogenicity in F344/N rats (EPA 1985a). Evidence of carcinogenicity was also observed in B6C3F1 mice of both sexes (EPA 1985a).

Mutagenicity

The majority of mutagenicity studies, with a variety of test systems, revealed no evidence of mutagenic activity by tetrachloroethene (EPA 1985a). Cerna and Kypenova (1977) reported positive results in plate tests with S. typhimurium and in host-mediated assays (EPA 1985a).

Teratogenicity/Reproductive Effects

The offspring of female rats and mice exposed to PCE at 2,000 mg/m^3 for seven hours daily on days six to 15 of gestation showed toxic effects, including a decrease in fetal body weight in mice and a small but significant increase in fetal resorptions in rats (EPA 1985a). Mice also exhibited teratogenic effects, including subcutaneous edema and delayed ossification of skull bones and sternebrae (EPA 1985a).

Chronic Effects

The principal toxic effects of tetrachloroethene in humans and animals from both acute and longer-term exposures include central nervous system depression and fatty infiltration of the liver and kidney with concomitant changes in serum enzyme activity levels indicative of tissue damage (EPA 1985a).

Individuals exposed to concentrations of PCE ranging from 6,258 to 10,600 mg/m^3 experienced lassitude, mental fogginess, and exhilaration, progressing at the higher dose to signs of inebriation (EPA 1980). Signs of central nervous system depression and cholinergic stimulation were also observed at concentrations of 1,622 ppm PCE in an animal study in rabbits, monkeys, rats, and guinea pigs (EPA 1980).

Rats exposed to 1,600 ppm PCE seven hours per day, five days per week, 18 times over 25 days exhibited central nervous system depression and hepatic and renal hypertrophy. Rats exposed to 230 ppm and 470 ppm PCE, eight hours a day, five days a week, over a period of seven months, exhibited congestion and swelling of kidneys and liver, respectively (Carpenter 1937). Female Sprague-Dawley rats exposed to PCE in air five days a week for 12 months at concentrations of 300 to 600 ppm showed liver atrophy, and the high-dose females developed an increased incidence of fluid-filled cysts in the liver (EPA 1980).

Fatty infiltration in the livers of mice was observed following exposure to 200 ppm, four hours per day, five days per week for eight months (EPA 1985a). A high incidence of toxic nephropathy was seen in mice and rats exposed orally to 500 mg/kg PCE for 78 weeks (NCI 1977).

In guinea pigs, a dose-dependent increase in liver weight and fatty infiltration of the liver was observed following exposure to 100, 200, or 400 ppm PCE for up to 169 exposures over 236 days (EPA 1985a).

Rabbits showed liver enzyme changes and renal function alterations following exposures to 200 to 300 ppm of PCE, four hours per day, five days per week for nine weeks (EPA 1985a).

Three of seven men occupationally exposed to PCE at concentrations of 1,890 to 2,600 mg/m^3 showed evidence of impaired liver function (EPA 1980).

Quantitative Description of Health Effects

Tetrachloroethene is formerly classified as a Group B2 carcinogen (EPA 1985b). This classification is currently under reconsideration. The decision whether PCE will be classified as a Group B2 or Group C carcinogen is pending. Cancer slope factors for exposure to PCE by ingestion and inhalation are 5.2×10^{-2} (mg/kg-day)$^{-1}$ and 2.0×10^{-3} (mg/kg-day)^{1}, respectively (EPA 1992).

The oral RfD of 0.01 mg/kg-day (EPA 2001) is based on a NOAEL of 20 mg/kg-day from a subchronic gavage study in mice. Mice received doses up to 200 mg/kg for six weeks. At doses greater than 20 mg/kg-day, various indications of hepatotoxicity were observed, including increased triglyceride levels and liver weights (Buben and O'Flaherty 1985).

Summary of Tetrachloroethene Criteria

Criterion	**Value**	**Source**
Oral RfD	1×10^{-2} mg/kg-day	EPA 2001
EPA carcinogen classification	Pending (formerly Group B2)	EPA 2001
Oral Slope Factor	5.2×10^{-2} (mg/kg-day)$^{-1}$	EPA 2001
Inhalation Slope Factor	2.03×10^{-3} (mg/kg-day)$^{-1}$	EPA 2001
MCL	5 µg/L	EPA 1993
Final MCLG	0	EPA 1993
AWQC (concentration associated with a 1×10^{-6} lifetime cancer risk)	0.8 µg/L	EPA 1980a

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Trichloroethene (TCE)

Introduction

Trichloroethene (TCE) is a colorless liquid mainly used as a metal degreaser. It is volatile with a sweet odor similar to chloroform. Trichloroethene was once used as a general anesthetic, but its use has been discontinued.

Toxicokinetics

The extent of TCE absorption after oral ingestion is virtually complete. With air exposure, absorption is proportional to concentration and duration of exposure. TCE is eliminated by pulmonary excretion of the unchanged parent compound and by liver metabolism of metabolites excreted in the urine (EPA 1985b).

Qualitative Description of Health Effects

TCE is a central nervous system depressant following acute and chronic exposure. High level exposure can result in death due to respiratory and cardiac failure.

Industrial use of TCE is often associated with dermatological problems including reddening and skin burns on contact and dermatitis resulting from vapors. These effects are usually the result of contact with concentrated solvent, however, and no effects have been reported from exposure to trichloroethene in dilute, aqueous solutions (EPA 1985b).

The hepatotoxic potential of TCE has been evaluated in human and animal studies. Animal studies have revealed transient increased liver weights, but relative liver weights decreased post-exposure (Kjhellstrand, et al. 1983). Observations of liver or renal dysfunction in workers have been infrequent, and factors other than TCE complicate interpretation of hepatorenal disturbances noted (EPA 1985b).

Carcinogenicity

Several epidemiological studies reported no significant excess cancer risk associated with occupational exposure to trichloroethene (Axelson, et al. 1978; Tola, et al. 1980; Malek, et al. 1979). In a follow-up to one of these studies, Axelson (1986a, 1986b) observed a slight excess of bladder cancer and lymphoma. In other epidemiological studies, no associations were found between TCE exposure and liver cancer (Novotna, et al. 1979; Paddle 1983) or malignant lymphoma (Hardell, et al. 1981). The aforementioned studies are limited by deficiencies that include small sample size, lack of analysis by tumor site and/or problems with exposure definition, duration of exposure, or follow-up. Due to these limitations, the available human studies do not allow a definite conclusion regarding the carcinogenicity of trichloroethene in humans.

Studies investigating the carcinogenic potential of TCE have been conducted, and two of these studies revealed significant increases in the incidence of liver tumors among both sexes of B6C3F1 mice exposed by gavage (NCI 1976; NTP 1982).

There is disagreement in the scientific community about the relevance of mouse liver tumors as indicators of human cancer risk. Several strains of laboratory mice, including the B6C3F1 hybrid, appear to develop a high and variable proportion of liver tumors with or without exposure to chemicals. Certain scientists believe that the increased incidence of mouse liver tumors should be treated in the same manner as the increased incidence of tumors at other rodent organ sites, while others believe that mouse liver tumors are an experimental artifact, which is not relevant to human hazard (EPA 1985b).

Mutagenicity

Studies investigating possible associations between occupational exposure to TCE and chromosome aberrations or sister chromatid exchanges have been inconclusive (Konietzko, et al. 1978; Gu, et al. 1981). Data from *in vitro* and *in vivo* genotoxicity assays provide suggestive evidence that commercial grade TCE is a weakly active indirect mutagen (EPA 1985b). Insufficient data are available to allow a conclusion regarding the genotoxic potential of pure trichloroethene.

Teratogenicity/Reproductive Effects

There was a significant increase in sperm abnormalities in mice that were exposed to 2,000 ppm, but not 200 ppm, trichloroethene (Land, et al. 1981). The functional significance of the abnormalities was not evaluated.

Quantitative Description of Health Effects

Trichloroethene was formerly classified as a Group B2 carcinogen (EPA 1985b). This classification is currently being reconsidered by EPA. Carcinogenic slope factors for ingestion and inhalation are listed below. The final maximum contaminant level (MCL) for trichloroethene is 5 µg/L (EPA 2001). The AWQC is 2.7 µg/L (EPA 1980).

Summary of Criteria

Criteria	**Value**	**Source**
Oral RfD	6×10^{-3} mg/kg-day	EPA *
EPA Carcinogenic Classification	Pending (Formerly B2)	EPA 1985b
Oral Slope Factor	1.1×10^{-2} (mg/kg-day)$^{-1}$	EPA 2001
Inhalation Slope Factor	6.0×10^{-3} (mg/kg-day)$^{-1}$	EPA 2001
MCL	5 µg/L	EPA 2001
Final MCLG	0	EPA 1995b
AWQC (Water and Fish Consumption)	2.7 µg/L	EPA 1980

* EPA-ECAO Regional support provisional value

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Toluene

Introduction

Toluene occurs naturally as a component of petroleum oil. It is used in the production of benzene and other organic solvents and as a solvent for paints, coatings, gums, oils, and resins.

Toxicokinetics

In humans, toluene is absorbed quickly through the respiratory tract, but less rapidly through the gastrointestinal tract. Dermal absorption of toluene in aqueous solution is directly related to concentration (EPA 1985a). Because of its lipophilic nature and low water solubility, toluene is expected to distribute and to accumulate in lipid tissue (EPA 1985b). In humans and animals, toluene is metabolized to hippuric acid and excreted via the urine. Unchanged compound is eliminated in exhaled breath (EPA 1985a).

Qualitative Description of Health Effects

Carcinogenicity

EPA (1985b) concludes that no human data and only inadequate data in animals on carcinogenicity of toluene exist. A chronic (106-week) inhalation bioassay of toluene conducted in F344 rats of both sexes resulted in no carcinogenic effects (CIIT 1980 as cited in EPA 1992). Gross and microscopic examination of tissues and organs revealed no increase in neoplastic tissues or tumor masses among rats treated at 30, 100, or 300 ppm when compared with controls. However, the highest dose used did not approach the maximum tolerated dose (MTD); therefore, toluene may not have been adequately tested for carcinogenicity (EPA 1985b).

Mutagenicity

Toluene has been tested for genotoxicity by many investigators using various assay methods and has not been demonstrated to be genotoxic (EPA 1985a).

Teratogenicity/Reproductive Effects

Toluene administered by gavage to CD-1 mice at 260 mg/kg-day on days 6 to 15 of gestation caused embryo lethality. Higher doses (430 or 870 mg/kg-day) also caused fetal and maternal toxicities and cleft palate (Nawrot and Staples 1979, Abstract as cited in EPA 1985a). It should be noted that details of the study are not available for review and other studies discussed by EPA did not report evidence of teratogenicity when toluene was given orally. In contrast, several studies indicate that moderate (200 to 300 ppm) acute doses of inhaled toluene caused developmental effects in mice, rabbits, and rats. Developmental effects were seen only at doses causing maternal toxicity, however (ATSDR 1989).

Acute/Chronic Effects

The oral LD_{50} in rats is between 5,300 and 7,500 mg/kg (EPA 1985b). The LC_{50} for inhaled toluene is 4,618 ppm after a 6-hour exposure in rats (EPA 1985a). The dermal LD_{50} in rabbits is 12.2 g/kg (EPA 1985a). In experimental animals, acute oral and inhalation exposures to toluene result in CNS depression and histological changes in the lungs, liver, and kidneys (EPA 1985b). In humans, the major acute effects of toluene (375 to 1,500 mg/m^3) are CDS depression and narcosis (EPA 1985b).

Toxic effects following prolonged exposure of experimental animals to toluene are similar to those seen following acute exposure, predominantly to the CNS, liver, kidneys, and lungs (EPA 1985b). In humans, chronic exposures to toluene vapors at levels of approximately 200 and 800 ppm have been associated with CNS and, possibly, peripheral nervous system effect, hepatomegaly, and hepatic and renal function changes (EPA 1985b).

Quantitative Description of Health Effects

Applying EPA's criteria for evaluating the overall weight of evidence of carcinogenicity to humans (EPA 1986a), toluene is appropriately classified in Group D — Not Classified. This category indicates that evidence for carcinogenicity in animals is inadequate (EPA 1986a).

The RfD Work Group of the Risk Assessment Forum (EPA 1986b) has identified an oral reference dose (RfD) based on a 13-week subchronic toxicity study conducted in male and female F344 rats (EPA 1992). Toluene was administered by gavage at doses of 312, 625, 1,250, 2,500, or 5,000 mg/kg, 5 days/week. Several toxic effects were observed at doses of 2,500 mg/kg and greater, including prostration, hypoactivity, excessive salivation, and tremors. At 625 mg/kg-day liver and kidney weight were significantly increased. Based on these findings, a no-observed-adverse-effect level (NOAEL) of 312 mg/kg was identified. The dose was adjusted to 223 mg/kg-day and an oral RfD of 0.2 mg/kg-day was derived.

EPA's Office of Drinking Water has set a maximum contaminant level goal (MCLG) of 1 mg/L for toluene in drinking water, based on NTP (1986). In addition, 1-day and 10-day health advisories have been established as 20 and 2 mg/L, respectively for a 10-kg child (EPA 1991).

The American Conference of Governmental Industrial Hygienists has recommended a time-weighted average threshold limit value of 100 ppm (approximately 435 mg/m^3) for occupational exposure to toluene.

Summary of Criteria

Criteria	Value	Source
EPA carcinogen classification	Group D	EPA 2001
Oral RfD	0.2 mg/kg-day	EPA 2001
Inhalation RfD	0.114 mg/kg-day	EPA 2001
Final MCLG	1 mg/L	EPA 1992
MCL	1 mg/L	EPA 2001
One-day HA (child)	20 mg/L	EPA 1992
10-day HA (child)	2 mg/L	EPA 1992
Longer term HA (adult)	7 mg/L	EPA 1992
Ambient Water Quality Criteria Water and Fish Consumption	14.3 mg/L	EPA 1992

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Vinyl Chloride

Introduction

Vinyl chloride is a manmade, colorless gas with a sweet odor. The chemical is used in the production of a variety of plastic and vinyl products such as furniture, packaging materials, wall coverings, and automotive parts.

Toxicokinetics

Vinyl chloride is rapidly absorbed in rats following ingestion and inhalation exposure. Dermal absorption of vinyl chloride is minor. Absorbed vinyl chloride is distributed primarily to the liver and kidney and also distributed to the muscle, lung, fat, spleen, and brain. The toxicity of vinyl chloride appears to be attributable to its metabolism in the liver to reactive polar metabolites. The metabolism to toxic metabolites is saturable between 105 and 220 ppm. At low doses of vinyl chloride, metabolites are excreted primarily in the urine. At high doses most of the solvent is expired as unchanged vinyl chloride (EPA 1980).

Qualitative Description of Health Effects

Carcinogenicity

Occupational exposure to vinyl chloride has been associated with increased incidence of hepatic angiosarcoma, a very rare type of cancer (25 to 30 cases per year in the U.S.). However, approximately 30 years after the introduction of vinyl chloride for use in the industrial production of PVC, it became apparent that workers exposed to vinyl chloride had an unusually high incidence of this type of tumor (ATSDR 1995). Histopathological examination of liver tissue from humans with hepatic angiosarcoma has led to the hypothesis that angiosarcoma develops as a result of hyperplastic changes in sinusoidal cells.

Vinyl chloride exposure has also been implicated in brain, lung, and hemolymphopoietic cancers in humans. A significant increase in cancer of the respiratory tract was reported in several studies. Although smoking history was not considered in the studies reporting a statistically significant increase in respiratory cancer, Waxweiler, et al. (1976, described in ATSDR 1995) noted that the types of respiratory tract cancer most frequently recorded were large-cell undifferentiated carcinoma or adenocarcinoma, which are two lung cancer types not usually associated with smoking. Animal studies in several species support the findings of epidemiological studies. Chronic inhalation and ingestion of vinyl chloride has induced cancer in the liver (liver angiosarcomas and hepatocellular carcinomas) and in other tissues in rats and mice (IARC 1979).

Mutagenicity

The mutagenic effects of vinyl chloride have been demonstrated in metabolically activated systems using *S. typhimurium, E. coli*, yeast, germ cells of Drosophila, and

Chinese hamster V79 cells. Vinyl chloride was effective in producing chromosome damage in rat bone marrow after a multiple-exposure regime. Tests for chromosomal aberrations in humans have yielded inconsistent results (EPA 1985).

Teratogenicity/Reproductive Effects

Inhalation exposures of rats, rabbits, and mice to vinyl chloride did not induce teratogenic effects (EPA 1985). Potential effects on reproductive capacity have not been studied.

Acute/Chronic Effects

At high inhalation exposure levels, workers have experienced dizziness, headaches, euphoria, and narcosis. In experimental animals, inhalation exposure to high levels of vinyl chloride can induce narcosis and death. Lower doses result in ataxia, congestion, and edema of the lungs and hyperemia in the liver (EPA 1985).

Chronic inhalation exposure of workers to vinyl chloride is associated with hepatotoxicity, central nervous system disturbance, pulmonary insufficiency, cardiovascular toxicity, gastrointestinal toxicity, and acro-osteolysis (EPA 1985). Twelve of 271 vinyl chloride polymerization workers exposed to vinyl chloride monomer for an average of 5.1 years exhibited abnormal liver function tests as measured by serum biochemistry. The 12 workers with abnormal liver function tests were considered to have vinyl chloride-induced liver dysfunction, also showing abnormal liver scans and biopsies. The geometric mean environmental concentration of vinyl chloride in the plant was 6 ppm (range 1 to 10 ppm). No control group was studied, but no additional cases of liver dysfunction were observed after vinyl chloride concentrations were reduced to below 1 ppm (CalEPA 1997). Chronic studies of experimental animals exposed to vinyl chloride by inhalation or ingestion report effects involving the liver, spleen, kidneys, hematopoietic system, and skeletal system (EPA 1984).

Quantitative Description of Health Effects

Applying EPA's criteria for evaluating the overall weight of evidence of carcinogenicity to humans, vinyl chloride has been classified in Group A — Human Carcinogen (EPA 1994a).

CalEPA (1996) and EPA (1984) reported cancer slope factors for vinyl chloride. The cancer slope factors for inhalation are based on an inhalation bioassay in rats (Maltoni and Lefemine 1975). Groups of 64 to 96 Sprague-Dawley rats were exposed to various concentrations of vinyl chloride for 4 hours a day, 5 days a week, for 52 weeks, and the survivors were sacrificed after 135 weeks. Angiosarcomas, particularly of the liver, were the predominant tumors observed. The linearized multistage model was fitted to the incidences of male and female rats with any type of malignant tumor (6/58, 10/59, 16/69, 22/59, and 32/59 in the 0, 50, 250, 500, and 2,000 ppm dose groups, respectively. The 6,000 and 10,000 ppm groups were not included in the final fitted model because the tumor incidence was said to have effectively plateaued at

51.7 percent and 62.3 percent. Using the linear non-threshold model, the data of Maltoni and Lefemine (1975), and interspecies scaling factors, EPA's inhalation slope potency factor of 3 x 10^{-1} (mg/kg-day)$^{-1}$ was calculated.

Maltoni et al. (1981, 1984) updated their previous study with additional series of experiments in which rats were exposed to varying concentrations of vinyl chloride. The study resulted in a broad, well-characterized concentration-response curve which was used with a pharmacokinetic PBPK model of Clewell et al. (1995), to reduce the uncertainty in extrapolating from animals to humans. As a result, the inhalation unit risk estimate is 4.4 x $10^{-6}/(\mu g/m)^3$ for continuous, lifetime exposure during adulthood, and 8.8 x $10^{-6}/(\mu g/m)^3$ for continuous lifetime exposure from birth (EPA, 2001).

The cancer slope factor for oral exposure to vinyl chloride is based on a long-term ingestion study in rats (Feron, et al. 1981). Groups of male and female Wistar rats were exposed to vinyl chloride via ingestion of polyvinyl chloride powder containing some unreacted monomer. The doses of vinyl chloride administered were 0, 1.7, 5.0, and 14.1 mg/kg-day. Dosing was continued for life with terminal sacrifices at 135 weeks for males and at 144 weeks for females. A significant dose-related increase in the incidence of hepatocellular carcinomas and hepatic angiosarcomas was observed in both males and females, with angiosarcomas becoming more prevalent with increasing doses. The linearized multistage model was fitted to the incidences of total female rats with tumors (2/57, 26/58, 42/59, in the 0, 1.7, 5.0, and 14.1 mg/kg-day dose groups, respectively). The incidence of hepatocellular carcinoma was not included in these tallies; it was assumed that rats having hepatocellular carcinoma also had hepatic neoplastic nodules, which were included in the tallies. In addition, the total number of animals bearing tumors in the high dose group was arbitrarily reduced to one less than the total number of animals examined, so the data would fit the linear non-threshold model used for estimation of carcinogenic potency. Using the data of Feron, et al. (1981) and the more recent data by Til, et al. (1991), a human cancer slope factor of 0.75 (mg/kg-day)$^{-1}$ was calculated. These results are also supported by the studies conducted by Maltoni et al. (1981, 1984).

Based on the results of the study performed by Ho, et al. (1991) in which 12 of 271 vinyl chloride-exposed workers were observed with abnormal liver function tests, CalEPA (1997) has proposed a Reference Exposure Level (REL) for development of noncancer effects following chronic, low level exposure of 5 $\mu g/m^3$. CalEPA (1997) reports that the strengths of the proposed REL includes the use of human exposure data from workers exposed over a period of years. Major areas of uncertainty are the uncertainty in estimating exposure, the potential variability in exposure concentration, and the lack of observation of a "no observed adverse effect level" (NOAEL).

EPA (1985) promulgated a drinking water MCLG of zero because vinyl chloride is a human carcinogen. The MCL in drinking water is 2 µg/L (EPA 1994).

Summary of Vinyl Chloride Criteria

Criteria	Value	Source
EPA Carcinogenic Classification	Group A	EPA 1994a
Oral Cancer Slope Potency Factor	7.5×10^{-1} (mg/kg-day)$^{-1}$	EPA 2001
Inhalation Cancer Slope Factor	1.6×10^{-2} (mg/kg-day)$^{-1}$	EPA 2001
Inhalation Cancer Slope Potency Factor	3×10^{-1} (mg/kg-day)$^{-1}$	EPA 1994a
MCL	2 µg/L	EPA 1994b
MCLG	0	EPA 1994b

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Xylenes

Introduction

Xylenes (*ortho, para,* and *meta* isomers) are used as solvents for paints, inks, and adhesives and as components of detergents and other industrial and household products. The three xylene isomers have very similar but not identical toxicologic properties. These three compounds generally have similar chemical and biological characteristics and therefore will be discussed together.

Toxicokinetics

Although the available data are limited, inference from metabolism and excretion studies suggests that absorption of orally administered xylenes is nearly complete. Data from animals and humans suggest that approximately 60 percent of an inhaled dose is absorbed following ingestion. Dermal absorption is reported to be minor following exposure to xylene vapors but may be significant following contact with the liquid.[1] Elimination of xylenes is through urinary excretion of metabolites and through pulmonary exhalation of unchanged solvent.[2]

Qualitative Description of Health Effects

Carcinogenicity

EPA[3] does not consider xylenes to be carcinogenic, based on negative animal and human data. The National Toxicology Program (NTP)[4] has tested xylenes for carcinogenicity by administering the compound orally to rats and mice. Fifty male and female F344 rats were treated by gauge with mixed xylenes at doses of 0, 250, or 500 mg/kg-day, five days/week for 103 weeks. Similarly, B6C3F$_1$ mice received 0, 500, or 1,000 mg/kg-day. NTP concluded at the end of the study that there was no evidence of carcinogenicity of xylene for rats or mice at any dose tested.

The frequency of sister chromatid exchanges and chromosomal aberrations were nearly identical between a group of 17 paint industry workers exposed to xylene and their respective referents.[5] In vitro, xylene caused no increase in the number of sister chromatid exchanges in human lymphocytes.[6]

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[1] U.S. Environmental Protection Agency. *Drinking Water Criteria Document of Xylenes (Final Draft).* Environmental Criteria and Assessment Office, Cincinnati, Ohio. ECAO-CIN-416. EPA 600/X-84-185-1. March, 1985.

[2] U.S. Environmental Protection Agency. National Primary Drinking Water Regulations; Synthetic Organic Chemicals, Inorganic Chemicals and Microorganisms, Proposed Rule. *Fed. Reg.* 50:46,936-47,025. November 13, 1985.

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[4] National Toxicology Program. *Carcinogenic Bioassay for Xylenes.* 1986.

[5] Haglund, U., I. Lundberg and L. Zech. Chromosome aberrations and sister chromatid exchanges in Swedish paint industry workers. Scand. J. Work Environ. Health. 6: 291-298. 1980.

[6] Gerner-Smidt, P. and U. Friedrich. The mutagenic effect of benzene, toluene and xylene studied by the SCE technique. Mutat. Res. 58: 313-316. 1978.

Studies indicate that xylene isomers, technical grade xylene or mixed xylene are not mutagenic in tests with Salmonella typhimurium[7] nor in mutant reversion assays with Escherichia coli.[8] Technical grade xylene, but not o- and m-xylene, was weakly mutagenic in Drosophila recessive lethal tests. Chromosomal aberrations were not increased in bone marrow cells of rats exposed to xylenes by inhalation.[9] Xylenes were not found to be mutagenic in a battery of short-term tests.[10]

Teratogenicity/Reproductive Effects

Xylenes appear to be fetotoxic and may increase malformations in the offspring of exposed experimental animals. The available teratogenic studies have reported generally retarded skeletal development and body weight gains in fetuses except for one oral study in mice in which the incidence of cleft palates was increased.[11]

Acute/Chronic Effects

Most of the available toxicity data for xylenes assess adverse effects associated with exposure by inhalation. Acute exposure to relatively high concentrations of xylenes adversely affects the central nervous system and lungs, and can irritate the mucous membranes. The liver is reportedly affected by longer-term exposure to lower levels of xylenes.[12,13]

Quantitative Description of Health Effects

Using the criteria for evaluating the overall weight of evidence of carcinogenicity to humans proposed by EPA's Carcinogen Assessment Group,[14] xylenes are appropriately assigned to Group D - Not Classified because data from animal studies is inadequate.[15]

The Reference Dose (RfD) for ingestion of xylenes is 2 mg/kg-day.[16] The RfD is based on a study by National Toxicology Program[17] in which groups of 50 male and 50 female Fischer 344

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[7] Florin, I., L. Rutberg, M. Curvall and C.R. Enzell. Screening of tobacco smoke constituents for mutagenicity using the Ames' test. Toxicology. 15: 219-232. 1980.

[8] McCarroll, N.E., C.E. Piper and B.H. Keech. An E. coli microsuspension assay for the detection of DNA damage induced by direct-acting and promutagens. Environ. Mutagen. 3: 429-444. 1981.

[9] Donner, M., J. Maki-Paakkanen, H. Norppa, M. Sorsa and H. Vainio. Genetic toxicology of xylenes. Mutat. Res. 74: 171-172. 1980.

[10] Litton Bionetics. *Teratology Studies in Rats: Xylene.* Final Report to American Petroleum Institute, Washington, D.C. LBI Project No. 20698-5 (As cited in EPA 1984). 1978.

[11] U.S. Environmental Protection Agency. *Drinking Water Criteria Document of Xylenes (Final Draft).* Environmental Criteria and Assessment Office, Cincinnati, Ohio. ECAO-CIN-416. EPA 600/X-84-185-1. March, 1985.

[12] U.S. Environmental Protection Agency. *Drinking Water Criteria Document for Xylene.* Environmental Criteria and Assessment Office, Cincinnati, Ohio. EPA 540/1-86-066. September, 1984.

[13] U.S. Environmental Protection Agency. *Drinking Water Criteria Document of Xylenes (Final Draft).* Environmental Criteria and Assessment Office, Cincinnati, Ohio. ECAO-CIN-416. EPA 600/X-84-185-1. March, 1985.

[14] U.S. Environmental Protection Agency. Guidelines for Carcinogenic Risk Assessment. *Red. Reg.* 51:33,992-34,003. September 24, 1986.

[15] U.S. Environmental Protection Agency. *Integrated Risk Information System.* 2000.

[16] U.S. Environmental Protection Agency. *Integrated Risk Information System.* 2000.

[17] National Toxicology Program. *Carcinogenic Bioassay for Xylenes.* 1986.

rats and 50 male and 50 female B6C3F1 mice were given gavage doses of 0, 250, or 500 mg/kg/day (rats) and 0, 500, or 1000 mg/kg/day (mice) for 5 days/week for 103 weeks. The animals were observed for clinical signs of toxicity, body weight gain, and mortality. All animals that died or were killed at sacrifice were given gross necropsy and comprehensive histologic examinations. There was a dose-related increased mortality in male rats, and the increase was significantly greater in the high-dose group compared with controls. Although increased mortality was observed at 250 mg/kg/day, the increase was not significant. Although many of the early deaths were caused by gavage error, NTP[18] did not rule out the possibility that the rats were resisting gavage dosing because of the behavioral effects of xylene. Mice given the high dose exhibited hyperactivity, a manifestation of CNS toxicity. There were no compound-related histopathologic lesions in any of the treated rats or mice. Therefore, the high dose is a FEL and the low dose a NOAEL.

EPA developed one-day, 10-day, longer-term and lifetime Health Advisories (HAs) for xylenes. The one-day, 10-day and longer-term HAs for children are all 40 mg/L, and the longer-term HA for adults and the lifetime HA are 100 mg/L and 10 mg/L, respectively.[19]

The maximum contaminated level for xylenes is 10 mg/L.[20]

Summary of Xylenes Criteria

Criteria	Value	Source
EPA carcinogen classification	Group D	EPA 2001
Oral RfD[1]	2 mg/kg-day	EPA 2001
EPA Drinking Water Health Advisories		
Lifetime Health Advisory (HA)	10 mg/L	EPA 1991
Longer-term HA (Child)	40 mg/L	EPA 1991
Longer-term HA (Adult)	100 mg/L	EPA 1991
10-day HA (Child)	40 mg/L	EPA 1991
One-day HA (Child)	40 mg/L	EPA 1991
MCL	10 mg/L	EPA 1991
MCLG	10 mg/L	EPA 1991

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[18] National Toxicology Program. *Carcinogenic Bioassay for Xylenes.* 1986.

[19] U.S. Environmental Protection Agency. *Integrated Risk Information System.* 2000.

[20] U.S. Environmental Protection Agency. *Drinking Water Regulations and Health Advisories.* Office of Water. Washington, D.C. 1991.

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Appendix D

Technical Memorandum – Groundwater Modeling

Central Truckee Meadows Remediation District

Technical Memorandum
Groundwater Modeling

July 9, 2002

Technical Memorandum

Contents

Section 1 Introduction

Section 2 Data Sources

Section 3 Conceptual Model

Section 8 References

Appendix A Geophysical Logs

Tables

Figures

Figures are located at the end of each section.

Section 1
Introduction

This *Technical Memorandum – Groundwater Modeling* (Technical Memorandum) was prepared by CDM on behalf of the Washoe County Department of Water Resources (Washoe County). The work documented in the Technical Memorandum was performed was an element of the Central Truckee Meadows (CTM) Remediation District (CTMRD) project. The primary objective of the CTMRD project is to characterize and evaluate groundwater contamination in the CTM. In addition to the groundwater modeling, project elements include a field investigation program, human health and ecological risk analysis, remedial alternatives development and evaluation, and preparation of a remediation plan.

1.1 Objectives

As stated in the *Final Updated Work Plan* for the CTMRD project (CDM, 2001) the objectives of the groundwater modeling task were:

- Develop the CTM water budget,
- Characterize the flow patterns in the shallow and deep aquifers and the interactions between these units,
- Estimate the capture zones of five water supply wells (High St., Morrill Ave., 4th St., Mill St., Kietzke Lane, and Corbett School) under current and future pumping conditions,
- Evaluate candidate remedial alternatives (with respect to effectiveness, protectiveness of human health and the environment, etc.), and
- Characterize the potential benefit to property owners resulting from any remedial action (including no remedial actions beyond institutional controls and monitoring).

The first three bullet items will be addressed directly in the Technical Memorandum. The last two bullets will be discussed in subsequent documentation.

1.2 Technical Memorandum Organization

This Technical Memorandum consists of the following eight sections and one appendix:

- Section 1 - Introduction
- Section 2 - Data Sources
- Section 3 - Conceptual Model

- Section 4 - Model Construction
- Section 5 - Model Calibration
- Section 6 - Groundwater Flow Model Results and Analyses
- Section 7 - Contaminant Transport Conceptual Model
- Section 8 - References
- Appendix A - Geophysical Logs

Section 2
Data Sources

This section discusses the various sources and types of data used in the preparation of the CTMRD groundwater model. These data sources were used as model input data, guidance in selecting model parameters, and calibration targets.

2.1 MMA/Guyton Model

McDonald-Morrissey Associates, Inc. (MMA) developed a MODFLOW groundwater flow model for Sierra Pacific Power Company (SPPCo), formerly Westpac Utilities (MMA 1993). This model was developed to obtain a better understanding of the flow system within the CTM basin, including responses to stresses. MMA served as the lead consultant in the formulation of the model with considerable input from LBG-Guyton Associates (Guyton). Guyton later updated the model in 1997 (Guyton 1997). MMA's initial model incorporated input data from 1961 - 1991. The update by Guyton extended the simulation period through 1995. This model will be referenced as the MMA/Guyton model.

The MMA/Guyton MODFLOW model was the primary source of data for the CTMRD model. Many of the CTMRD model inputs were taken directly from the MMA/Guyton model. The following features of the MMA/Guyton model, used in the development of the CTMRD model, will be described briefly below:

- Model Layering
- Model Domain/Grid
- Hydraulic Conductivity Distribution
- Surface Water Features
- Areal Recharge
- Mountain Front Recharge
- Water Supply/Industrial Pumping
- Domestic Pumping

Additional descriptions of the MMA/Guyton model parameters are found in references by MMA (1993), Guyton (1997), and CDM (1996).

2.1.1 Model Layering

The MMA/Guyton model was divided into 3 layers. Layering in the model follows the geologic sequencing that will be discussed Section 3.2. Guyton described the alluvial materials in terms of four zones, numbered from 1 to 4, increasing with depth.

Simply, Layer 1, the top layer, represents Zone 1 of the alluvium. Layer 2 represents Zone 2 of the alluvium. Layer 3 represents Zone 3. The Truckee Formation and volcanic rocks are not included in the MMA/Guyton model. These last units are not included because MMA/Guyton believed that these units had hydraulic conductivities that were much lower than the other units. All the significant pumping stresses to the aquifer occur above Zone 4. Figure 2-1 shows a conceptual picture of the layering in the MMA/Guyton model compared to this general geologic sequencing.

The layering from the MMA/Guyton model was used as the initial layering in the CTMRD model.

2.1.2 Model Domain and Grid

Figures 2-2, 2-3, 2-4 show the MMA/Guyton model domain for layers 1, 2, and 3, respectively. As shown in these figures, this model covered both Central and South Truckee Meadows. The model's grid is rectangular with each block-centered cell having a uniform spacing of 1,320 feet (one-quarter mile) in both the X and Y coordinates. The grid has 56 rows and 48 columns. Each layer in the MMA/Guyton model shows different extents due to the physical shape of the Truckee Meadows basin. The deeper layers in the MMA/Guyton model have a smaller extent than layers above because the deeper layers are pinched out as contact is made with the volcanic rock.

The MMA/Guyton model domain served as guidance in establishing the initial layout of the CTMRD model. The model domain was modified based on the geologic mapping discussed in Section 2.5.1.

2.1.3 Hydraulic Conductivity Distribution

The range hydraulic conductivities used in the MMA/Guyton model are shown in Table 2-1. The MMA/Guyton model did not specify a thickness for layer 3 and, therefore, only transmissivity values are available. Figures 2-5 and 2-6 show the distribution of hydraulic conductivity in model layers 1 and 2, respectively.

Table 2-1
Summary of Hydraulic Conductivity and Transmissivity Values Used in MMA/Guyton Model

Parameter	Minimum	Average	Maximum
Hydraulic Conductivity, Layer 1	1 ft/d	45 ft/d	70 ft/d
Hydraulic Conductivity, Layer 2	5 ft/d	15 ft/d	60 ft/d
Transmissivity, Layer 3	100 ft^2/d	255 ft^2/d	820 ft^2/d

The hydraulic conductivities used in the MMA/Guyton model were used to establish initial ranges of conductivities to be used in the CTMRD model. Data from CDM's field program (Section 2.4) and hydrologic/groundwater mapping (Section 2.5.1) provided additional information regarding hydraulic conductivities.

2.1.4 Surface Water Features

Figure 2-7 shows the cells in the MMA/Guyton model designated as river nodes to represent surface water features such as ditches, streams, and rivers in the Truckee Meadows. The river stage and river bed elevations used in the MMA/Guyton model were transferred to the CTMRD model, with adjustments made to match the new numerical grid. The streambed conductance used in the MMA/Guyton model was used as initial values in the CTMRD model.

2.1.5 Areal Recharge

The MMA/Guyton model contained several sources of areally distributed recharge. These sources included recharge from precipitation, excess agricultural irrigation, municipal water system pipe leakage, and lawn/garden irrigation. The precipitation recharge rate used in the MMA/Guyton model was set to a constant value of 0.5 inches per year. The other recharge types varied from year to year as agricultural and urban land uses changed.

This recharge data was transferred for use in the CTMRD model.

2.1.6 Mountain Front Recharge

Figure 2-7 shows the locations where the MMA/Guyton model incorporated mountain front recharge (MFR). The application of MFR to the groundwater model represents inflows from the surrounding mountains to the alluvial sediments near the edges of the basin.

MFR is applied along the majority of the eastern and western edges of the model. The greatest MFR rates are applied to the western edge of the model based on watershed areas and rainfall rates. The MMA model does not explicitly apply MFR along the northern edge of the model.

Orr Ditch flows along a significant portion of the northern edge of the CTM basin and both MFR and Orr Ditch serve as potential sources of water to the groundwater system. Rather than separately simulating both MFR and Orr Ditch as potential inflows, these two features were combined where Orr Ditch and the northern model boundary are co-located. Simulated inflows from the portion of Orr Ditch that flows along the northern model boundary have been increased approximately 50% to account for the rate of MFR estimated from watershed areas and precipitation records.

The MMA/Guyton model represented MFR using a constant flow rate throughout the 1961-1995 transient simulation. While, initially based on the MFR rates used in the

MMA/Guyton model, the CTMRD model varied MFR over time, as discussed in Section 4.2.6.3.

2.1.7 Water Supply/Industrial Pumping

Municipal water supply pumping is a major discharge point for groundwater in the CTM basin. The major water producer in the basin is the Truckee Meadows Water Authority (TMWA), formerly known as SPPCo and Westpac Utilities. Figure 2-8 shows the locations of the TMWA and other industrial pumping wells.

Pumping information was transferred for use in the CTMRD model. Additional pumping data used in the CTMRD model is discussed in Sections 2.1.8, 2.1.9, 2.2, and 2.3.

2.1.8 Domestic Pumping

The MMA/Guyton model also represented domestic pumping as a groundwater discharge point. It is believed that this pumping represent smaller non-municipal water uses. This pumping was assigned to various nodes across the model to represent areas where domestic pumping was likely to occur. Both the domestic pumping rates and locations were transferred for use in the CTMRD model.

2.1.9 Helms Gravel Pit

The MMA/Guyton model represented the operation of Helms Gravel Pit (HGP) in Sparks by assigning dewatering pumping in the appropriate area of the model during the 1961 - 1995 transient simulation. Figure 2-7 shows the location of the HGP nodes.

This pumping data was not transferred directly to the CTMRD model. While the MMA/Guyton model represented dewatering pumping by assigning fluxes to the model, the CTMRD model assigned time-varying water levels to the area covered by HGP. The water level values assigned to HGP represent the elevation of water in the HGP during construction and dewatering operations. The time-varying water levels also account for the creation of Sparks Marina Park Lake (SMPL) after the 1997 flood filled HGP. The simulated fluxes calculated by fixing the water level in the HGP/SMPL will be evaluated and compared to known pumping rates.

2.1.10 Valley Inflow/Outflow

The MMA/Guyton model also represented subsurface inflow from Chalk Bluff and Spanish Springs as sources of groundwater to the CTM basin. Subsurface outflow was represented at Vista Canyon. The locations of these inflow/outflow nodes are shown in Figure 2-7. The MMA/Guyton model used a constant rates to represent the valley inflow/outflow throughout the 1961-1995 transient simulation. These inflows/outflows were transferred to the CTMRD model.

2.1.11 Horizontal Flow Barrier

The MMA/Guyton model included the use of MODFLOW's Horizontal Flow Barrier (HFB) package. This package allows the input of a vertical barrier to slow or block horizontal groundwater flow. The location of the HFB used in the MMA/Guyton model is shown in Figure 2-7.

It is believed that the HFB in the MMA/Guyton model represents a fault structure discussed more fully in Section 3.2.2.3. The fault structure is also represented in the CTMRD model by a zone of low hydraulic conductivity. The CTMRD fault zone follows the same basic alignment as in the MMA/Guyton model. The exact alignment was adjusted to account for observed water levels as discussed in Section 3.2.2.3.

2.2 Data from Washoe County DWR

The Washoe County Department of Water Resources (DWR) supplied information on well locations, water levels, water quality, and pumping rates.

Figure 2-9 shows the locations of the monitoring wells that the DWR maintains records for. A record of water level and water quality readings was available for many of these wells. Typically, water levels have been monitored monthly since late 1999 or early 2000. However, the frequency and length of the water level record varies by well.

The DWR also provided pumping rates for the Hidden Valley supply wells for January 1997 through July 2001. This pumping data was provided as a weekly record. The Hidden Valley supply wells are shown on Figure 2-8.

2.3 TMWA Data

The Truckee Meadows Water Authority (TMWA) provided pumping and reinjection records for their supply wells for January 1995 through August 2001. Records were supplied as monthly totals by well. This data was used to extend the CTMRD transient beyond 1995 where the MMA/Guyton dataset ended.

TMWA also provided hourly pumping records for 11 pumping wells for July 31, 2001 through September 25, 2001. This period encompasses the time frame when continuous data loggers were installed in monitoring wells near 5 of the TMWA wells (see Section 2.4.4).

2.4 CDM Field Program

To augment existing data and fill some data gaps, CDM performed a field program as part of this project. A description of the field program and results are described fully in the *Field Investigation Program Data Summary* (CDM 2001). The following items were particularly useful in the development of the groundwater model:

- Installation of new monitoring wells
- Slug tests
- Geophysical logging
- Short-term aquifer response to pumping

2.4.1 New Monitoring Wells

As part of the field program for the CTMRD, CDM installed 36 new monitoring wells, 20 shallow and 16 deep. The shallow wells are denoted by "CTM-#S" and the deep wells with "CTM-#D". Each of the shallow monitoring wells are screened at a depth of between 25 and 100 feet below ground surface. The deep monitoring wells are screened between 150 and 350 feet below ground. The locations of the new CTM wells are shown on Figure 2-10. The boring logs for these wells are presented in *Field Investigation Program Data Summary* (CDM 2001).

2.4.2 Slug Tests

Slug tests were performed at the 20 shallow wells. The results of these tests are shown in Table 2-2. Computed hydraulic conductivity values range from less than 1 to around 80 feet per day, consistent with previous estimates for the shallow alluvium (Section 3). Some of the slug tests could not be analyzed because the water levels in the wells responded too rapidly. These wells are noted by an "n/a" in Table 2-2. While this slug test data only represents conditions very close to each of the wells, the data was useful in establishing the initial hydraulic conductivities values and ranges used in the CTMRD model.

Table 2-2
Hydraulic Conductivity Results (ft/d) from Slug Tests

Well	Bouwer & Rice Method		Hvorslev Method	
	Falling Head	Rising Head	Falling Head	Rising Head
CTM-1S	n/a	n/a	n/a	n/a
CTM-2S	3.5	12.6	5.2	11.5
CTM-3S	7.5	18.2	44.5	19.5
CTM-5S	28.3	38.6	45.0	69.5
CTM-6S	6.6	10.0	7.9	9.7
CTM-7S	2.0	2.1	2.9	2.8
CTM-9S	0.3	1.5	0.4	1.8
CTM-11S	2.2	10.5	3.0	12.8
CTM-13S	10.5	10.4	12.6	15.4
CTM-14S	38.1	29.8	19.3	32.3
CTM-15S	16.3	9.5	14.7	13.4
CTM-16S	n/a	n/a	n/a	n/a
CTM-18S	3.7	6.6	4.2	9.0
CTM-19S	5.3	13.2	2.9	6.0
CTM-20S	n/a	n/a	n/a	n/a
CTM-21S	27.6	48.8	28.8	56.2
CTM-28S	n/a	n/a	n/a	n/a
CTM-29S	72.3	n/a	85.8	n/a
CTM-31S	50.4	50.4	44.1	44.5
CTM-37S	56.6	37.5	56.8	43.0

n/a: not analyzed

2.4.3 Geophysical Logging

Down-hole, geophysical logging was performed at 11 of the new, deep monitoring wells. Continuous logging of gamma, induction conductivity, and resistivity was done in each of these wells. The results of this testing is shown in Appendix A.

The gamma logs did not indicate significant clay content in these wells. The few high gamma readings seen in some of the wells do not seem to indicate any continuous or extensive clay layers in the CTM area.

However, the geophysical logging did indicate a very significant amount of interbedding in some of the wells. This interbedding is shown on the conductivity logs by the "spikes" in the readings (i.e. alternately areas of low and high readings). While there does appear to be this significant amount of interbedding, there does not seem to be noticeable correlation between the depths of this interbedding between wells. Overall, the interbedding noted in the logs would result in a high resistance to vertical flow.

2.4.4 Short-Term Aquifer Response to Pumping

Aquifer response to changes in pumping at TWMA wells was monitored to help estimate aquifer hydraulic parameters, especially in the deeper alluvium (Zones 2 and

3). This program also helped quantify the hydraulic resistance between the shallow alluvium (Zone 1) and the deeper alluvium where the TMWA pumping occurs.

Twelve continuous data loggers were placed in monitoring wells in five locations near TMWA wells. The data loggers were placed on August 17, 2001 and removed on September 14, 2001. Data loggers were placed in 7 shallow wells and 5 deep wells as shown in Table 2-3. The data loggers recorded water levels in each of the monitoring wells every 15 minutes.

Table 2-3
Data Logger Installation Locations

TMWA Well(s)	***Monitoring Locations***	
	Shallow Well(s)	***Deep Well***
High Street, Morrill Avenue	CTM-7S, 155	CTM-8D
Mill Street	CTM-11S, 133m	CTM-12D
Kietzke Lane	CTM-21S	CTM-22D
Corbett School	73	CTM-17D
Peckham Way	76a	CTM-23D

As discussed in Section 2.3, hourly pumping data was received from TMWA for the same period for 11 TMWA wells. The eleven wells included the 6 wells shown in Table 2-3 and 5 additional TMWA wells located close enough to these 6 wells that they might impact the water levels in the data loggers.

Figures 2-11 through 2-15 show the water level data recorded by the data loggers and the pumping rates for the corresponding TMWA well(s). It is evident all the figures that the water levels in the deeper monitoring wells were directly impacted by the pumping rate in the adjacent TMWA well(s). The Peckham Way well was turned off for the entire period of the data logger installation. The pumping schedule at the TMWA wells was not available prior to installation of the data loggers so that this condition was not foreseeable.

The shallow water levels did not show noticeable response to changes in TMWA pumping. The deeper wells, however, did show significant response to changes in TMWA pumping. For example, the water level in well CTM-12D responded over 10 feet to the shut off of the Mill Street well on August 27, 2001. Similar responses were seen in CTM-8D, CTM-22D, and CTM-17D during this same time period.

The fact that the deep wells responded rapidly to the changes in pumping and the shallow wells did not respond further supports the concept of a high degree of vertical resistance to flow within the aquifer, as discussed in Sections 2.4.3 and 2.4.4. Vertical resistance isolates the shallow wells and creates confinement in the deeper aquifer. In an aquifer with a higher degree of confinement, water is released from storage due to the compression of the aquifer and the expansion of water as a result of lowering the hydraulic head. In an unconfined aquifer, water is released from storage through gravity drainage as the water table drops.

Typically, water released from storage in an unconfined aquifer is much greater than that in a confined aquifer for the same drop in hydraulic head. In an unconfined aquifer, the release of water from storage as the water table drops tends to "damp" changes in the water table elevation. Therefore, a change in hydraulic head will be seen much sooner at a distance from a pumping well in a confined aquifer than at the same distance in an unconfined aquifer.

To analyze hydraulic properties near the TMWA pumping wells, the pumping time histories of the TMWA wells were input into the groundwater model. Hydraulic properties (e.g., vertical and horizontal hydraulic conductivity) were adjusted so that simulated water levels reasonably replicated the observed data logger records in the observation wells. Section 5.2 discusses the short-term transient pumping simulations. Figures 4-6 through 4-13 show the hydraulic properties chosen after all calibration work was completed.

2.5 Other Data Sources

Additional data used in this study are described below.

2.5.1 Hydrogeologic Mapping

The majority of the CTM basin is encompassed in five 7.5′ USGS quadrangles: Verdi, Reno, Vista, Mt. Rose NE, and Steamboat. In addition to the standard topographic quadrangle maps, geologic and hydrologic/groundwater maps were available.

2.5.1.1 Geologic Quadrangle Maps

Geologic maps were available for all five of the quadrangles mentioned above. These maps illustrate the spatial distribution, character, and relative ages of the surficial materials within the quadrangle. These maps were used to aid in the delineation of the CTM basin boundary. The basin is bounded by the contact between the alluvial materials in the basin and the volcanic rocks that comprise the bottom and sides of the basin. The geologic mapping was also used to delineate zones of hydraulic conductivities in the model.

Portions of each geologic quadrangle map were scanned and digitized into an electronic format. Areas of the maps that were known to be outside of the potential model area were not included in the scanning/digitizing process. These areas included areas far removed from the CTM basin and mountainous areas consisting of exposed volcanic rocks. Alluvial and fluvial deposits were the primary units digitized.

Figure 2-16 shows the digitized geologic units superimposed on the scanned quadrangle maps. The units in Figure 2-16 have been grouped by geologic abbreviation. To simplify the interpretation, units have been categorized to general groups (e.g. all floodplain deposits (*Qfl, Qfo, Qfvi, Qfvo, Qfvy*) are shown as *Qf*). This mapping was used to more accurately locate the edges of the CTMRD model. The locations of the geologic units were readily transferred to the CTMRD model because the maps were digitized into an electronic format. This mapping was also used to help establish an initial, relative distribution of hydraulic conductivity for the CTMRD model.

2.5.1.2 Hydrologic/Groundwater Quadrangle Maps

The hydrologic/groundwater maps were only available for the Reno and Vista quadrangles. While only two of the five quadrangles covering the model study area were available, these two maps cover a large portion of the model area. Figure 2-17 represents the information shown on the hydrologic/groundwater maps.

These maps show an estimate of relative water yield from the deposits in the CTM basin. Relative water yield is shown using a high-intermediate-low type ranking system. The maps also give an indication as to the thickness of various deposits and the type of deposit underlying that unit. This information was used to establish patterns of hydraulic conductivity for the CTMRD model.

2.5.2 Precipitation Records

Precipitation records for the Reno, Stead, and Mt. Rose precipitation gages were also acquired. Figure 2-18 shows the annual precipitation records for these three gages. These records were useful in the establishment of recharge to the CTM basin. The use of these records with respect to mountain front recharge will be discussed in Section 4.2.6.3

2.5.3 USGS Water Levels

Historical water level elevation data were obtained for two United States Geological Survey (USGS) wells with long-term records. Water level measurements at well USGS 393150119452801 (USGS-1) and well USGS 392930119481001 (USGS-2) were used to evaluate historical conditions in the basin and to evaluate historical long term transient results (Section 5). The locations of these wells are shown in Figure 2-19. Wells USGS-1 and USGS-2 are approximately 42 and 89 feet deep, respectively. Both of these wells are, therefore, screened in the shallow alluvium.

2.5.4 Miscellaneous Reports

Various other reports, as listed in Section 8, were also consulted. These reports described the following types of data:

- Hydrogeology of the CTM basin

- Quarterly report on Helms Gravel Pit dewatering rates
- TMWA (formerly Westpac Utilities and SPPCo) activities at supply wells
- Quarterly reports on the remediation activities at the Sparks Solvent/Fuel Site (SSFS)

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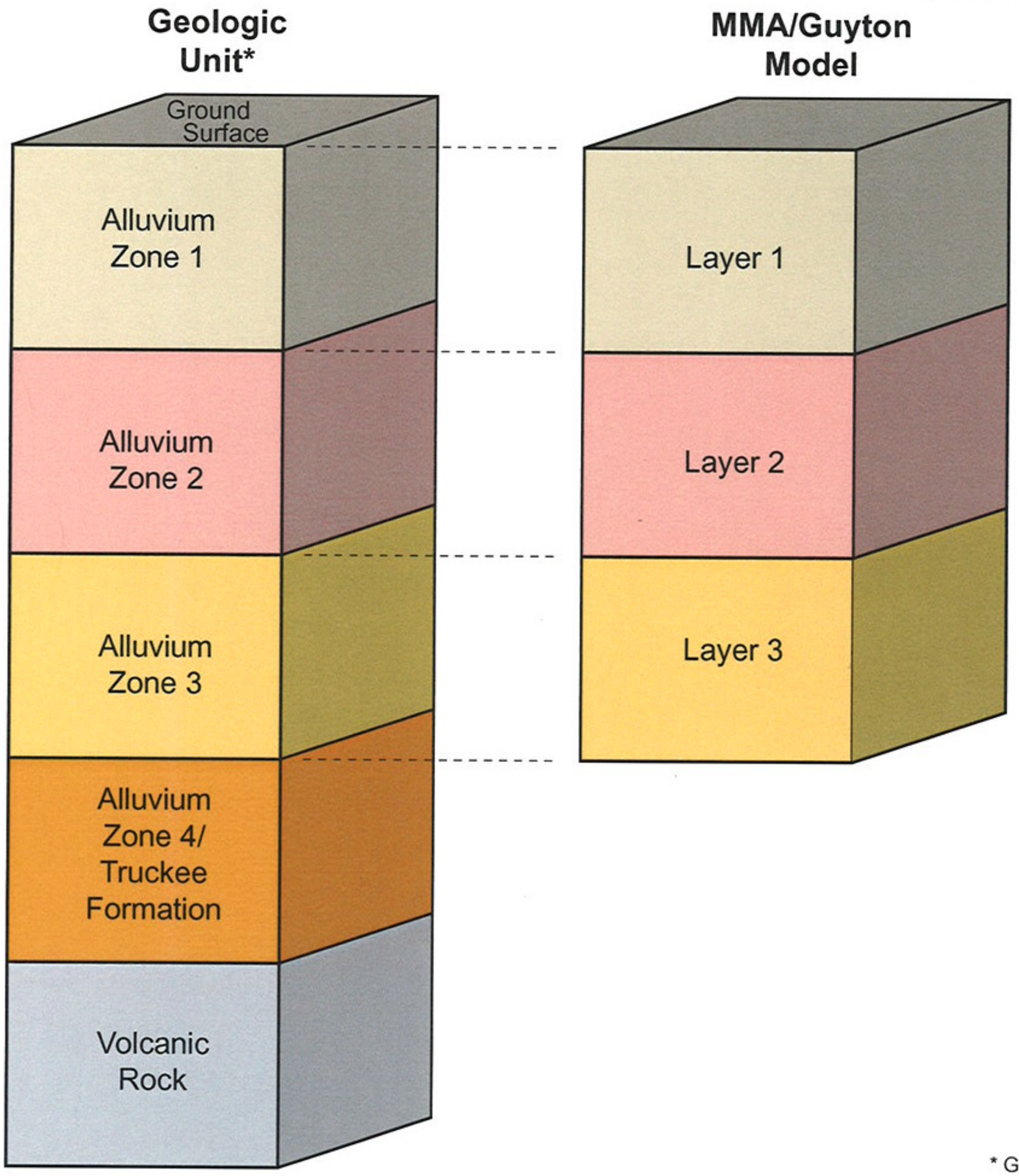

* Geologic units as described by Guyton (1997).

CDM

Figure 2-1
Conceptual Diagram of Geologic Units and MMA/Guyton Model Layering
Central Truckee Meadows Remediation District

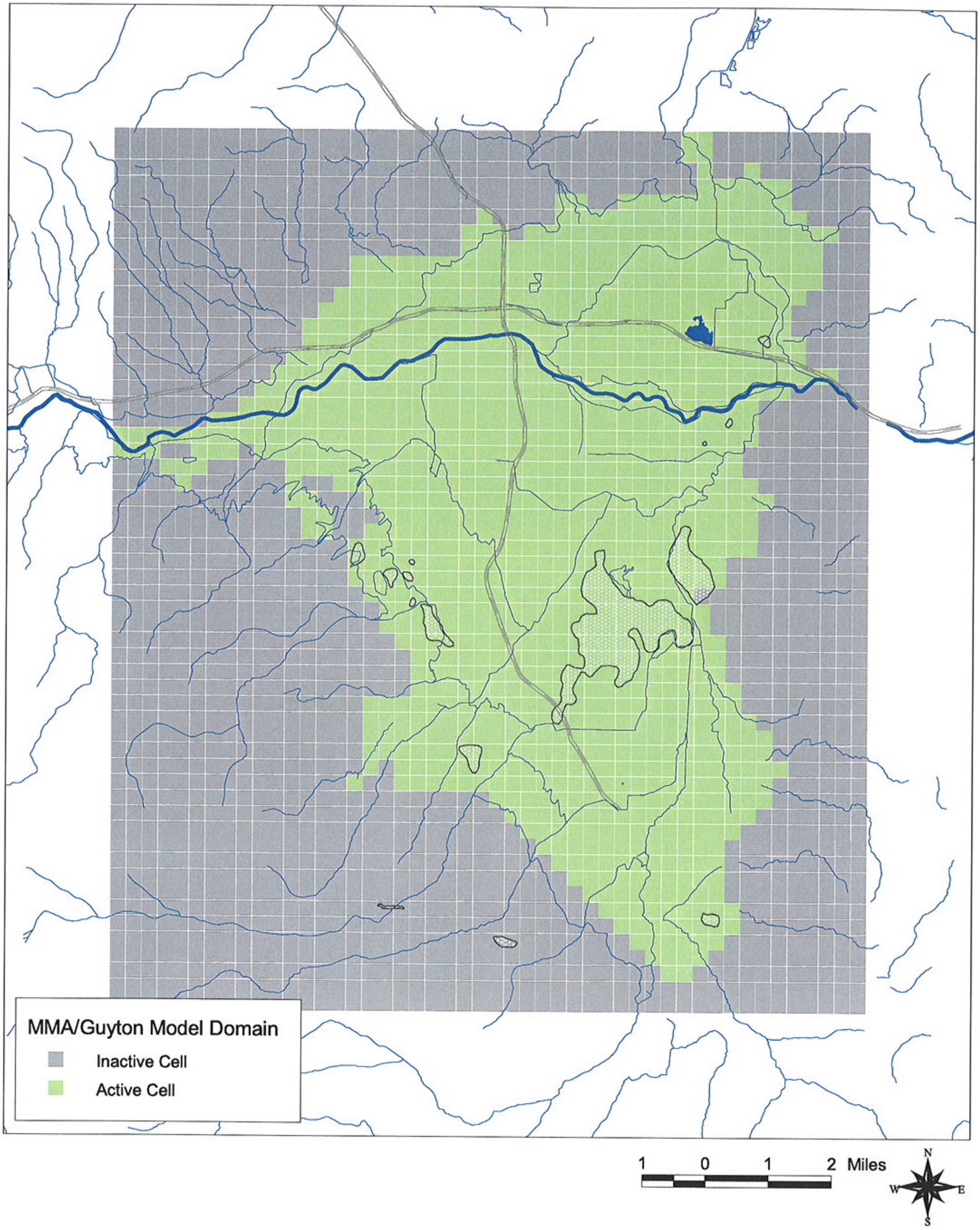

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Figure 2-2
MMA/Guyton Model Domain, Layer 1
Central Truckee Meadows Remediation District

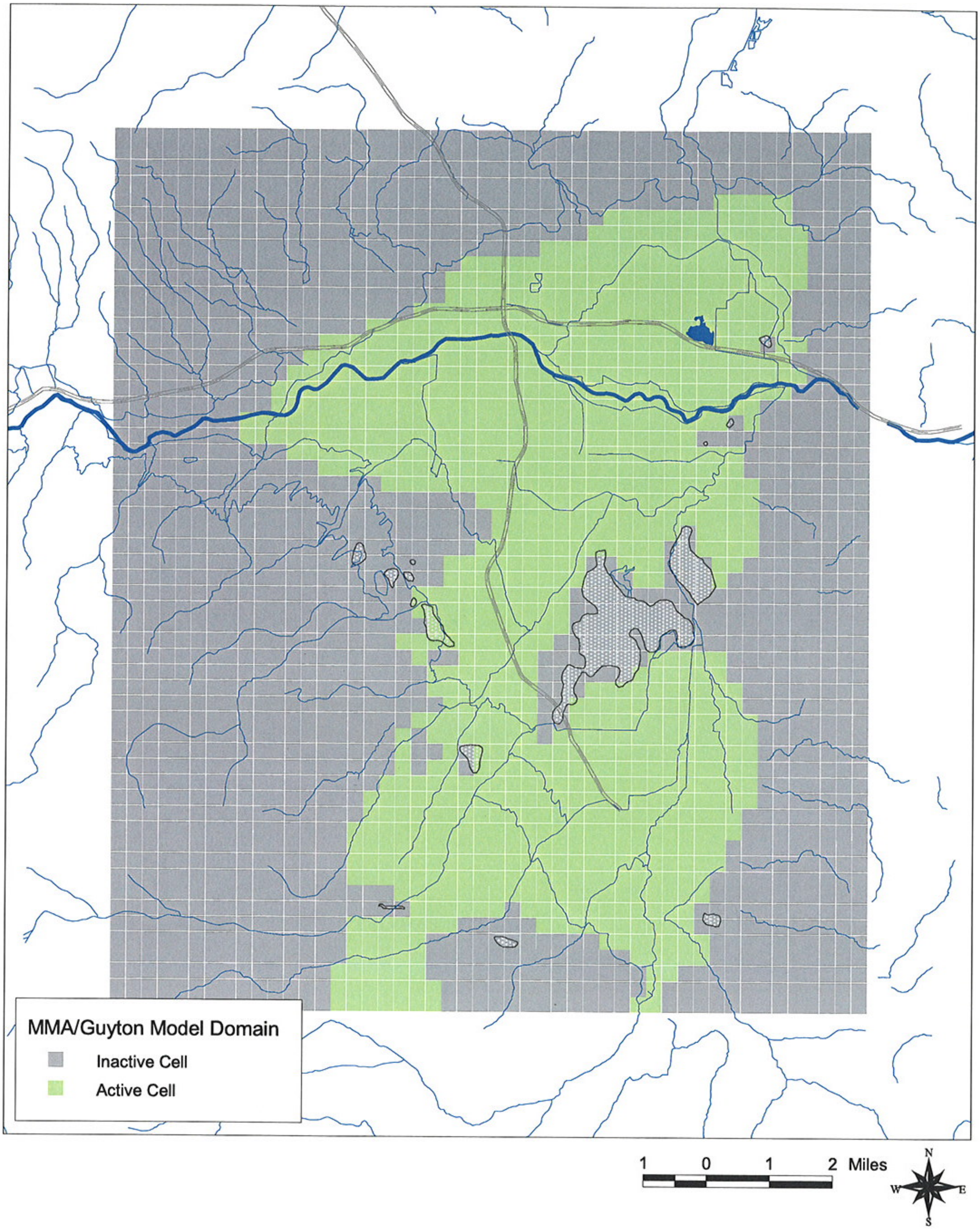

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Figure 2-3
MMA/Guyton Model Domain, Layer 2
Central Truckee Meadows Remediation District

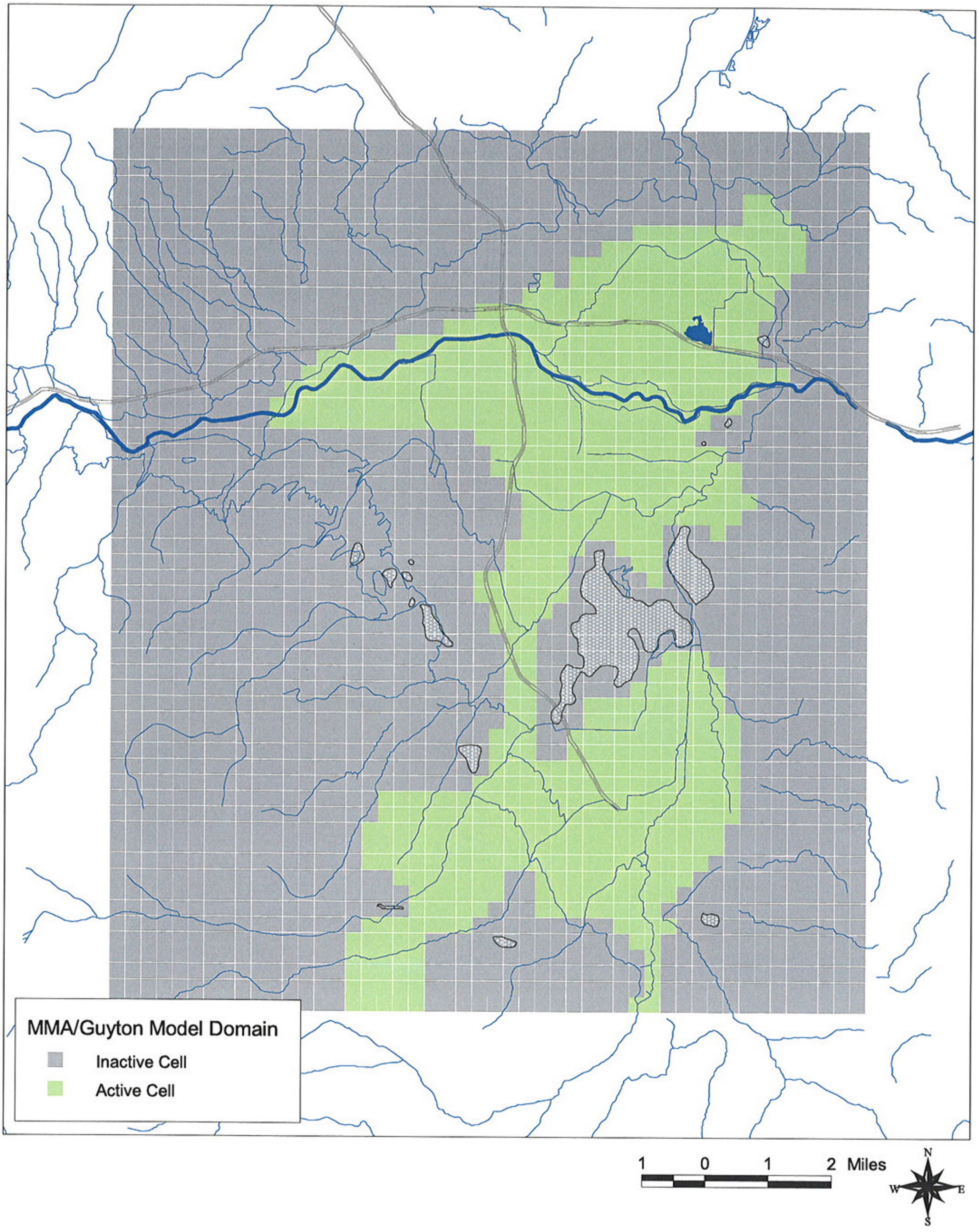

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Figure 2-4
MMA/Guyton Model Domain, Layer 3
Central Truckee Meadows Remediation District

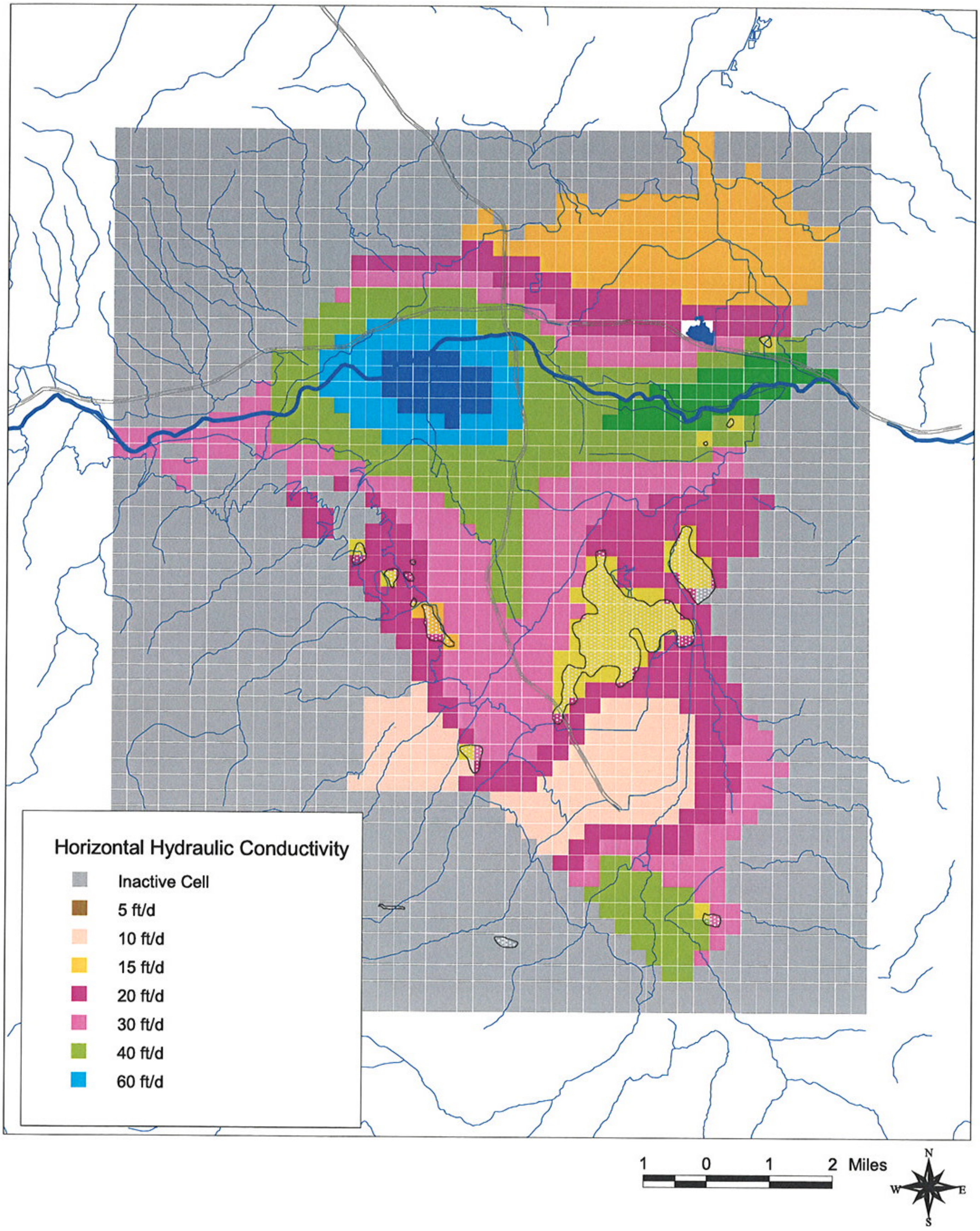

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Figure 2-5
MMA/Guyton Hydraulic Conductivity Distribution, Layer 1
Central Truckee Meadows Remediation District

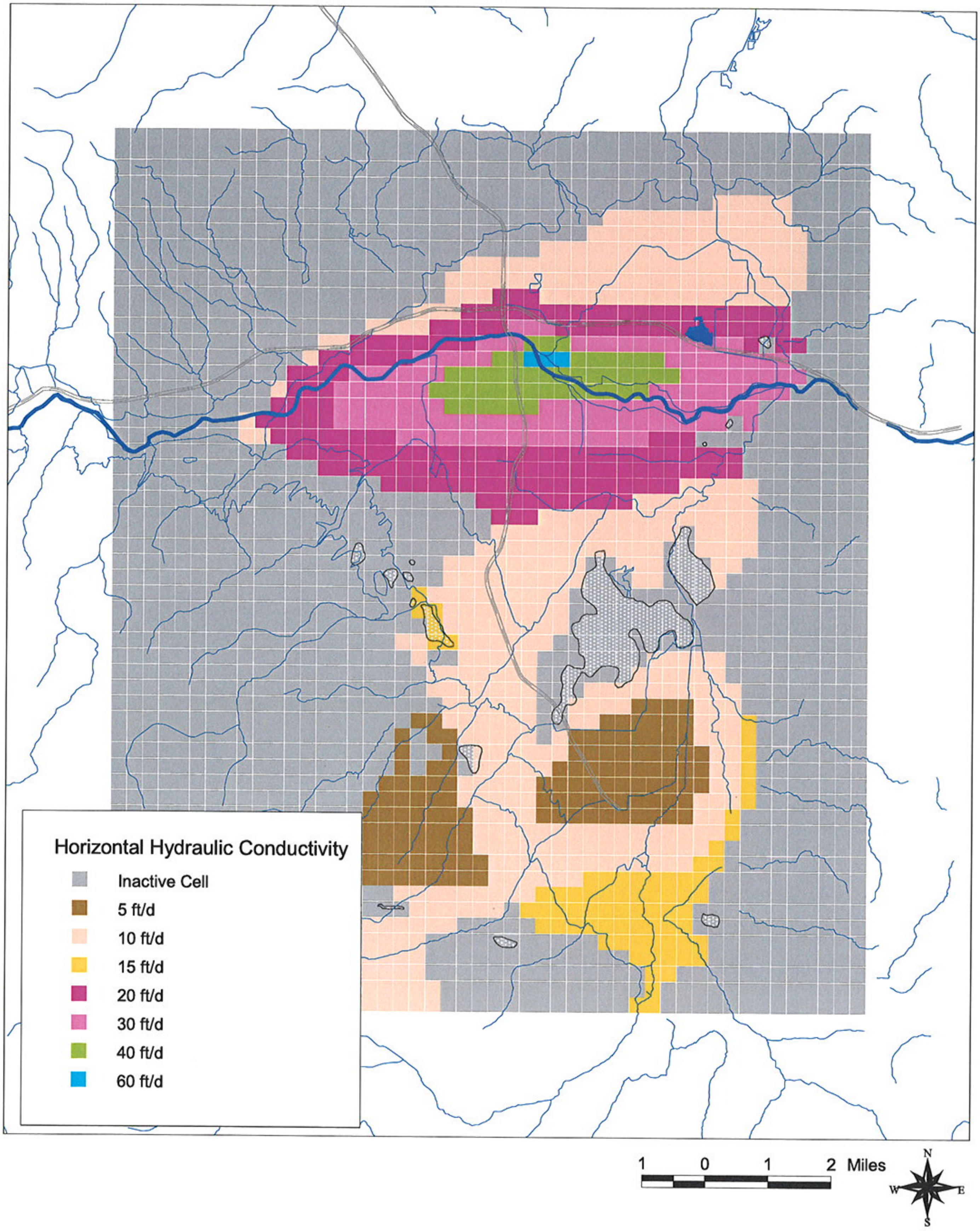

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Figure 2-6
MMA/Guyton Hydraulic Conductivity Distribution, Layer 2
Central Truckee Meadows Remediation District

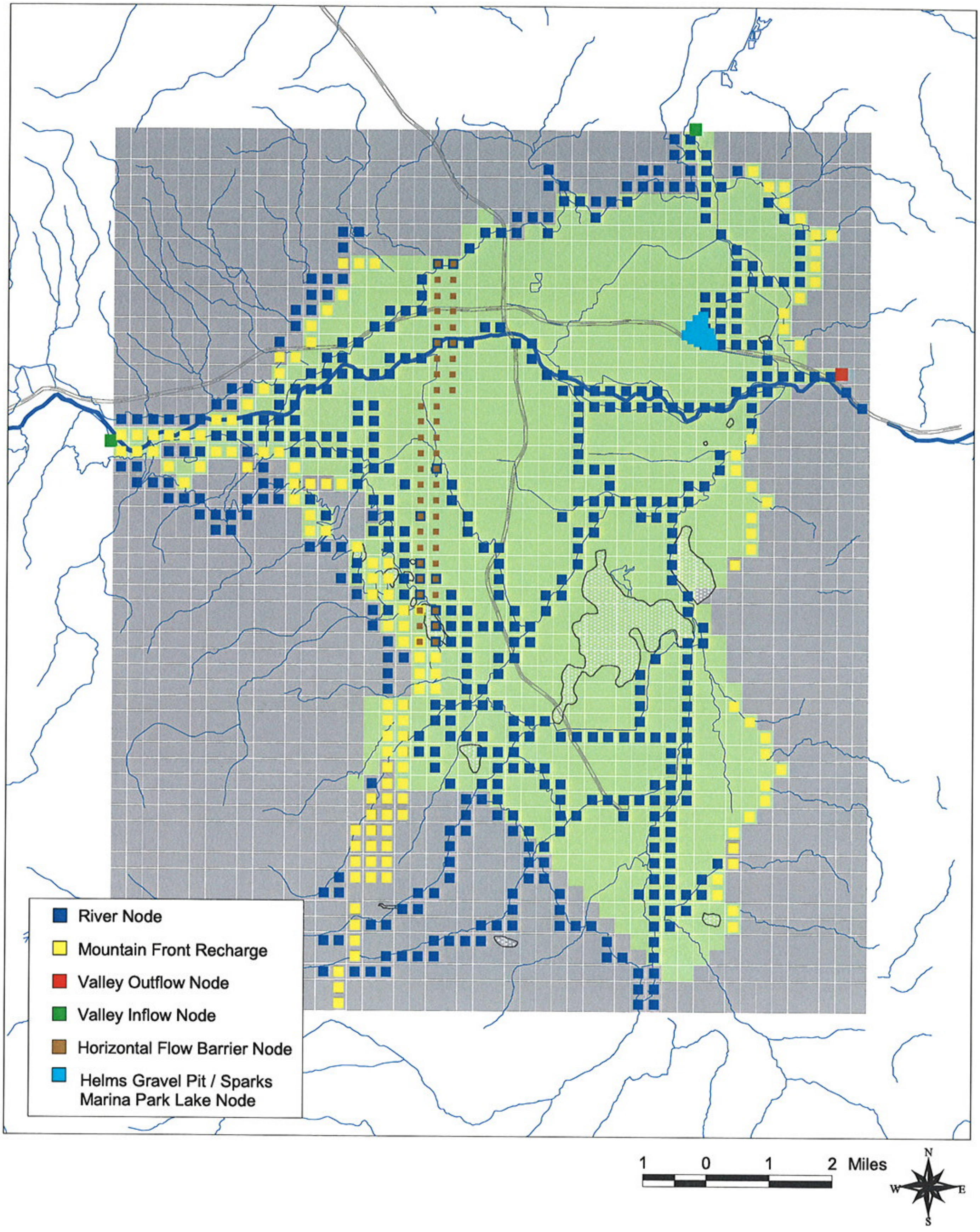


Figure 2-7
MMA/Guyton Boundary Conditions
Central Truckee Meadows Remediation District

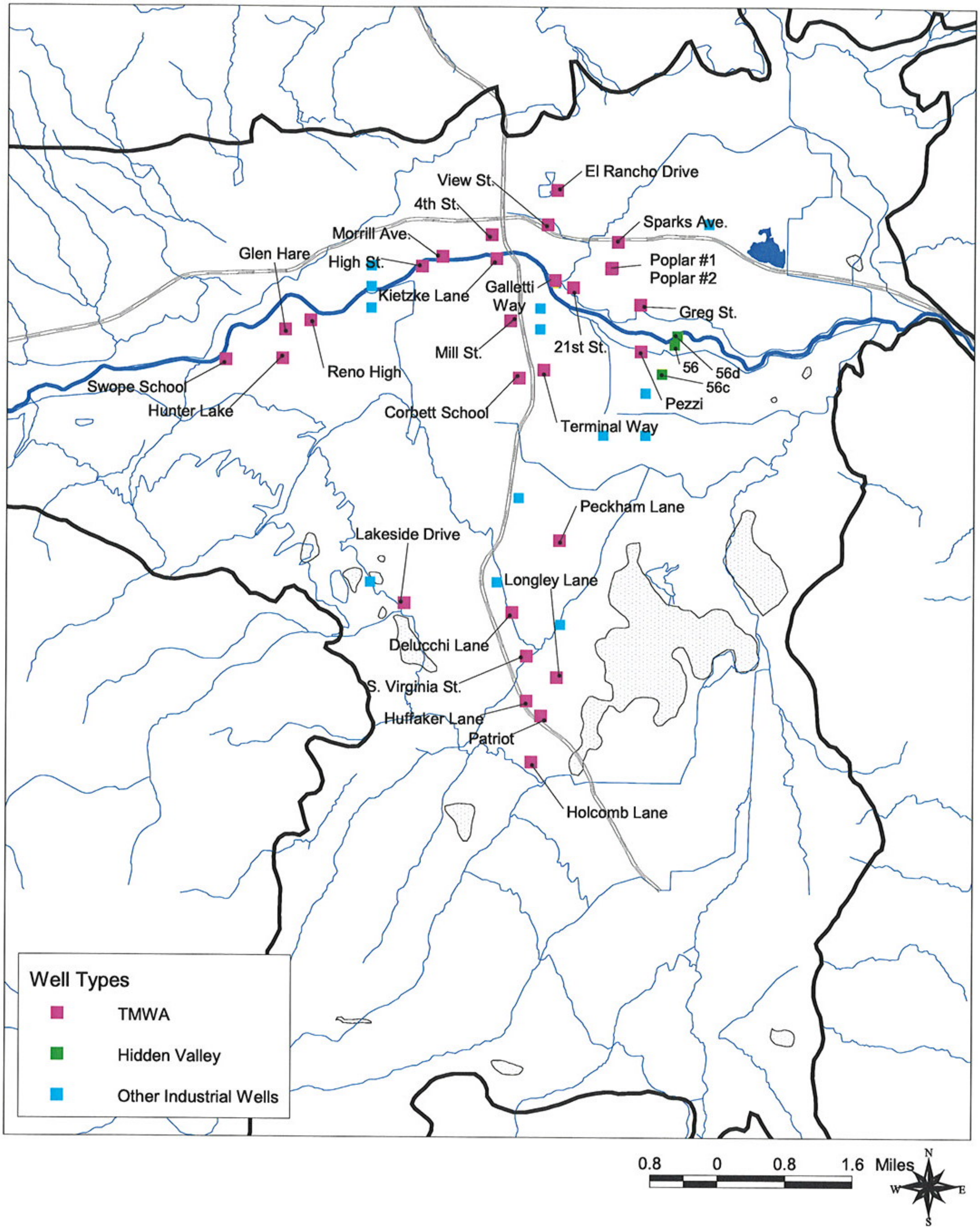


Figure 2-8
Location of Pumping Wells in MMA/Guyton Model
Central Truckee Meadows Remediation District

Figure 2-9 is located in a map pocket
at the end of the document.

CDM

Figure 2-9
Locations of Wells Monitored by Washoe County DWR
Central Truckee Meadows Remediation District

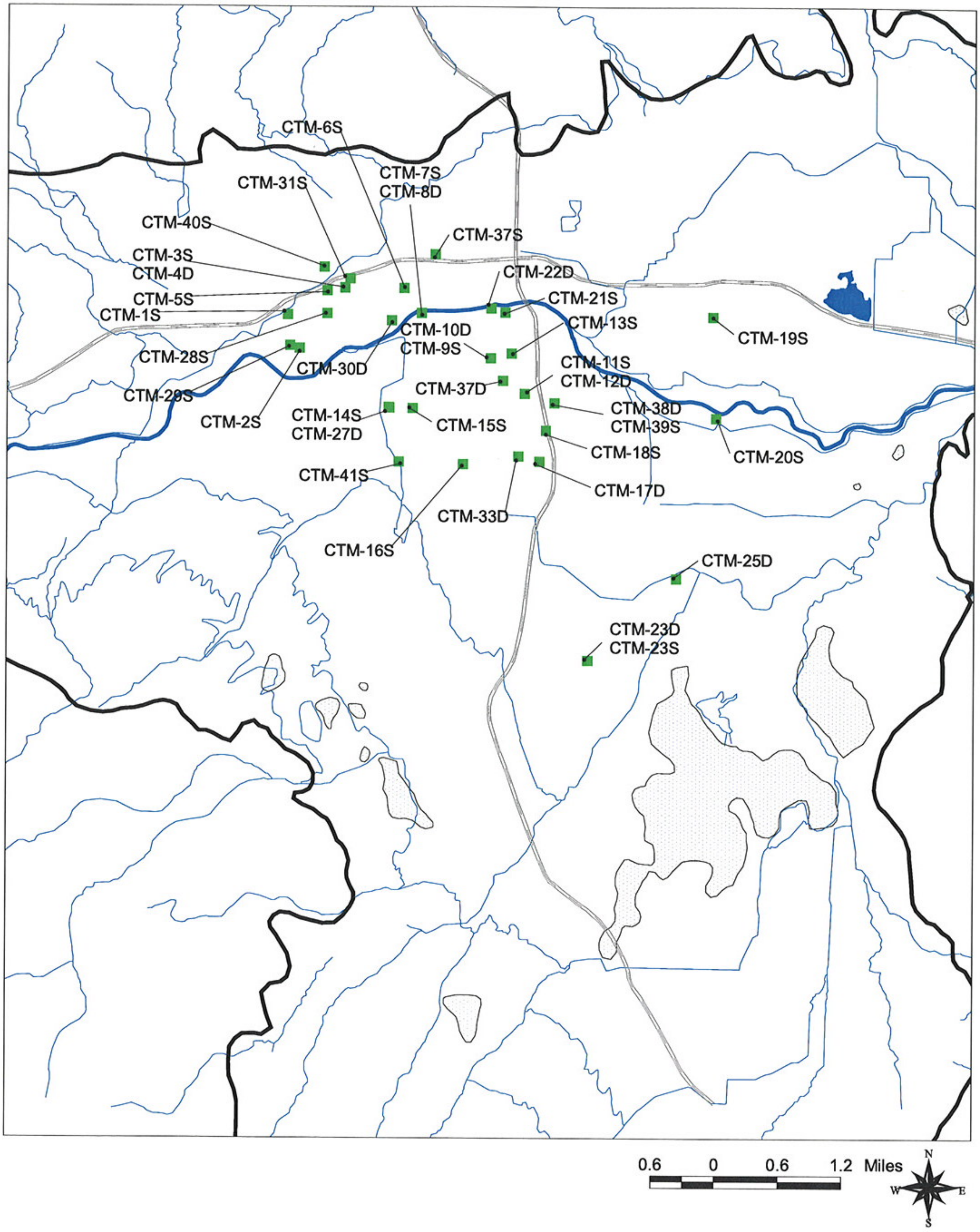


Figure 2-10
Location of Newly Installed CTM Monitoring Wells
Central Truckee Meadows Remediation District

CDM

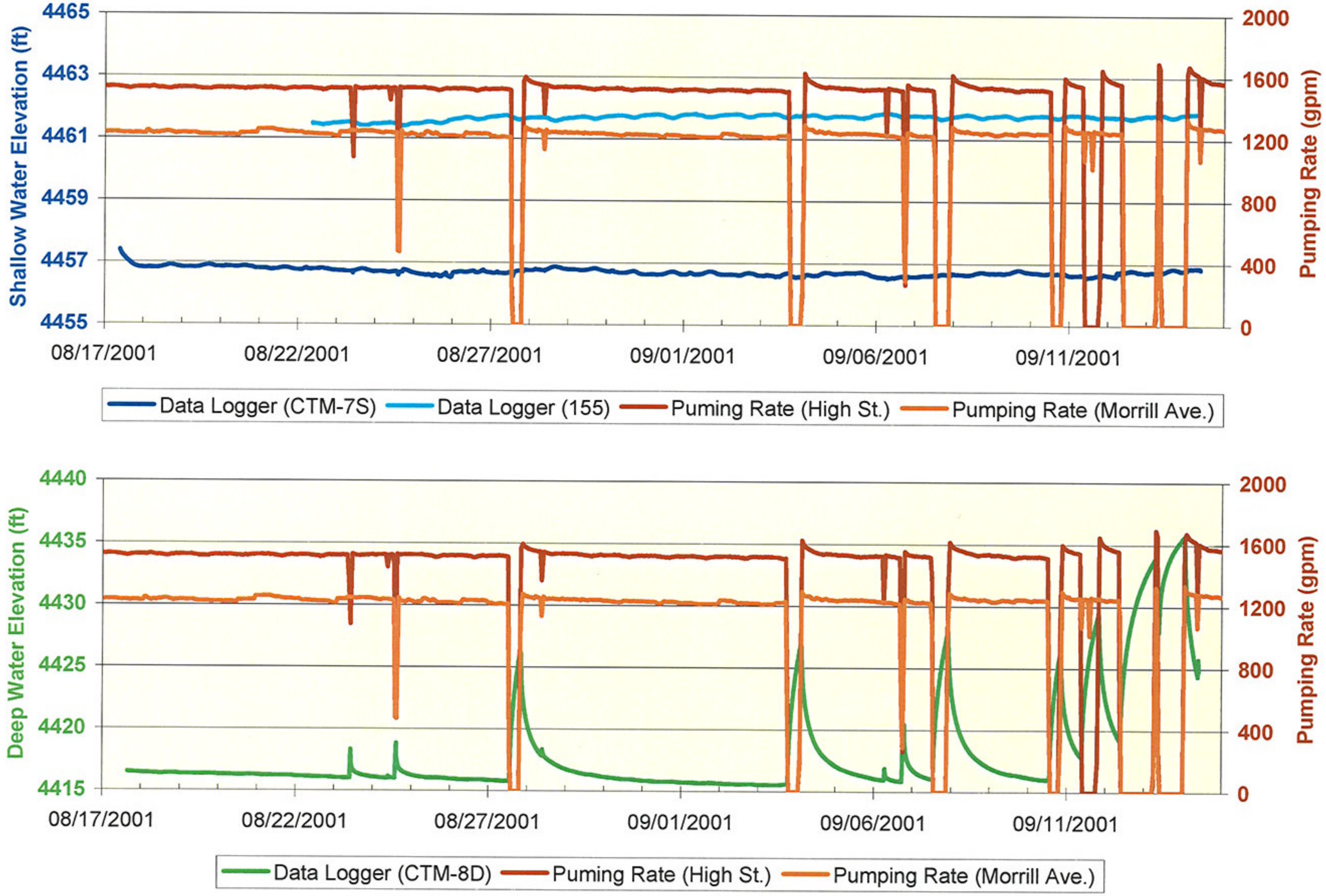
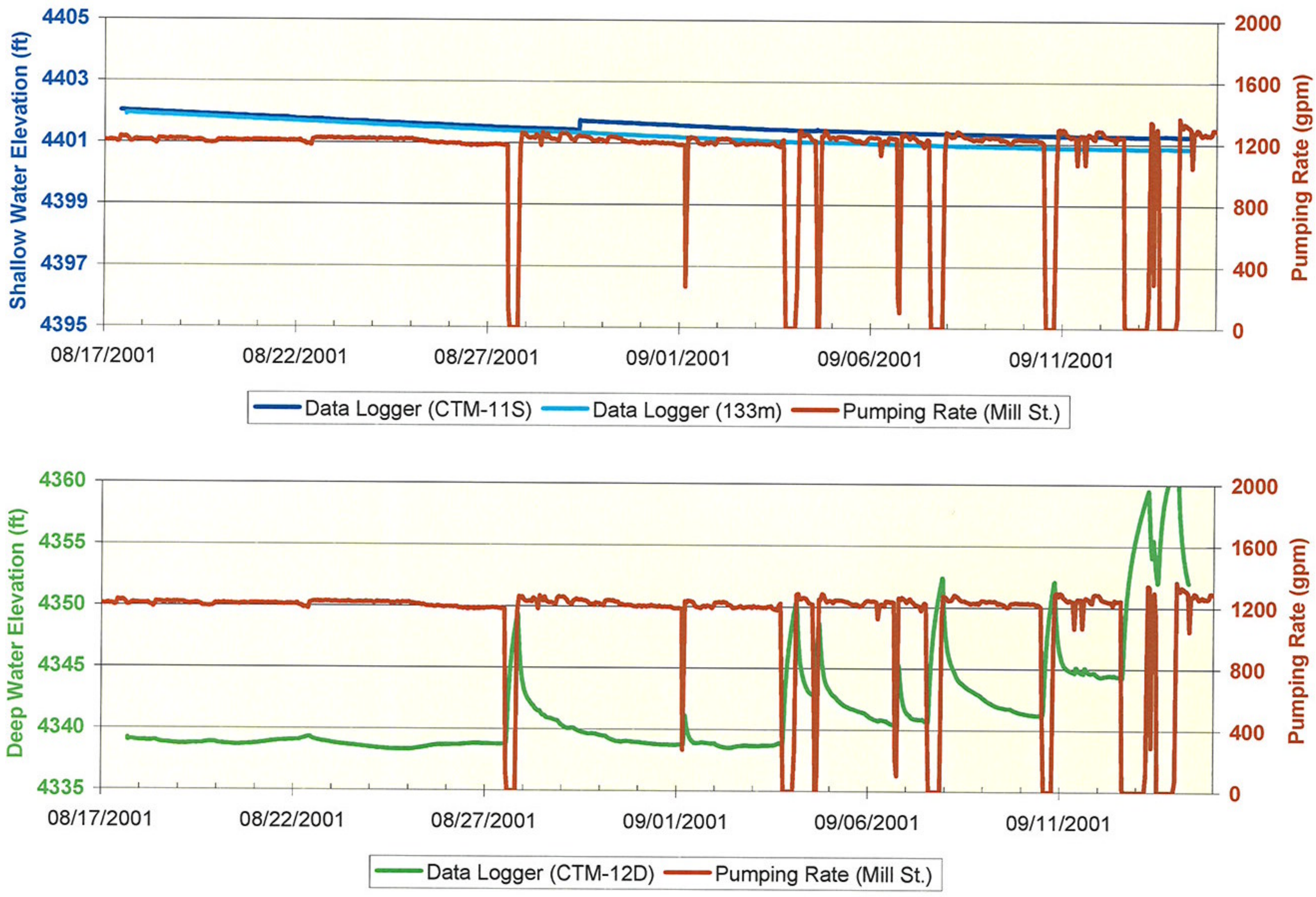


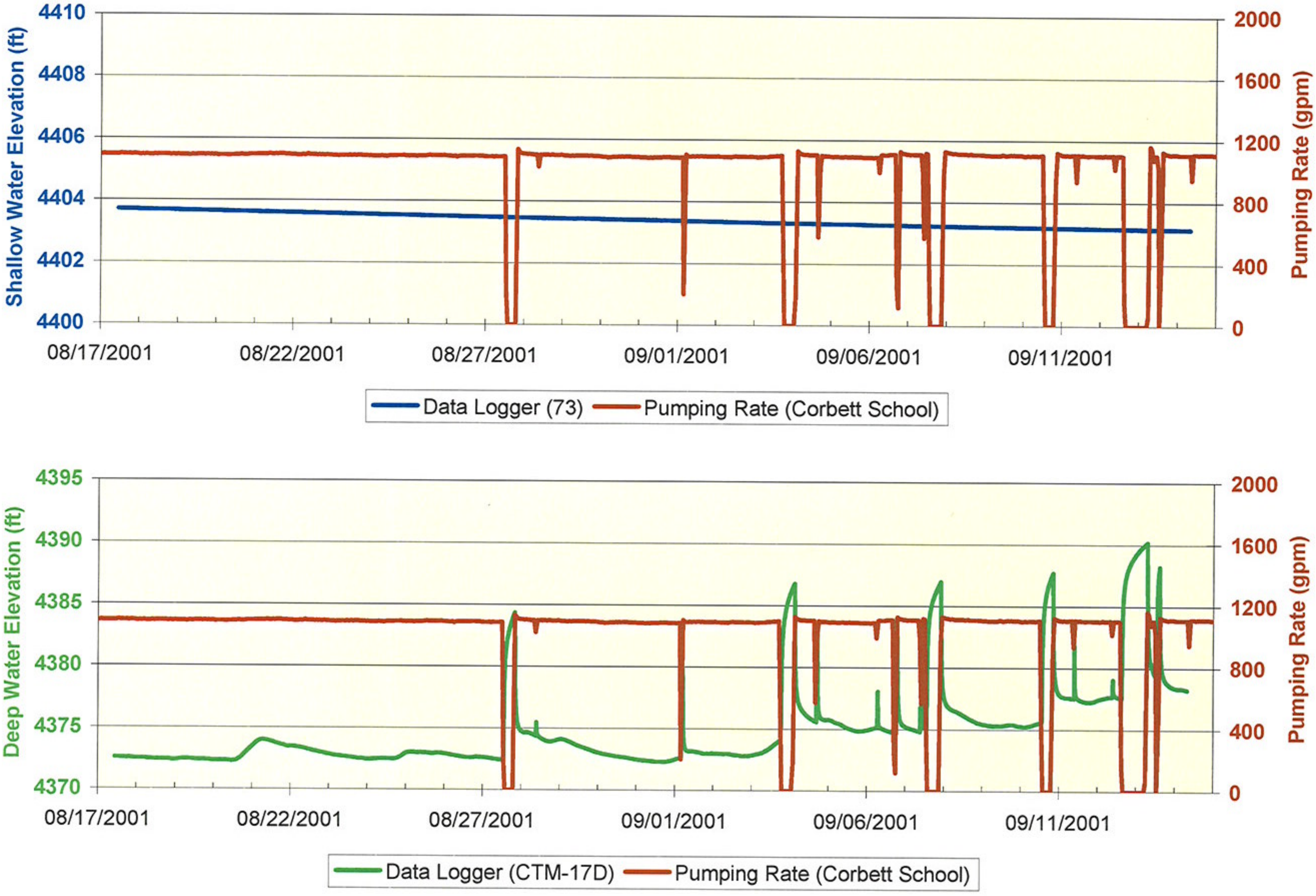
Figure 2-11
Data Logger Results Near High St. and Morrill Ave. Wells
Central Truckee Meadows Remediation District

Logger Results-Model TM.xls: High-Morrill
06/25/2002



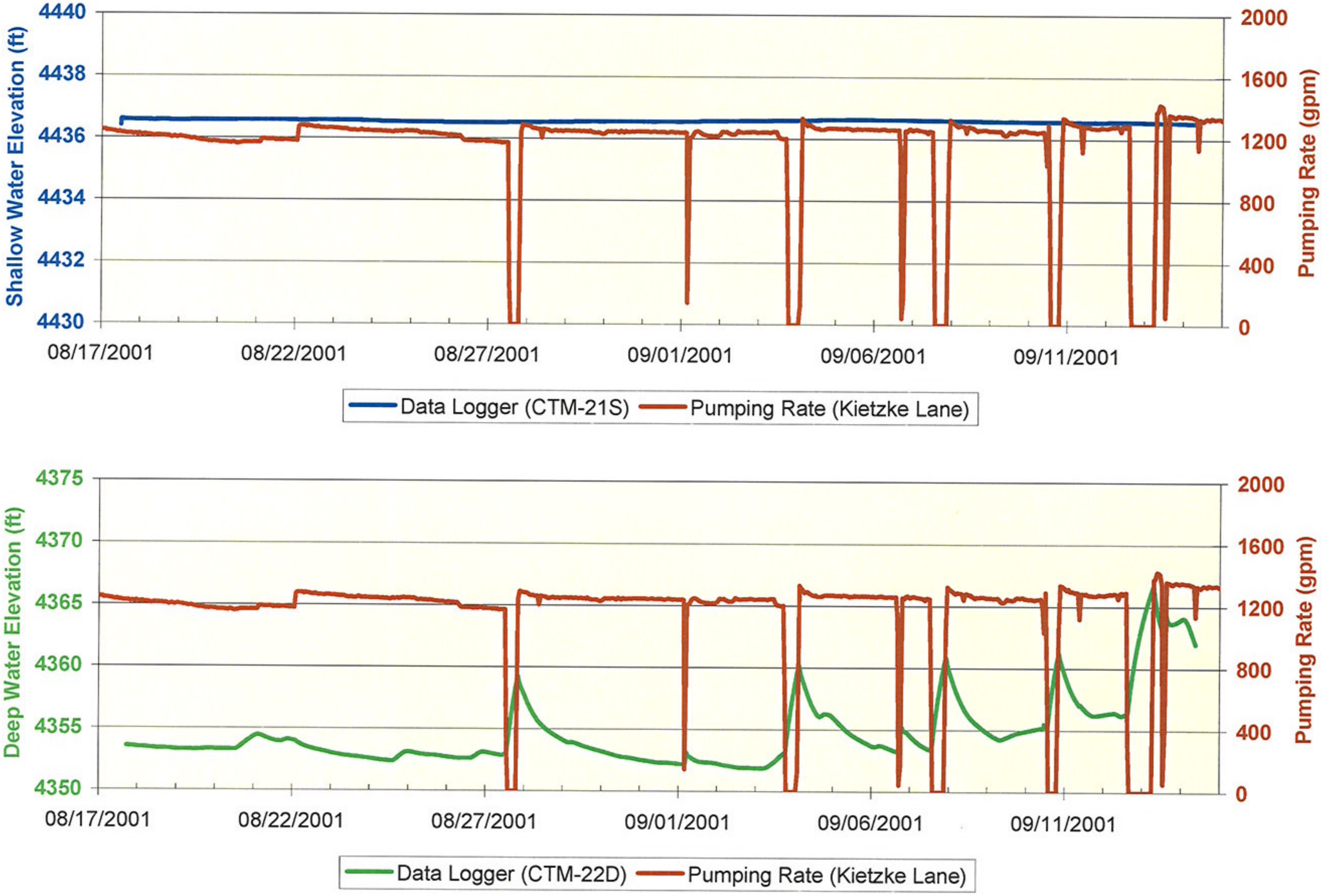
Logger Results-Model TM.xls: Mill
06/25/2002

Figure 2-12
Data Logger Results Near Mill St. Well
Central Truckee Meadows Remediation District



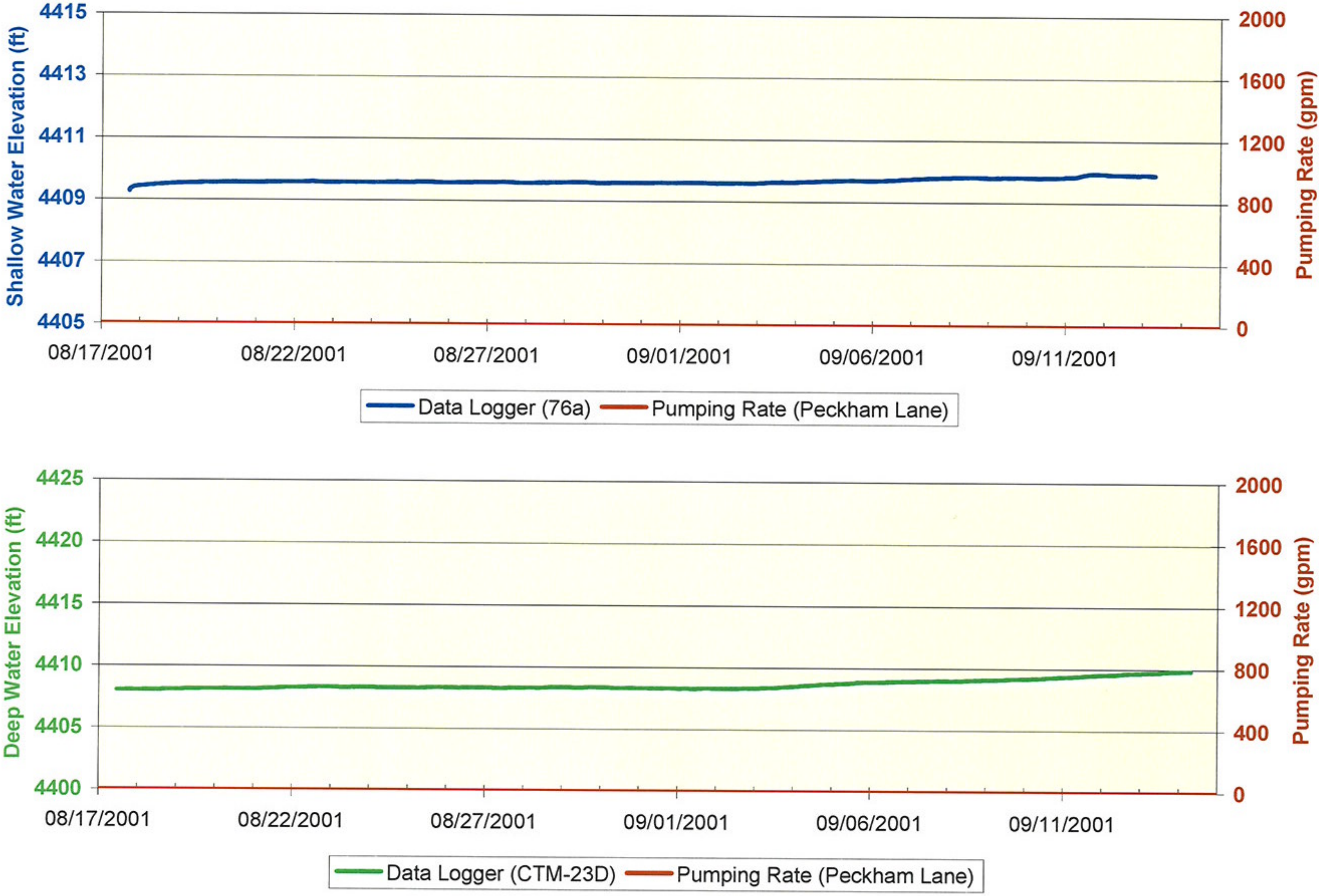
Logger Results-Model TM.xls: Corbett
06/25/2002

Figure 2-13
Data Logger Record Near Corbett School Well
Central Truckee Meadows Remediation District



Logger Results-Model TM.xls: Kietzke
06/25/2002

Figure 2-14
Data Logger Record Near Kietzke Lane Well
Central Truckee Meadows Remediation District



Logger Results-Model TM.xls: Peckham
06/25/2002

Figure 2-15
Data Logger Results Near Peckham Lane Well
Central Truckee Meadows Remediation District

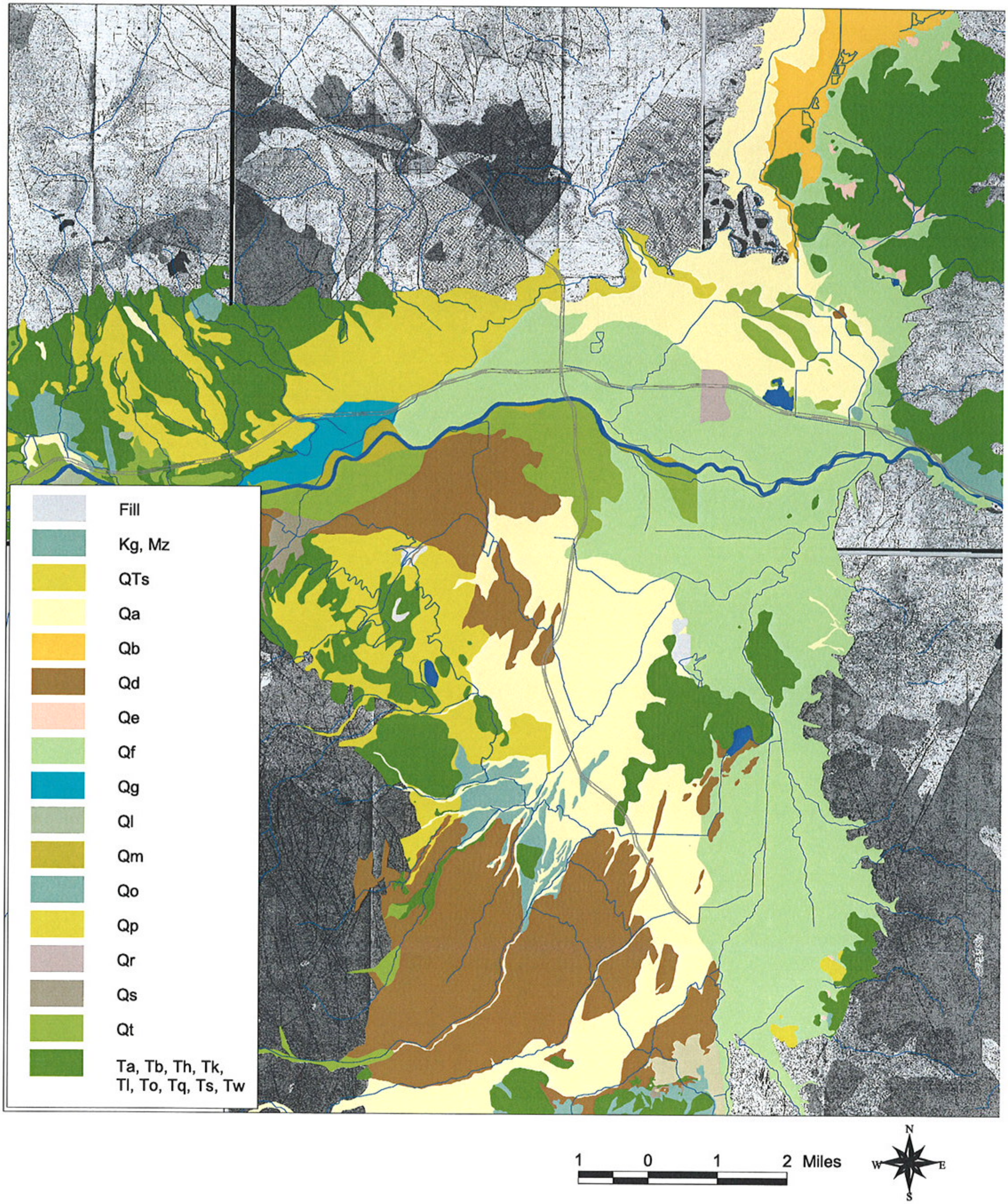
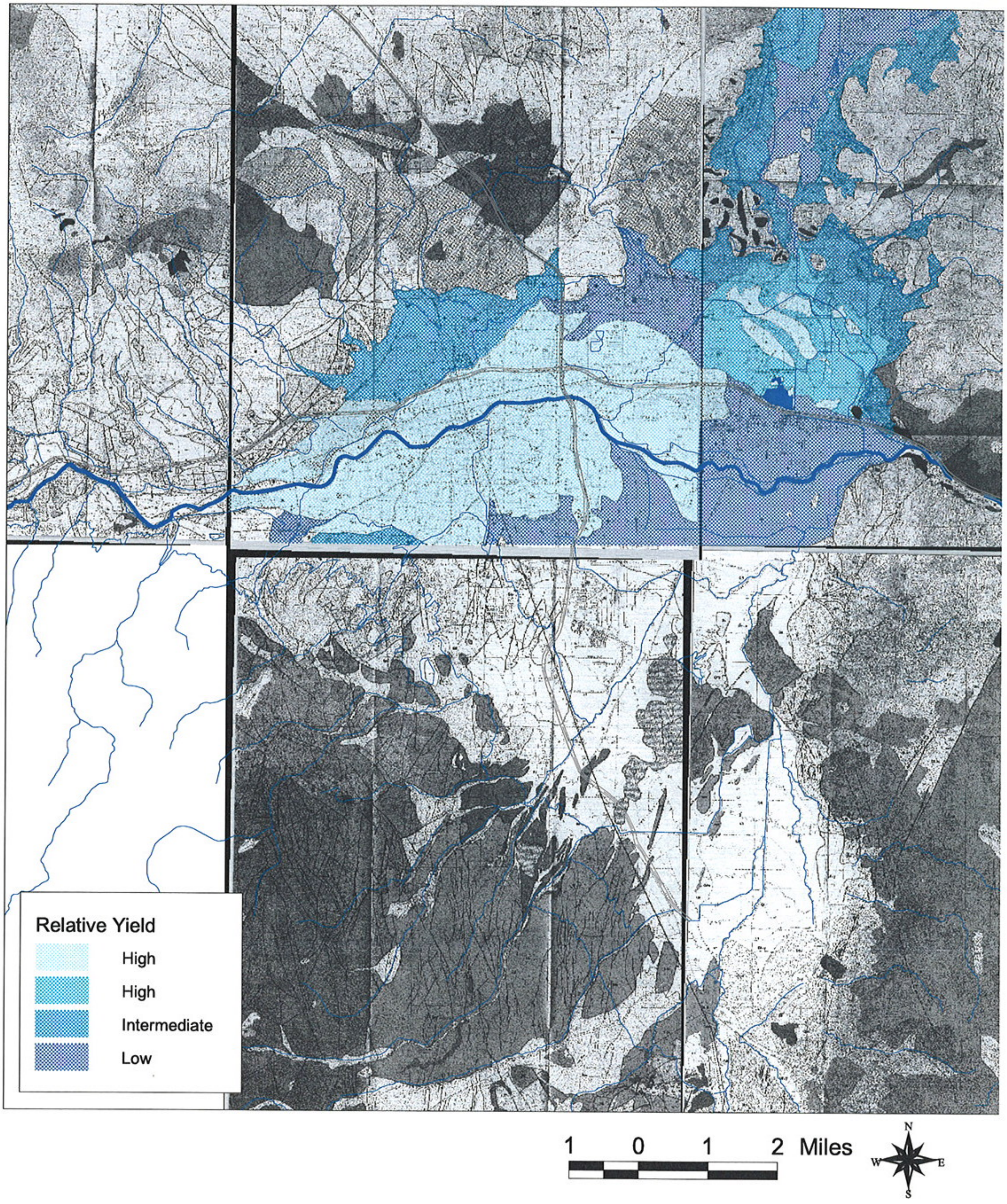
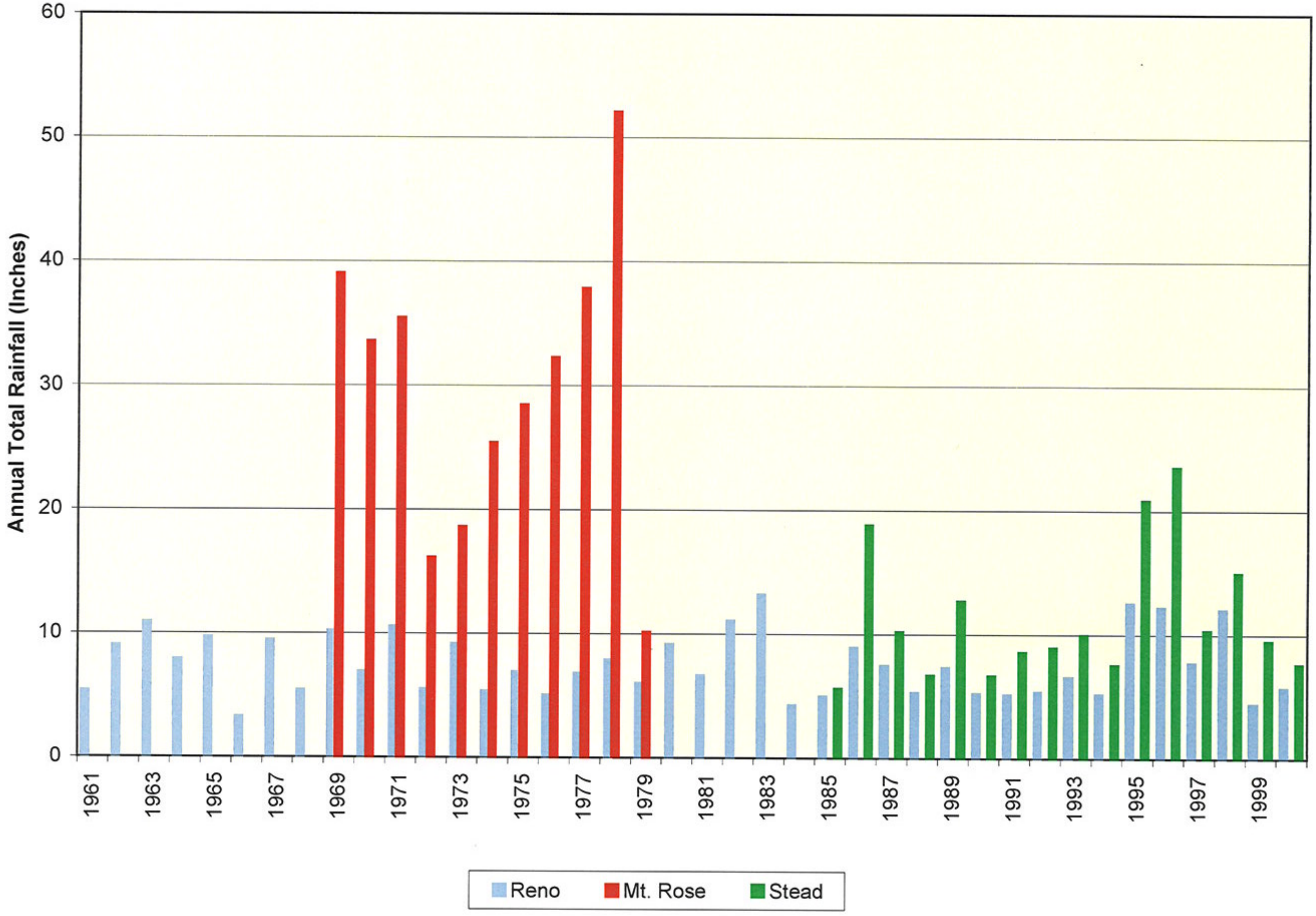


Figure 2-16
Surficial Geology Mapping
Central Truckee Meadows Remediation District



CDM

Figure 2-17
Relative Yield
Central Truckee Meadows Remediation District



reno_precip2.xls: AnnualChart
06/25/2002

Figure 2-18
Annual Precipitation In Study Area
Central Truckee Meadows Remediation District

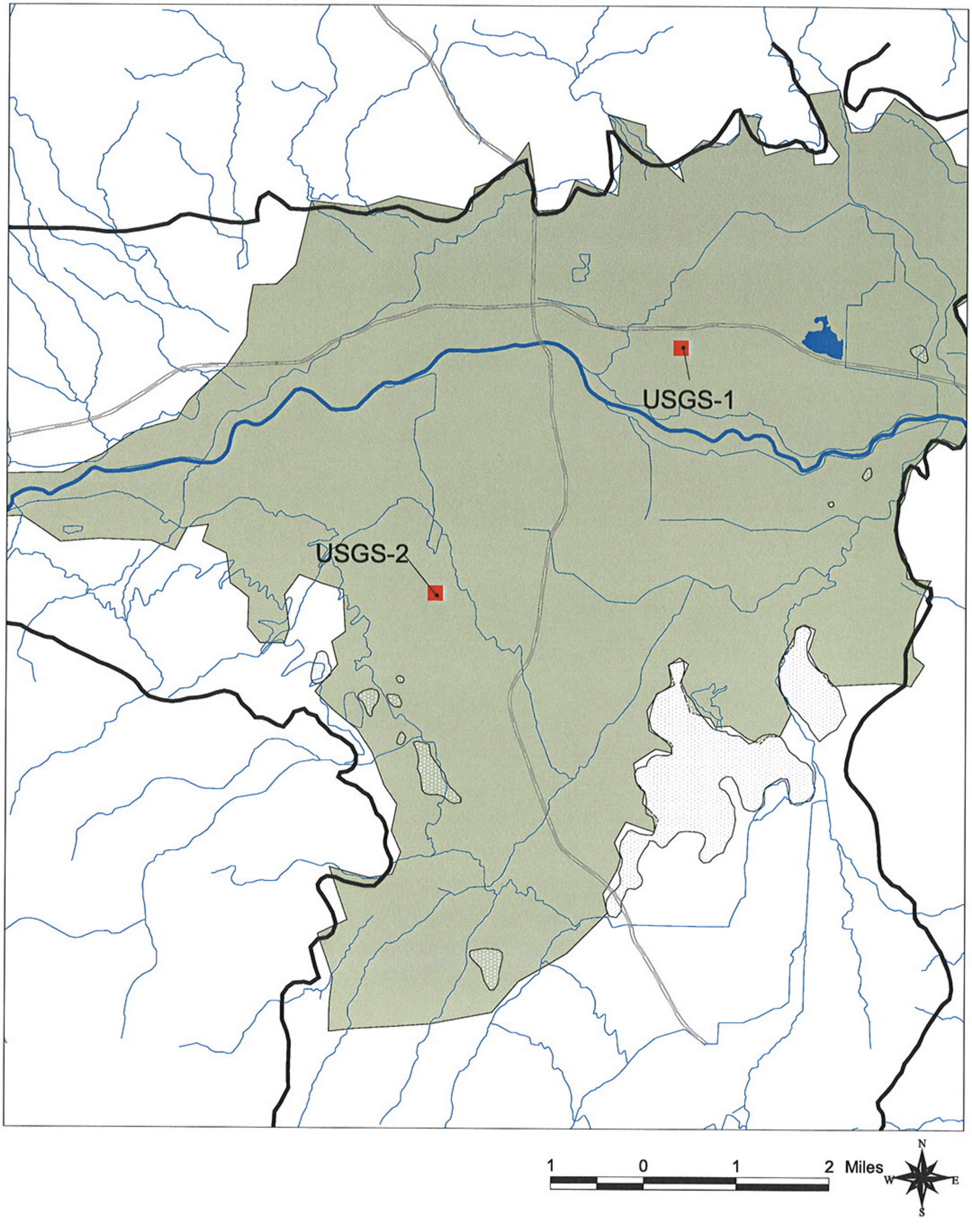


Figure 2-19
Location of USGS Monitoring Wells
Central Truckee Meadows Remediation District

Section 3
Conceptual Model

The conceptual model described in this section was a key element developing the numerical groundwater model. The conceptual model is based largely on reports by LGB-Guyton (1997) and McDonald Morissey Associates, Inc. (MMA) (1993). Other sources of information include Cohen (1964), Cooley (1971), and CDM's work in the CTM basin, both for the CTMRD and at the Sparks Solvent/Fuel Site (SSFS) (CDM 1996).

3.1 Physical Setting

Understanding and fully describing the physical setting of the study area is the first step in building a groundwater model. Describing the physical setting helps to identify:

- Horizontal and vertical extent of the model
- Mechanisms by which water may enter and exit the system

The Truckee Meadows refers to the topographic basin bounded by volcanic rock outcrops of the Virginia Range and Pah Rah mountains to the east, the Carson Range to the west, Steamboat Hills to the south, and the Peavine Mountain bedrock outcrops to the north. Figure 3-1 outlines the physical setting of the Truckee Meadows and identifies the CTM Remediation District study area.

In general, the geology of the area is conceptualized as bedrock basin composed of volcanic rocks of relatively low permeability and filled with a sequence of sedimentary deposits, which tend to decrease in permeability with depth below ground surface.

Primary inflows to the groundwater flow system include mountain front recharge (MFR), leakage from rivers and streams, infiltration of excess irrigation water, inflow from adjacent valleys, infiltration of municipal water applied to lawns and gardens, leakage from irrigation ditches, system losses from municipal water distribution systems, and direct infiltration of precipitation. Primary outflows from the groundwater system include municipal and industrial pumping, evapotranspiration, seepage to springs, pumping at Helms Gravel Pit (HGP)/Spark Marina Park Lake (SMPL), seepage to rivers and streams, domestic pumping, seepage to irrigation ditches, and outflow to adjacent valleys.

It is important to note that a significant portion of groundwater pumped for municipal and industrial purposes, as well as from HGP/SMPL, is returned to the overall system as point discharges into the Truckee River in the eastern portion of CTM. A significant quantity of municipal and industrial pumping returns to the Truckee River through the regional wastewater treatment plant. Water pumped from

HGP/SMPL, a surface water body feed almost entirely by groundwater, is discharged to Peoples Ditch, which, in turn, discharges to the Truckee River.

Precipitation in the Truckee Meadows region ranges from 6 to 10 inches per year. In the higher elevations of the Carson Range, which bound the Truckee Meadows to the west, annual precipitation is on the order of 40 inches per year (H. Klieforth, Desert Research Institute, unpublished map, 1983). Precipitation that falls in the Carson Range and drains to the Truckee Meadows is a significant source of MFR.

The primary surface water feature in the Truckee Meadows is the Truckee River, which enters the basin from the west through the Carson Range and leaves through a canyon in the Virginia Range at the northeast boundary of the basin. During its course through the Truckee Meadows from Chalk Bluff to Vista Canyon, the elevation of the Truckee River drops approximately 250 feet (from approximately 4,620 to 4,370 feet mean sea level).

The primary tributary to the Truckee River in the study area is Steamboat Creek, which enters the basin through a bedrock gap adjacent to Steamboat Hills, flows north-northeast around the eastern boundary of Huffaker Hills, and joins the Truckee River just before it leaves the basin to the east. Steamboat Creek is fed by Whites Creek, Thomas Creek, and Dry Creek/Boynton Slough, which all drain the Carson Range.

Besides these natural drainage features, there is a network of irrigation ditches build to supply water to farms and ranches in the Truckee Meadows. Seven primary ditches divert water from the Truckee River: Steamboat, Last Chance, Lake, Cochran, and Pioneer ditches on the west side of the Meadows, south of the Truckee River, and Highland and Orr ditches on the north side of the Meadows. Excess water from Orr ditch, which delivers water north of the Truckee Meadows to Spanish Springs Valley, is returned to the Truckee River in the North Truckee Drain. Return flows from the western ditches are conveyed in either Boynton Slough or Steamboat Creek.

3.2 Geologic Description

Two major deposits form the geologic composition of the Truckee Meadows: volcanic rocks and sedimentary deposits. Volcanic rocks comprise the mountains surrounding the Meadows and the low hills along the margins of the basin, and underlie the basin fill. The sedimentary deposits, which serve as the basin fill, were divided into two categories by MMA: the Truckee Formation, which refers to older and less permeable deposits, and the alluvium, which refers to younger, less consolidated and more permeable deposits. The alluvium is, in turn, divided into "younger" and "older" components. A more detailed characterization of each rock type follows.

3.2.1 Volcanic Rocks

In general, the volcanic rocks of the Truckee Meadows (also termed the "bedrock"), which are extrusive in nature, consist of lava flows, tuff, agglomerate, and tuff breccia of mostly andesitic composition, and exist at depth beneath the basin deposits. Figure 3-2, a contour map of the elevation of the top of the volcanic rocks beneath the basin fill, was obtained from MMA's 1993 Draft Report. According to MMA, the elevation of this bedrock floor was determined based on data obtained from borehole geophysical logs, drillers' logs of wells, geologic maps, cross sections obtained from various reports, and in cases where geologic data were lacking, from projections of volcanic-rock surfaces exposed at the basin margin. It is noted that these bedrock elevations range from being well defined (e.g., on the western margin of the basin where bedrock is shallow and easily identified in driller's logs), to uncertain (e.g., in the deeper parts of the basin where the volcanic/sedimentary rock interface is based on projections of surface slopes). Based on the contours presented in this figure, depth to bedrock in the Central and South Truckee Meadows basins may be greater than 3,000 feet and 2,500 feet, respectively.

The hydraulic conductivity of the volcanic rocks of the mountains, while not known with a high degree of certainty, is believed to be less than 0.01 feet per day (fpd). It is hypothesized that fracturing, faulting, and weathering have probably occurred where the bedrock is exposed in small knobs along the margin of the basin, or where it is found at shallow depths beneath the alluvium. The hydraulic conductivity in such areas is believed to be as much as 1 fpd. Due to such fracturing at the basin margin, MMA postulates that a significant percentage of MFR enters the groundwater flow system as subsurface flow within the alluvial system through fractures in the bedrock along the east side of the Carson Range (the western boundary of the groundwater flow system).

With respect to the development of this particular CTMRD model, how the MFR actually enters the groundwater flow system is less important than obtaining reasonable estimates of the quantity of MFR and locations where MFR enters the system. This reasoning is primarily because the areas of interest for this study are located toward the center of the basin, where sediments are thick and depth to bedrock is great. As a result, the groundwater model is expected to be relatively insensitive to the effects of the vertical location of MFR inflow.

3.2.2 Sedimentary Deposits

Cohen and Loeltz (1964) indicate that the unconsolidated deposits filling the CTM basin are comprised of the Truckee Formation, older alluvium, and younger alluvium.

3.2.2.1 Truckee Formation

The Truckee Formation is exposed in the northwest part of the study area where the Truckee River enters the basin. In areas where the formation is exposed, it is composed of massive to thinly bedded siltstone, silty sandstone, sandy conglomerate, diatomite, and diatomaceous silt- and sandstones. Drillers' logs have also characterized penetration of the Truckee Formation by abundant blue, green, and gray clay. The formation is considered less permeable than the alluvium, although quantification of hydraulic conductivity in this unit is rare.

An evaluation of well data by MMA/Guyton indicates that the Truckee Formation does not exist in the region between Windy Hill and Huffaker Hills (Figure 3-1) where bedrock is found at shallow depths. This location will be used as the southern boundary of the current CTMRD model as described in Section 4.

3.2.2.2 Alluvium

The alluvium is the most permeable formation beneath the Truckee Meadows and is the primary unit through which water flows and contaminant transport occurs. The alluvium is composed of varying proportions of silt, sand, and gravel. Lenses of clay and clayey materials have also been observed, although to a lesser degree. The alluvium has been classified into two subdivisions termed the "younger" and "older" alluvium (Cohen 1964).

Lacustrine deposits within the alluvium do exist in various areas of the basin, and are most prevalent in the eastern portion of the valley, north of Huffaker Hills (Figure 3-1). Of particular importance to the CTMRD project is the potential existence of a clay-rich soil horizon found in southeast Truckee Meadows (Simon Hydro-Search, 1991) and in portions of downtown Reno. This horizon is believed to be significant at a depth of approximately 100 feet below ground surface with a thickness of 10 to 20 feet. However, no evidence of basin-wide feature of this type was found during the geophysical logging program performed for this project (Section 2.4.3). The geophysical logging indicated relatively few clay lenses in the wells that were logged, and the lenses that were noted do not seem to be continuous across the basin.

Cohen and Loeltz (1964) and MMA/Guyton discuss the difficulty in separating the two alluvial units with certainty (there is a lack of traceable beds between wells). However, they do note that some features are common throughout the alluvium and are distinguishable through the analysis of geophysical logs, drillers' logs and drill cuttings. In particular, a broad zone of relatively coarse boulders is noted throughout a majority of the north basin and part of the south basin. The base of this coarse unit ranges in depth from 55 to 400 feet.

For the purpose of conceptualizing the alluvial flow system beneath the Truckee Meadows, Guyton (1993) performed an analysis of the existing well data and subdivided the alluvium into four major zones: Zone 1 represents the shallowest alluvial unit and Zone 4 represents the deepest.

Zone 1, which extends to an average depth of approximately 100 feet, is characterized by poorly sorted gravel, boulders, silt, and clay, and contains a higher proportion of boulders than the other three zones. A decrease in, or absence of boulders, is used to indicate the bottom of this zone. MMA notes a decrease of resistivity in electric logs at the interface of Zones 1 and 2, which may indicate a reasonably consistent clay-rich horizon as mentioned above. CDM's geophysical logging program did not seem to indicate a significant drop in the resistivity logs as MMA notes. As discussed in Section 2.4.3, this recent logging did not seem to indicate a continuous clay layer as has been described in the past. MMA/Guyton estimate the hydraulic conductivity in Zone 1 to range from 10 to 70 fpd.

According to the MMA/Guyton conceptual layering discussion, Zone 2 averages approximately 200 feet thick and is similar to Zone 1 deposits except for lesser amounts of boulders and a greater proportion of clay. The base of this zone is generally marked by the first appearance of "blue clay" in driller s logs, although in some cases such clay is encountered above the base of this zone. Blue clay is normally associated with the Truckee formation, but may also be indicative of an oxygen deficient depositional environment. Hydraulic conductivity estimates by Guyton for Zone 2 ranged from 5 to 60 fpd. While Zone 2 is slightly less permeable than Zone 1, it has a much higher transmissivity than Zone 1 (due to its thickness), and is therefore a larger overall transmitter of water.

Zone 3 ranges in thickness from 300 to 500 feet in the deeper parts of the basin, but is much thinner at the basin margins and in the region between Huffaker Hills and Windy Hill. Clays and silts are more common in Zone 3 than in Zones 1 and 2 (blue clay is also common), although electric log resistivity tends to be greater in Zone 3 than in Zone 2. The recent geophysical logging program performed tests on only a few wells that were potentially drilled into Zone 3. Even these wells may have penetrated only the topmost portion of Zone 3. Therefore, little new information regarding this zone is available. Due to a lack of wells and test holes, the base of this unit is not as well defined as that of Zones 1 and 2. Guyton estimates hydraulic conductivity in Zone 3 to range from 5 to 30 fpd.

Zone 4 underlies Zone 3, but a lack of data makes characterization difficult. The few wells penetrating this zone indicate a formation composed primarily of fine-grained materials. One well in the eastern portion of the south basin suggests Zone 4 may be as much as 1,500 feet thick and is composed primarily of silt and sand. Permeability estimates of Zone 4 are not provided by MMA/ Guyton, but are estimated to be similar to those found in the Truckee formation.

The geophysical logging and short-term transient monitoring programs done for this project (Section 2.4) indicate a high degree of vertical resistance to flow in the CTM basin. It is likely that this vertical anisotropy was caused by alternate high and low energy depositional environments. These environments could have led to alternate deposition of alluvial fans and lake and river deposits. These different types of units could have led to interbedded materials by depositing alternating units of coarse and fine grained alluvial materials. These alternating sequences would result in vertical anisotropy causing an overall resistance to vertical groundwater flow.

The hydraulic conductivity values used in CDM's modeling work at SSFS were similar to those mentioned above. In the shallow portion of the SSFS model, roughly corresponding to Zone 1, hydraulic conductivity values ranged from 6 to 75 fpd. The majority of this area used a simulated hydraulic conductivity near 40 fpd. The deeper portions of the SSFS model (corresponding to Zones 2 and 3) primarily used hydraulic conductivity values ranging from <1 to 25 fpd, with 25 fpd being the predominant value.

3.2.2.3 Faulted Zone

The surficial geology mapping of the area indicates a faulted area in the vicinity of the High Street and Morrill Avenue wells. The shaded area on Figure 3-3 roughly delineates the location of the fault lines on the geology mapping. The faulting on the geology map may represent the surface expression of an offset between horizontal bedding layers. This offset may creating an impediment to groundwater flow resulting in significant vertical gradients.

The primary evidence to support the existence of a fault feature is the observed water levels in the vicinity. Figure 3-3 also shows the location of two lines of monitoring wells. One line extends from well 137 to well 33c. The other line consists of wells CTM-14S, 122a, and CTM-15S. Both of these lines of wells are roughly parallel to the direction of groundwater flow and perpendicular to the faulted zone. These wells are roughly equal distances apart. Figure 3-4 shows time histories of observed water levels for these lines of wells. Figure 3-4 indicates a typical change of 4-5 feet between the wells in the northern line but an abrupt change of about 35-40 feet between wells 145 and 34. Figure 3-4 also indicates a similar drop of about 30 feet between wells 122a and CTM-15S compared to a drop of about 4 feet between wells CTM-14S and 122a. The fault is, therefore, believed to exist between wells 145 and 35 and between wells 122a and CTM-15S.

It is noted that the faulted zone shown on the geology quadrangle maps does exactly agree with the location of the fault indicated by the water levels. However, the water level changes noted above are believed to be sufficient evidence to support the hypothesis that the fault extends further north than indicated on the maps.

The available information did not provide information regarding the depth of the fault. This faulted zone is evidence of the anisotropy that exists with in the CTM basin.

3.3 Water Inflows and Outflows

The CTM groundwater flow system is complex. The MMA/Guyton model simulates eight separate sources of recharge and seven sinks of discharge, which are represented in their model. Since the gross amount of recharge to the CTM groundwater system is small (less than 1 foot per year over the area simulated by MMA) relative to many other groundwater flow systems, seemingly minor sources of water to the groundwater system may, in fact, be significant. An example of this is the combined source of recharge stemming from water distribution system leakage and lawn watering. MMA in their compilation of recharge sources, estimate that this source of water accounts for almost 10 percent of the recharge to the CTM groundwater flow system.

Preliminary estimate of basin inflow and outflows for the current modeling study were made based on previous studies. These estimates are summarized in Table 3-1. Revised inflow and outflow rates for the calibrated model are presented in Section 5.

Cohen and Loeltz (1964) performed a water balance in their 1964 report outlining some of the major sources of, and sinks for, water in the Truckee Meadows. MMA used these estimates as a starting point to build the numerical model. All the sources, however, were re-evaluated in light of new data that were not available in the original 1964 report.

While some of the original estimates made by Cohen and Loeltz (1964) were reviewed and adopted as reasonable estimates, others were deemed either outdated or inaccurate. In addition, several sources of, and sinks for water were not included in the Cohen and Loeltz (1964) study. For instance, MFR was not inventoried as a groundwater source, and groundwater sinks were listed as either pumping, basin subflow or other. As a result, MMA (1993) completed a revised and more detailed inventory of potential sources of, and sinks for groundwater in the basin.

Sources and sinks of water to the groundwater flow system are listed in Table 3-1. The rates shown in the table primarily reflect the 1990 time frame.

Table 3-1
Estimated Inflow and Outflow for Truckee Meadows Basin[1]

Inflows	***Estimated Value***	***Reference***
Mountain Front Recharge (MFR) / Canal Leakage	10,000 afy	MMA (1993)
River Leakage	4,000 afy (Truckee River) 1,000 afy (other streams)	Cohen and Loeltz (1964)
Agricultural Irrigation	7,588 afy	1987 Time Period, Guyton/MMA model
Lawn Watering	2,335 afy	CDM (1996)
Water System Leakage	2,070 afy	CDM (1996)
Adjacent Valley Subflow	3,510 afy	MMA (1993)
Irrigation Ditch Leakage	6,000 afy	Cohen and Loeltz (1964)
Direct Infiltration from Precipitation	1,500 afy	0.5 inches/year over model area
Outflows	***Estimated Value***	***Reference***
Pumping (Municipal, Industrial, Domestic, HGP Dewatering)	3,000 afy	MMA (1993)
Seepage to Rivers and Streams; Evapotranspiration	30,000 afy (20,000 afy north of Huffaker Hills, 10,000 afy south of Huffaker Hills)	MMA (1993)
Subsurface Outflow	<500 afy	Cohen and Loeltz (1964)

Units: afy = acre-feet per year
[1] Note that these estimates are for the entire Truckee Meadows (Central and South).

3.3.1 Groundwater Sources

Mountain Front Recharge/Canal Leakage

Cohen and Loeltz (1964) did not include mountain front recharge (MFR) as part of their water balance calculation. MFR is a general term for the infiltration of surface runoff (derived primarily from precipitation and snow-melt) into the alluvium at the foot of mountain ranges where relatively impervious bedrock dips beneath much more pervious units of porous media. In addition, MFR can also occur from water infiltrating into bedrock fractures and entering the porous media flow system as subsurface flow. Original MMA estimates of MFR were on the order of 10,000 acre-feet per year (afy).

There are also canals, streams, and creeks that flow, at the basin margins, from areas underlain by bedrock to areas underlain by unconsolidated alluvium. MFR also include surface water that infiltrates to the groundwater from these surface water features.

Adjacent Valley Subflow

MMA found Cohen and Loeltz's (1964) estimate of 1,000 afy of subsurface flow from adjoining valleys to be too low. Based on a 1984 study by Katzer and others, subsurface flow from the Galena Creek drainage area (south of Truckee Meadows) into the Truckee Meadows flow system is estimated to be 2,700 afy. In addition, Pleasant Valley (south of Truckee Meadows) is estimated to contribute 500 afy, Chalk Bluff 160 afy, and Spanish Springs Valley 150 afy. These estimates suggest a total subsurface inflow from tributary valleys of 3,510 afy.

Truckee River and Other Streams

Cohen and Loeltz (1964) estimate infiltration of Truckee River water in 1960 to be approximately 4,000 afy, but note that the data available at the time of their analysis were not suitable for accurate quantification. MMA neither supports nor refutes the accuracy of this figure, but does point to recent evaluations of Truckee River losses during a period of low flow in September 1992. These evaluations show that most river losses to the groundwater system occur primarily in the middle portion of the river's 14-mile course through the Truckee Meadows. MMA model results indicate a leakage rate of approximately 9,000 afy at the end of their simulation, 1990, from rivers, streams, and ditches.

Cohen and Loeltz (1964) estimate infiltration from streams other than the Truckee River to be less than 1,000 afy. Based on stream flow measurements on Whites and Thomas Creeks in 1957 and 1990, and on Dry and Evans Creeks in 1990, MMA supports this figure as reasonable.

Agricultural Irrigation

The average application of irrigation water to Truckee Meadows agricultural lands is estimated to be 4 acre-feet per year per acre (afy/ac), 3 afy/ac of which is assumed to be consumed by plants. This implies an effective recharge to the groundwater system of 1 afy/ac of irrigated land. The percent of irrigated acreage for each model cell was compiled by Guyton for the years 1954, 1966, 1979, and 1987. Table 3-2 shows the estimated acres of irrigated land based on the 1 afy/ac application rate. Irrigated acreage estimates for 1961 to 1965, 1967 to 1978, and 1980 to 1987 were interpolated from these compiled values. Estimates from 1988 to 1991 were extrapolated from the 1980 and 1987 values. The 1993 Draft Report by MMA notes that the amount of irrigated land in the Truckee Meadows decreased from 1960 to 1990, such that irrigated acreage in 1990 was only one-third of what it was in 1960. This project assumed a constant 1990 rate for the time period after 1990.

Table 3-2
Estimated Acreage of Irrigated Land In Truckee Meadows Basin(1)

Year	Acres
1954	22,175
1966	18,405
1979	14,235
1987	7,588

(1) Note that these estimates are for the entire Truckee Meadows (Central and South).

Lawn Watering

Based on estimates by Guyton (John Seifert, written communication with MMA, 1993), 4.5 percent of total municipal water system deliveries is recharged to the groundwater system through its outdoor application to lawns and gardens. Unreferenced estimates cited by MMA indicate that 46 percent of the water distributed by Westpac from 1964 to 1969 was used outdoors. Similarly, Murray, Burns, and Kleinlen estimate that between 1985 and 1993, 35 percent of water deliveries to commercial customers and 48 to 51 percent of water deliveries to residential customers were applied outdoors. MMA assumes that 45 percent of municipal water deliveries are used for outdoor watering purposes, of which 10 percent effectively recharges the groundwater system. Using these estimates, recharge from the residential irrigation ranged from 1,320 afy in 1961 to 2,335 afy in 1990. This information was also used in the CTMRD model.

Municipal Water System Leakage

Based on estimates by Guyton (John Seifert, written communication with MMA, 1993), system leakage from municipal water systems in the Truckee Meadows is approximated to be 3.5 percent of water deliveries. Applying this figure yields water system leakage losses ranging from 1,000 afy in 1960 to 2,070 afy in 1990.

Irrigation Ditch Losses

In 1944, the U.S. District Court estimated that conveyance losses from Truckee Meadows irrigation ditches ranged from 0 to 30 percent of diverted water. The Federal Water Master's Office usually diverts 30 to 35 percent more water than the application rate of 4 afy per acre.

Cohen and Loeltz (1964) estimated irrigation ditch losses to be on the order of 6,000 afy during 1960. Even though irrigated acreage has declined significantly since the

1960s, MMA maintains that losses from the ditches may not be much different today than in the 1940s and 1950s. MMA postulates that , even though less water is conveyed in the ditches compared to the past, the ditches still contain a depth of water. Under the assumption that water losses in the ditches due to evapotranspiration (from the water surface and from vegetation along the channel banks) are similar to that for agricultural irrigation, MMA concludes that irrigation ditch losses of 6,000 afy (as estimated by Cohen and Loeltz 1964) from 1960 to 1990 are reasonable.

Direct Infiltration of Precipitation
Most of the valley floor receives about 8 to 10 inches of precipitation per year. A groundwater recharge rate of 0.5 inches per year has been estimated by Cooley et. al. (1971) and Van Denburgh (1973). The rate was also used in CDM's model of the SSFS and in the Guyton/MMA model.

3.3.2 Groundwater Sinks

Flow to Rivers and Evapotranspiration
Boynton Slough, Steamboat Creek and the lower reach of the Truckee River are the principal surface water features that receive excess irrigation water from groundwater seepage and overland flow. Evapotranspiration, which occurs mostly during the growing season between April and October, is greatest in the eastern part of the Truckee Meadows.

These two sinks were estimated to amount to a total of 30,000 afy in 1960, with 20,000 afy discharging from the groundwater in the Central Truckee Meadows (area north of Huffaker Hills), and 10,000 afy discharging from the South Truckee Meadows (area south of Huffaker Hills).

Pumping
Pumping for domestic, municipal, and commercial/industrial purposes occurs in the Truckee Meadows. Pumping also occurs at the HGP/SMPL, and for remedial purposes (e.g. Sparks Solvent/Fuel Site [SSFS]) within the CTM study area.

Prior to the 1997 flood, active pumping was in place to completely dewater the HGP. The average dewatering rate during 1995 and 1996 was approximately 5.8 million gallons per day (mgd) (6,500 afy). During the 1997 flood, HGP was filled with approximately 900 million gallons of water in a few days.. Active pumping still exists at the SMPL, which replaced HGP, with the goal of maintaining a water level in the lake of approximately 4,375 ft. The pumping rate after the flood has fluctuated greatly due to on-going SMPL construction activities. The average pumping rate during 2000 and the first half of 2001 was approximately 1 mgd (1,120 afy).

Subsurface Outflow
Subsurface outflow from the Truckee Meadows occurs through the alluvium underlying the Truckee River as it leaves the basin to the east through the Virginia

Range. This underflow rate is estimated to be less than 20 afy. Cohen and Loeltz (1964) estimate total losses to the groundwater flow system due to underflow to be less than 500 afy.

3.4 Groundwater Flow

Groundwater flow conditions in the CTM can be divided into three historical periods separated by two anthropogenic actions. In the 1880s irrigation ditches were constructed that altered recharge to the groundwater system, and in the 1950s groundwater withdrawals began to steadily increase as the amount of irrigated land in the basin concurrently decreased.

Pre-1880

Prior to the 1880s, when irrigation ditches were constructed, the groundwater flow system was dominated by natural recharge from the Truckee River and infiltration of runoff from the mountains surrounding the basin (primarily the Carson Range to the west). In terms of general groundwater movement, water entered the system along the basin's western boundary in the north basin and flowed eastward. In the south basin, water entered the system along the basin's western and southern boundary and flowed in a northerly or northeasterly direction. Both north and south of Huffaker Hills, water left the groundwater system along the eastern edge of the Truckee Meadows through evapotranspiration and/or discharge to streams and rivers in topographically low areas.

1880 to 1950

Development of irrigation ditches and subsequent conveyance losses from them resulted in significant increases in recharge to the groundwater system, leading to a rise in groundwater levels and the establishment of a new flow system equilibrium. MMA hypothesized that this new equilibrium probably occurred prior to the 1950s, but no numerical simulations are presented to support this. The overall configuration of the flow field during this time period was probably very similar to what it was prior to construction of the irrigation ditches.

Cohen and Loeltz (1964) note "hundreds" of flowing wells that existed in the northeastern region of the basin, primarily north of Huffaker Hills. The heads in these wells were not more than 20 feet above ground surface, and discharge from them was usually only a few gallons per minute (gpm), although some wells were noted to flow as much as 30 to 50 gpm. These flowing wells indicate confined conditions, most likely due to lakebed deposits in the younger alluvium.

1950 to 1990

Increased groundwater pumping beginning in the 1960s, and continuing to the present, resulted in significant flow field changes from 1960 to 1990. Declines in water levels and artesian pressures are evident from the reduced amount of flowing wells in the basin. Cooley and others (1970) note that few wells were flowing during their hydrologic investigation of the Truckee Meadows.

Figures 3-5 and 3-6 show composite simulated groundwater contours for 1959 - 1962 and 1991 - 1992, respectively, as computed by MMA. It is believed that the composite groundwater contours were generated by a combination of shallow and deep water levels. By the early 1990's, significant changes to the flow system had occurred. In the south basin the general configuration of the flow field was similar to that observed in 1960, but in the north basin groundwater flow was diverted to two areas of groundwater decline. In the downtown Reno area, a steep cone of depression, as deep as 80 feet, resulted from municipal and industrial pumping in the area. TMWA has a pumping plan in place using the Mill, Kietzke, Corbett, High, and Morrill wells as a management tool to contain PCE contamination that has been detected in these wells. Water level declines along the Truckee River to elevations below the channel bottom are hypothesized to have resulted in increased exfiltration from Truckee River to groundwater.

Prior to the creation of Helms Gravel Pit, evapotranspiration and discharge to the Truckee River were the primary sources of groundwater discharge in the eastern portion of the CTM. Due to the extreme amount of pumping to dewater the pit, however, groundwater levels declined significantly. This led to significant declines in evapotranspiration and groundwater discharge to the river (which were in effect replaced by pit dewatering pumping), and a significant change to the groundwater flow regime in the northeastern portion of Truckee Meadows.

1990 to Present

The major change in the flow system since 1990 was the 1997 flood. On January 1, 1997 the Reno/Sparks area experienced a major flood event. Because of rapid rainfall and snowmelt, there was a significant rise in water level in the Truckee River. This rise reversed the flow in the discharge ditch (Peoples' Drain Ditch) for approximately one week. For that week, the Truckee River continued to flow into the pit via Peoples' Drain Ditch filling the 80-acre, 120 foot deep Helms Gravel Pit (HGP) with approximately 900 million gallons (2,760 ac-ft) of water. The dewatering pumps in Helms Gravel Pit were buried under water and mud. This filling of Helms Gravel Pit permanently changed the flow regime in the vicinity of the pit.

The remedial pumping at SSFS has also increased during the late 1990s. For example, the groundwater pump and treat system, which began operations in 1996, had an average pumping rate of about 370 gpm (58 afy). Since then pumping rates have been increased to approximately 850 to 900 gpm (133 to 141 afy).

TMWA has 24 production wells in the Central Truckee Meadows, with various, multiple screened intervals. Figure 3-7 presents the location of these wells. TMWA uses these wells to augment the Truckee River-based drinking water supply. Annually, water supply for the metropolitan Reno area is typically provided as 75 to

80 percent from surface water and 20 to 25 percent from groundwater, where some 70 percent of the groundwater produced is pumped between May and October. Groundwater pumping increases in the summer and during droughts. The Washoe County Department of Public Works maintains three production wells near the intersection of McCarran Boulevard and Mill Street, west of McCarran and south of the Truckee River.

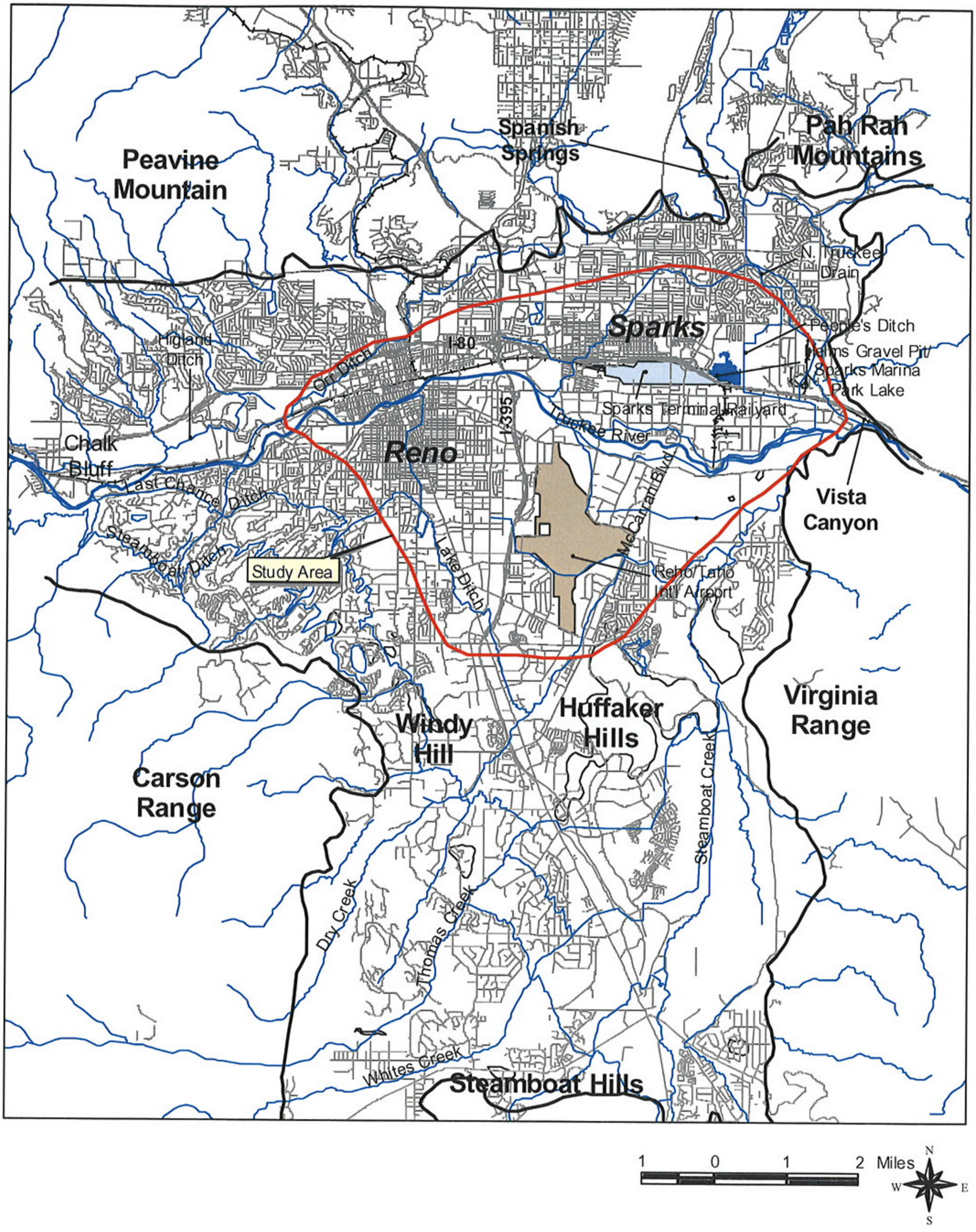
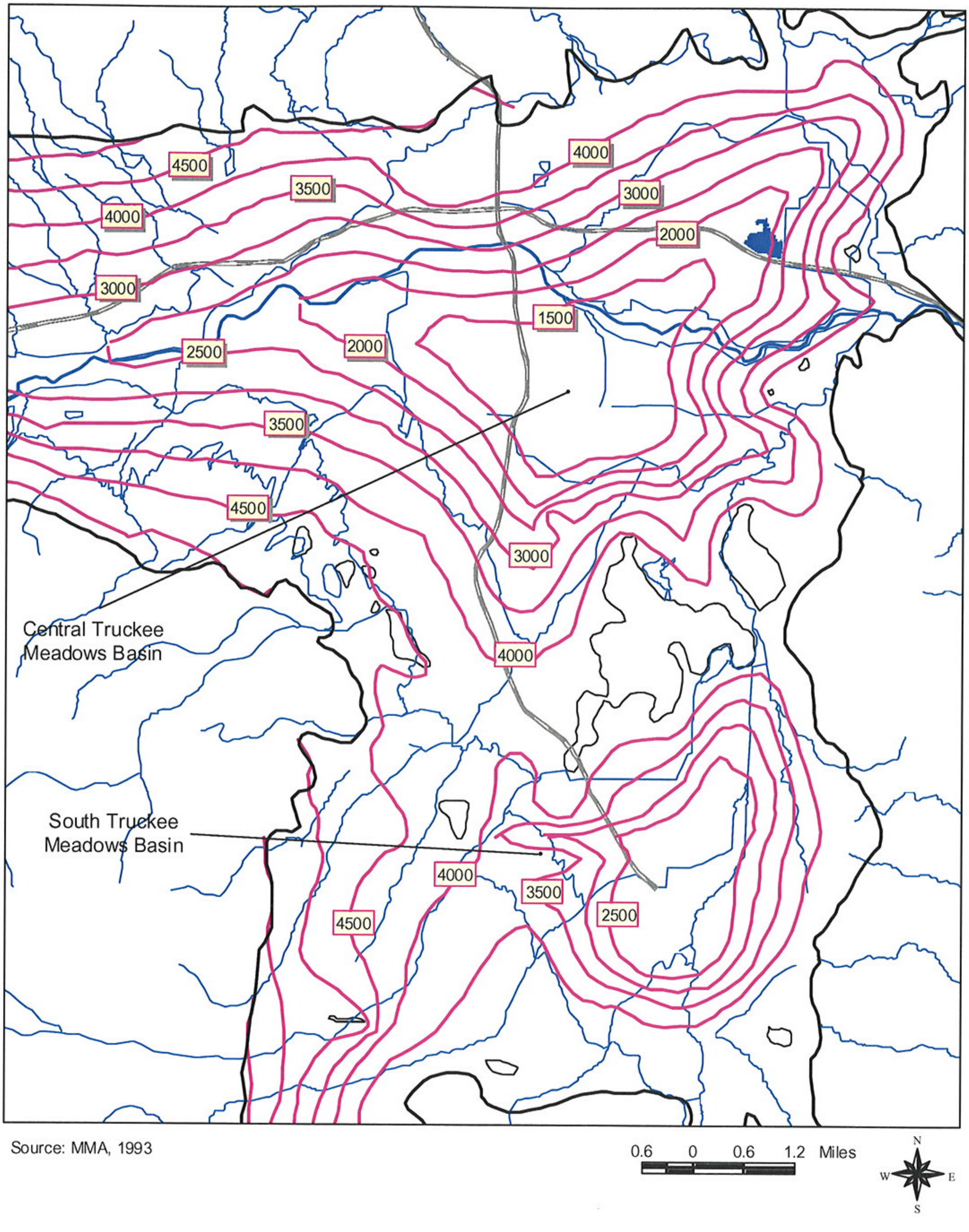


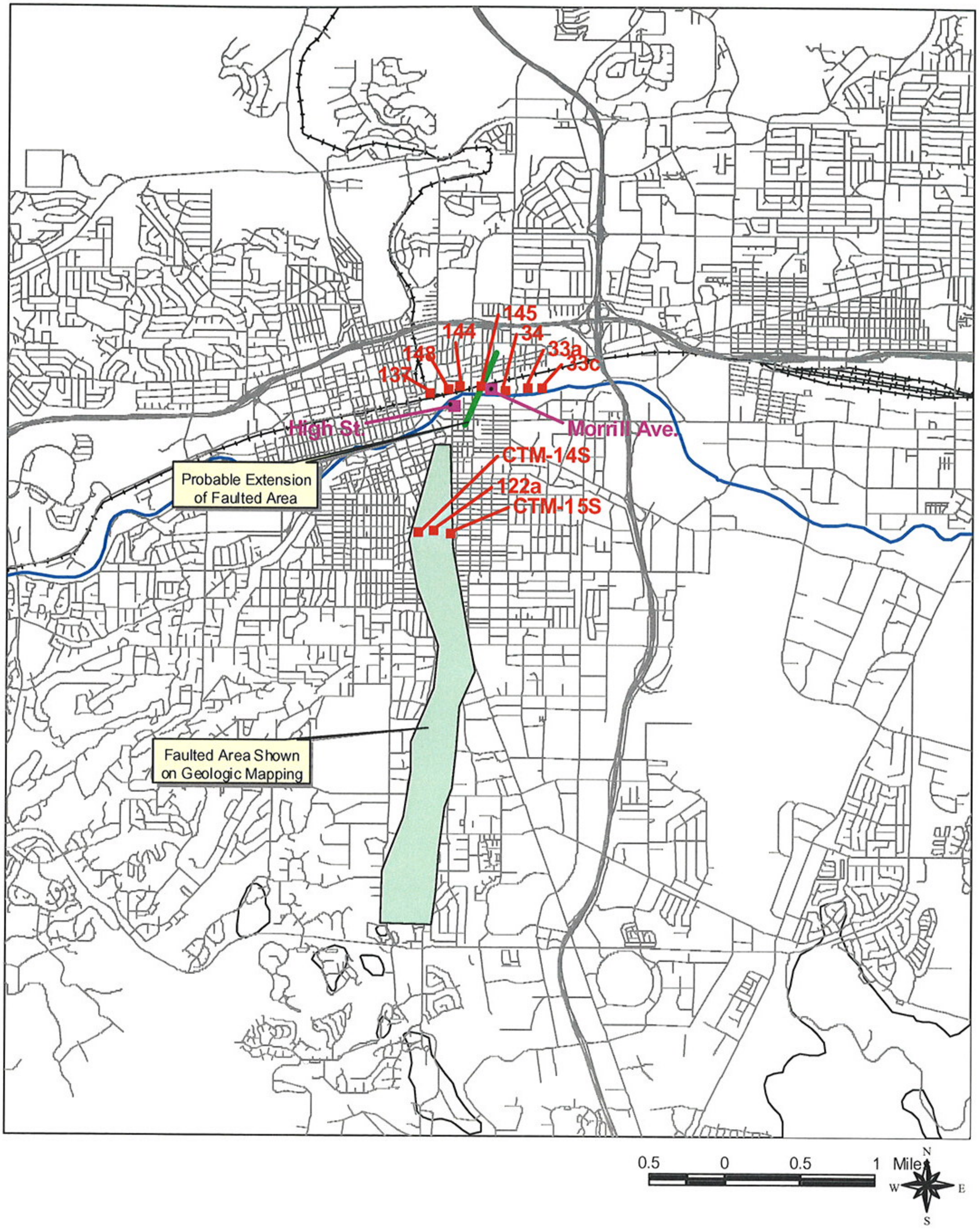
Figure 3-1
Physical Setting and Study Area
Central Truckee Meadows Remediation District



Source: MMA, 1993

CDM

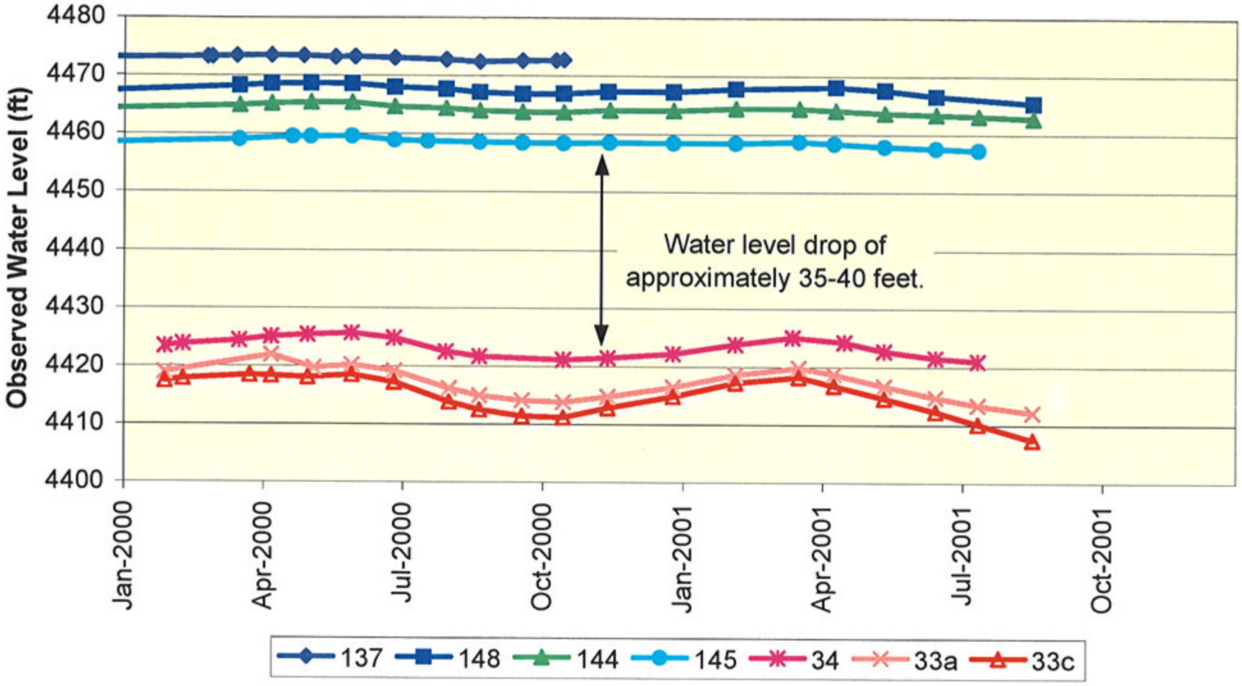
Figure 3-2
Elevation of Volcanic Rock Surface
Central Truckee Meadows Remediation District



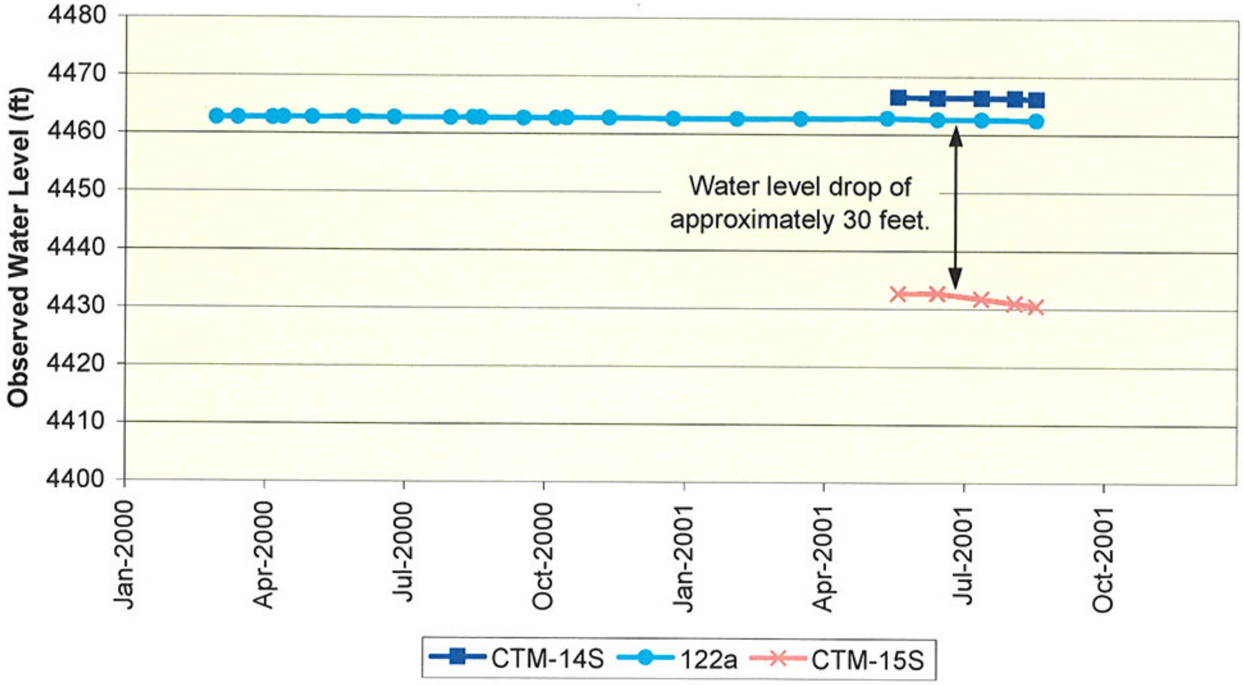
CDM

Figure 3-3
Location of Faulted Area
Central Truckee Meadows Remediation District

Northern Line of Wells

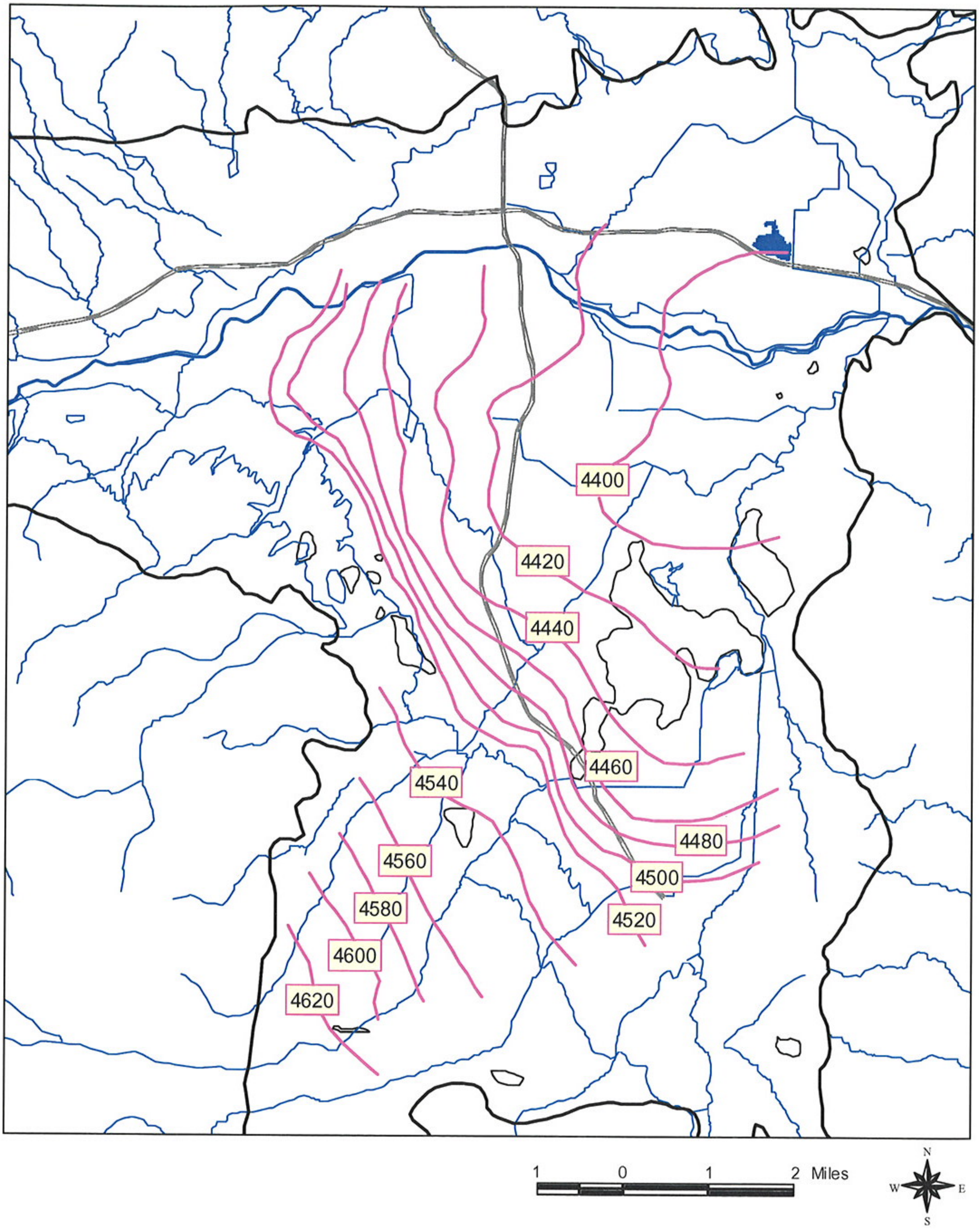


Southern Line of Wells



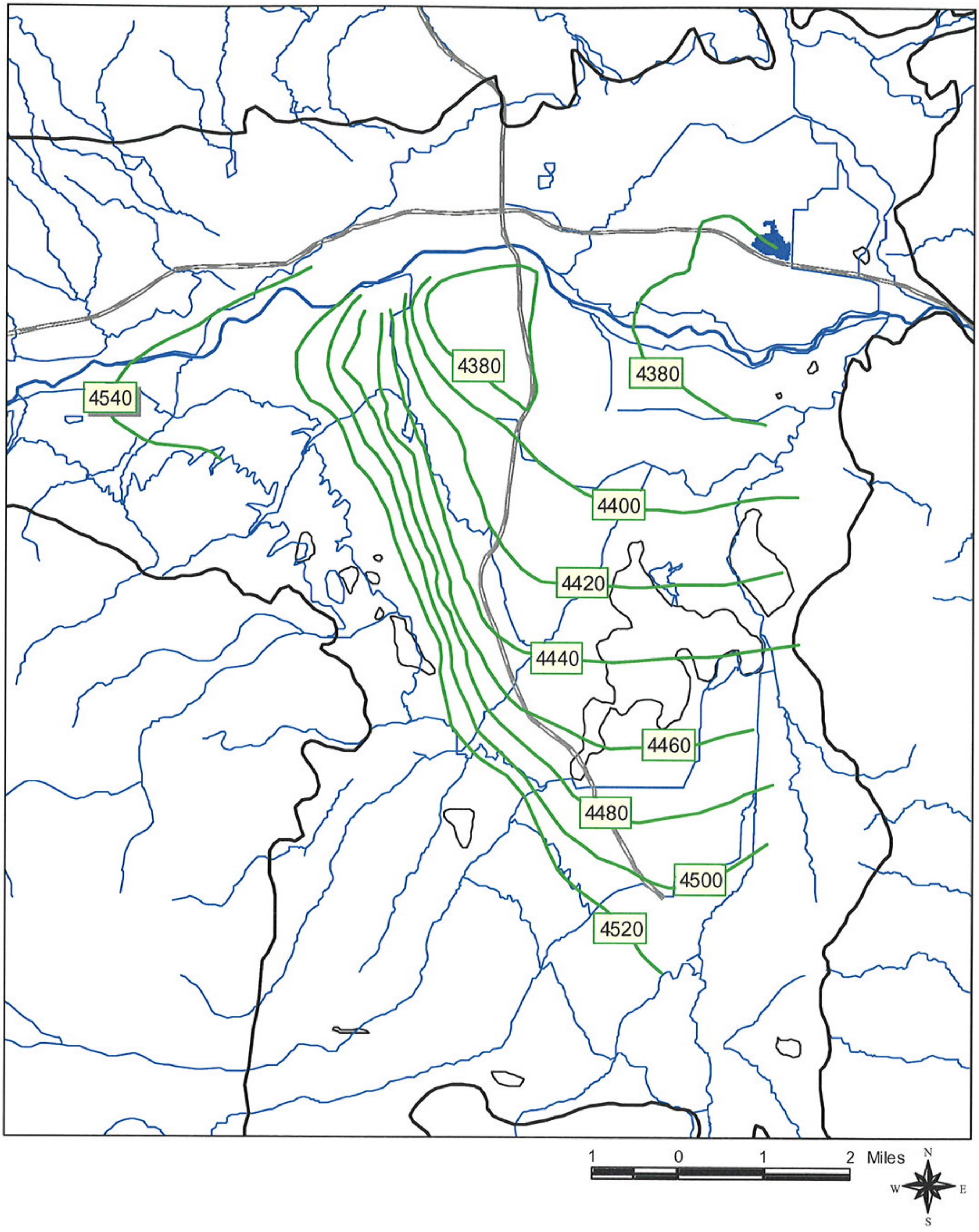
Fault_WLs.xls: Chart
06/25/2002

Figure 3-4
Water Level Time Histories for Wells Spanning Fault
Central Truckee Meadows Remediation District



CDM

Figure 3-5
1959-1962 Composite Potentiometric Surface
Central Truckee Meadows Remediation District



CDM

Figure 3-6
1991-1992 Composite Potentiometric Surface
Central Truckee Meadows Remediation District

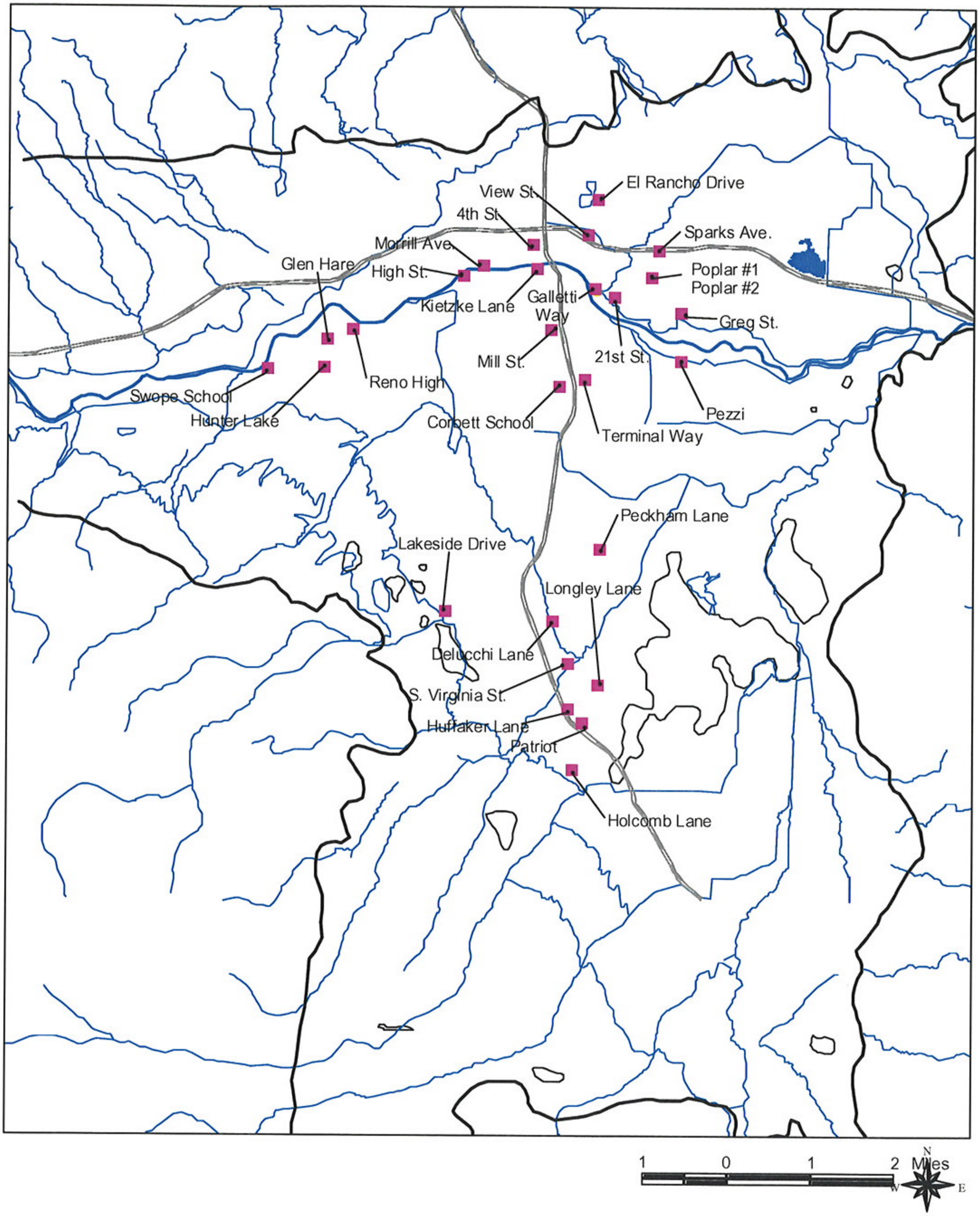


Figure 3-7
Location of TMWA Pumping Wells
Central Truckee Meadows Remediation District

Section 4
Model Construction

The Central Truckee Meadows Remediation District (CTMRD) model was developed based on data listed in Section 2 and the conceptual model discussed in Section 3. The modeling approach and details of the model construction are provided in this section.

4.1 Modeling Approach

The objectives of the modeling investigation were to develop and calibrate a numerical groundwater flow model that could be used to evaluate remediation alternatives for Central Truckee Meadows Remediation District (CTMRD) Remediation Plan. The MMA/Guyton model was the primary, initial source of data for the CTMRD model. The MMA/Guyton model included a transient simulation of basin groundwater conditions for the period 1961 to 1995.

The following steps outline the numerical modeling approach used during this investigation.

- <u>Flow Model Construction</u> (Section 4.2): The CTMRD model was developed based on the MMA/Guyton model input and hydrogeologic data from the study area. The CTMRD model simulates groundwater flow in the alluvial materials overlying the volcanic rock.

- <u>Model Calibration</u> (Section 5): Due to the transient nature of the CTM basin, no suitable steady-state condition was available for calibration of the CTMRD model. This model was calibrated in a transient mode to the following conditions.

    - *Short-term Transient Calibration (August 2001):* This transient calibration involved the simulation of short-term water levels changes in response to changes in TMWA pumping rates.

    - *Long-term Transient Calibration (1999-2001):* The CTMRD model was also calibrated to transient water levels from 1999 to 2001.

    - *Historical Transient Simulation (1961-2001):* Transient simulations of the period 1961 to 2001 were performed in developing a CTMRD model that could reasonably reproduce water level changes in the basin during this period.

- <u>Flow Path Analysis</u> (Section 6): The calibrated CTMRD model was used to simulate flow paths in the CTM basin. This analysis was done primarily to assess the flow patterns near the TMWA wells.

4.2 Flow Model Construction

This section describes the components used to construct the CTMRD groundwater flow model.

4.2.1 Model Codes

The modeling software to be used for this study includes DYNFLOW (single phase groundwater flow) and DYNTRACK (mass transport). These models have been used and accepted at other sites in the Reno area including the Sparks Solvent/Fuel Site (SSFS). This modeling software includes the ability to import and export data to other software packages such as GIS and CADD software.

4.2.1.1 DYNFLOW

The groundwater flow computer code used in this study is the fully three-dimensional, finite-element groundwater flow model, DYNFLOW. This model has been developed over the past 18 years by CDM engineering staff, and is in general use for large scale basin modeling projects and site specific remedial design investigations. It has been applied to over 150 modeling studies in the United States.

The governing equation for three-dimensional groundwater flow that is solved by DYNFLOW is:

$$S_s \frac{\partial \phi}{\partial t} = \frac{\partial}{\partial x_i}\left(K_{ij} \frac{\partial \phi}{\partial x_j} \right); i, j = 1, 2, 3$$

The state variable ϕ represents the potentiometric head [L]; K_{ij} represents the hydraulic conductivity [LT^{-1}] tensor; S_s is the specific storativity (volume/volume/length), [L^{-1}]; x_j is a Cartesian coordinate and t is time.

DYNFLOW uses a grid built with a large number of tetrahedral elements. These elements are triangular in plan view, and give a wide flexibility in grid variation over the area of study. An identical grid is used for each level of the model, but the thickness of each model layer (the vertical distance between levels in the model) can vary at each point in the grid. In addition, 2-dimensional elements can be inserted into the basic 3-dimensional grid to simulate thin features such as faults. One-dimensional elements can be used to simulate the performance of wells which are perforated in several model layers.

DYNFLOW accepts various types of boundary conditions on the groundwater flow system including:

- Specified head boundaries (where the piezometric head is known, such as at rivers, lakes, or other points of known head)
- Specified flux boundaries (such as rainfall infiltration, well pumpage, and no-flow "streamline" boundaries)
- Rising water boundaries; these are hybrid boundaries (specified head or specified flux boundary) depending on the system status at any given time.

- Head-dependent flux (3rd type) boundaries including "River" and "General Head" boundary conditions.

The DYNFLOW code has been reviewed and tested by the International Groundwater Modeling Center (IGWMC) (van der Heijde 1985, 1999).

The code has been extensively tested and documented by CDM.

4.2.1.2 DYNTRACK

The transport code used in this study is DYNTRACK. DYNTRACK uses the random-walk technique to solve the advection-dispersion equation. DYNTRACK has been developed over the past 15 years by CDM engineering staff.

The partial differential equation describing transport of conservative solutes in a groundwater flow field is:

$$n_e \frac{\partial C}{\partial t} = \frac{\partial}{\partial x_i}\left(n_e D_{ij} \frac{\partial C}{\partial x_j} - q_i \frac{dC}{dx_i} \right); i, j = 1, 2, 3$$

DYNTRACK uses a Langrangian approach to approximate the solution of the partial differential equation of transport. This process uses a random walk method to track a statistically significant number of particles, wherein each particle is advected with the mean velocity within a grid element and then randomly dispersed according to specified dispersion parameters. In this study only advective transport was simulated.

DYNTRACK has also been reviewed and tested by the IGWMC (van der Heijde 1985).

4.2.2 Domain

Following the conceptual model described in Section 2, the domain of the CTMRD model is shown in Figure 4-1. The domain encompasses approximately 55 square miles; the domain includes the alluvial deposits in the CTM basin and extends to the contact with volcanic rock in most areas. Exceptions to this are the valleys at Chalk Bluff, Spanish Springs, and Vista Canyon. These areas were not explicitly included in the model. Estimated groundwater inflows to the CTM from Chalk Bluff and Spanish Springs were included, as wells as outflow from Vista Canyon. The southern edge of the model between Dry and Thomas Creek also does not represent a contact with volcanic rocks. This location is believed to be a hydraulic divide between the South Truckee Meadows (STM) and Central Truckee Meadows (CTM) basins. A discussion of the boundary conditions at these locations is included in Section 4.2.6.

The domains of the CTRMD and MMA/Guyton models are similar in the CTM area. The principal differences between the two model domains are as follows.

- South Truckee Meadows. The MMA/Guyton model included the STM basin in the domain. The CTMRD model does not include this area. The STM basin is located far enough from the main CTMRD study area to not be necessary for this modeling work.

- Contact with Volcanic Rock. The location of the contact between the alluvial deposits and the volcanic rocks was modified based on the available geology mapping as described in Section 2.5.1. The finite-element method used by DYNFLOW allows for a more exact replication of this boundary than the MODFLOW code used in the MMA/Guyton model.

4.2.3 Grid

The computational finite-element grid shown in Figure 4-2 consists of 6,286 triangular elements in plan view, defined by 3,303 node points at the vertices of the triangles. Model heads, fluxes, surface water features, and boundary conditions are computed or specified at nodes. Hydraulic parameters for aquifer units are specified for elements.

The density of node points, and therefore computational resolution, varies in the model and is most dense within the study area, where node spacing is approximately 500 to 600 feet. The grid node spacing generally increases with distance from the site where less computational resolution is required.

The model grid is further refined around the TMWA pumping locations. At these wells, a node point is placed at the location of the well and the node spacing gradually increases with distance from the well. This increased density is required to better represent the changes in water levels simulated during the short-term calibration. This short-term calibration is described is Section 4.3.

4.2.4 Layering

Figure 4-3 shows a conceptual figure relating the layering in the CTMRD model to the geologic units described in Section 3.2 the MMA/Guyton model layering. The original MMA/Guyton model consisted of 3 layers (numbered from top to bottom). Vertically, the CTMRD model extends from the ground surface down to the contact with volcanic rock (Figure 3-2). The vertical extent of this is divided into 6 layers (numbered from bottom to top), defined by 7 levels.

As discussed in Section 3, the MMA/Guyton model represented Zone 1 with Layer 1. This layer corresponds to Layer 6 in the CTMRD model. Layer 2 in the MMA/Guyton model was subdivided into Layers 4 and 5 in the CTMRD model. The subdivision was necessary so that layer 5 could represent the identified aquitard unit in the Sparks area.

The thickness of Layer 3 in the CTMRD model was estimated from the transmissivity in Layer 3 of the MMA/Guyton model and estimated hydraulic conductivities in this unit. Layers 1 and 2 in the CTMRD model represent alluvium Zone 4/Truckee Formation. This unit was subdivided to more accurately model pumping in the basin. The bottom of the CTMRD model (Level 1) was interpreted from a map of the elevation of volcanic rock (MMA 1993) previously shown in Figure 3-2.

Figure 4-4 shows cross section AA, a typical east-west cross section through the CTMRD model using the same layer definitions shown in Figure 4-3. Figure 4-5 shows a typical north-south section. The locations of these cross sections are shown in Figure 4-2.

4.2.5 Hydraulic Properties

Figures 4-6 through 4-11 show the hydraulic property sets assigned to model layers 1 through 6, respectively. Figures 4-12 and 4-13 show these material distributions in cross section. Table 4-1 shows a comparison of horizontal hydraulic conductivities specified in the CTMRD model and in the MMA/Guyton model

Table 4-1
Comparison of CTMRD and MMA/Guyton
Modeled Horizontal Conductivities

Geologic Unit	***CTMRD***		***MMA/Guyton***	
	Layer	***K_h Range(1)***	***Layer***	***K_h Range***
Alluvium Zone 1	6	2-60 ft/d	1	1-70 ft/d
Alluvium Zone 2	5	5-50 ft/d	2	5-60 ft/d
	4	2-50 ft/d		
Alluvium Zone 3	3	10-15 ft/d	3	n/a(2)
Alluvium Zone 4/	2	0.05 ft/d	n/a(3)	
Truckee Formation	1	0.05 ft/d		

(1) Conductivity of fault is excluded from range.
(2) Conductivity not specified in MMA model.
(3) Not represented in MMA model.

The following aspects of the distribution of hydraulic conductivities should be noted:

- Conductivity Zones: The initial hydraulic conductivity zones, both shape and value of conductivity, were based on the hydrogeologic mapping discussed in Section 2.5.1. In general, hydraulic conductivity decreases with depth.

- Vertical Conductivity: A great deal of vertical resistance to flow was incorporated into the hydraulic property sets. This vertical resistance takes the form of high ratios of horizontal to vertical hydraulic conductivity. The observed water levels between the shallow and deep wells, as well as the geophysical logging and short-term transient monitoring programs, support these high ratios. The details of the model calibration are presented in Section 5. As discussed in Sections 2 and 3, this high degree of vertical resistance to flow is most likely caused by alternating high and low energy depositional environments. These alternating environments would have resulted in sequencing of more and less permeable units.

- Faulted Zone: As discussed in Section 3.2.2.3, it was necessary to place an area of low hydraulic conductivity between wells 145 and 34 and wells 122a and CTM-15S. This area represents a faulted zone that causes a significant drop in water levels over relatively short distances.

4.2.6 Boundary Conditions

The following section describes the boundary conditions that were assigned to the CTMRD model. Boundary condition locations are shown on Figure 4-14.

4.2.6.1 Basin Boundary

Along the CTMRD model boundary, boundary conditions are set as follows:

- Specified Flux: A specified inflow flux boundary was set along the basin edges where MFR is represented. Along the basin edges where MFR is not represented (e.g. the southwestern edge), a specified flux equal to zero is set. Specified flux boundaries are also established at locations where adjacent valley sub-flow occurs. On the surface of the model, specified flux assignments are made to represent recharge.

- Head Dependant Flux: Evapotranspiration was simulated at the model surface using a head dependant flux as discussed in Section 4.2.6.5.

- No Flow: A no-flow boundary condition was set at the bottom of the model, corresponding to the top of the volcanic rock.

4.2.6.2 Pumping

Groundwater pumping and injection in the basin was included in the model simulations. Groundwater pumping in the basin consists of industrial, public and domestic groundwater supply withdrawals. Groundwater injection occurs primarily in the winter, when surplus water is injected into the groundwater for storage. A summary of the pumping assignments is presented below.

- Pumping Locations: Industrial and public supply withdrawal and injection was represented in the model by assigning the fluxes to nodes that corresponded to the horizontal and vertical coordinates of each well screen.

- Time Variation: Industrial and public supply pumping was adjusted yearly for years 1961 to 1995 and monthly thereafter. Pumping assignments to individual wells were based on the MMA/Guyton model input for early years (1961 - 1995) and TMWA, Washoe County, and CDM records for later years (1995 - 2001).

- Wells Screen Across Multiple Layers: For wells screened across multiple model layers, pumping is assigned to the levels associated with those levels. The pumping assigned to a particular level is calculated as the percentage of transmissivity associated with that level compared to the total transmissivity of the screened interval.

  One-dimensional elements were also used to distribute industrial and public supply pumping fluxes over multiple model levels for long/multiple well screens. One-dimensional elements redistribute the pumping flux so that the head at the pumping node is nearly equal across the model levels where pumping is assigned. This functionality represents a single water level at well.

- Domestic pumping: Domestic pumping flux assignments for the CTMRD model were obtained from the MMA/Guyton model. The domestic pumping fluxes were assigned to the top two levels in the CTMRD model based on the pumping locations in the MMA/Guyton model. The time variation of domestic pumping is shown in Table 4-2.

Table 4-2
Time Variation of Domestic Pumping

Time Period	Rate[1] Assigned Based on Year
1961-1969	1965
1970-1979	1975
1980-1989	1985
1990-2001	1995

(1)From MMA/Guyton Model

- Remedial pumping: Remedial pumping was simulated at the Sparks Solvent/Fuel Site (SSFS). Monthly pumping rates were applied to represent this system.

4.2.6.3 Recharge

Groundwater recharge in the CTMRD model area includes precipitation infiltration, agricultural return-flow, recharge from leaking subsurface pipes, and mountain front recharge along the edges of the basin. Groundwater recharge assignments for the calibration simulations were derived from input to the MMA/Guyton model. All groundwater recharge was assigned at the water table. A summary of the groundwater recharge assignments for the calibration simulations is presented below.

Precipitation Infiltration and Agricultural Return Flow

In the MMA/Guyton model, the groundwater recharge assignments included precipitation infiltration, as well as an agricultural return flow component. The groundwater recharge in the MMA/Guyton model was adjusted annually, for the period of the simulation (1961-1995).

For the CTMRD model transient simulations, groundwater recharge was adjusted annually from 1961 to 1995 based on the annual assignments in the MMA/Guyton model. After 1995, groundwater recharge was fixed at 1995 values.

A recharge rate of 0.5 inches per year was applied across the model except in agricultural areas. In agricultural areas additional recharge is applied to represent agricultural return flow. Figure 4-15 shows a time history of the combined precipitation infiltration and agricultural return-flow fluxes for the CTMRD model.

Urban Return Flow

The MMA/Guyton model also included a groundwater recharge component associated with urban return flow. This recharge represents various urban water uses such as leaking subsurface pipes and lawn irrigation. This recharge component was also represented in the CTMRD model.

The time varying assignments of urban return flow is shown in Table 4-3.

Table 4-3
Time Variation of Urban Return Flow

Time Period	*Rate[1] Assigned Based on Year*
1961-1964	1961
1965-1971	1965
1972-1979	1972
1980-1989	1984
1990-2001	1995

[1]From MMA/Guyton Model

Figure 4-16 shows a time history of the applied groundwater recharge from subsurface leaking pipes for the historical transient simulation (1961-2001).

Mountain Front Recharge

Groundwater recharge was also assigned to selected nodes at or near the model edge to represent the contribution of groundwater recharge from adjacent upland areas. This recharge component, called mountain front recharge (MFR) was fixed for the period 1961 to 1995 in the MMA/Guyton model.

For the CTMRD model historical transient simulation (1961-2001), MFR was adjusted annually based on MFR fluxes in the MMA/Guyton model and precipitation data. Figure 4-17 shows the model domain, upgradient watershed areas and model boundary nodes where MFR fluxes were applied. Stations where precipitation is measured are also shown.

Precipitation records are available for Reno Airport (1937-2000), Mount Rose (1969-1979), and Stead (1985-2000). The average annual precipitation at Reno Airport, Mount Rose and Stead is 7.3 inches, 30.0 inches, and 11.4 inches respectively. Annual precipitation at Mount Rose and Stead is approximately 4.2 and 1.6 times greater, respectively, than the annual precipitation measured at Reno Airport.

The largest MFR fluxes were assigned in the MMA/Guyton model to nodes located along the southwestern edge of the model because of the large size of the upland watershed and the higher precipitation amount reported for the upland area southwest of the Truckee basin (Mount Rose gage).

For the CTMRD model, MFR at the southwestern model boundary was estimated to be 15 percent of annual precipitation measured at the Mount Rose gage, over the tributary upland watershed area. MFR at the northwestern and eastern model boundaries was estimated to be 10 percent of annual precipitation recorded at the Stead station over the tributary upland watershed. The lower percentage of precipitation was applied as MFR at the northwest and east boundaries (10% versus 15% in southwest) because of drier conditions there. The percentage values used in these calculations are based on CDM experience on projects in similar basins in Nevada and California.

The precipitation records at the Mount Rose and Stead stations are shorter than those measured at Reno Airport. To compute MFR for the historical transient simulation (1961-2001), the precipitation records for these stations were extended based on the precipitation pattern at the Reno station. The estimated Mt. Rose record was estimated by multiplying annual precipitation values from the Reno station by 4.2. A factor of 1.5 was used to estimate the Stead record. The multiplier of 4.2 represents the average ratio of the Mt. Rose precipitation record to the Reno record from 1969 to1979. The factor of 1.5 is the average ratio of the Stead and Reno gages between 1985 and 2000. Table 4-4 summarizes the calculations used to estimate MFR for the CTMRD model. Figure 4-18 includes a time history of the annual MFR fluxes applied to the historical transient simulation.

MFR was varied annually based on annual precipitation totals. No time lag between precipitation and recharge was incorporated.

As discussed in Section 2.1.6, MFR at the northern boundary of the model was incorporated into the boundary condition specification for Orr Ditch where the ditch and model boundary are co-located.

4.2.6.4 Surface Water

A head dependent flux (or "River") boundary condition was specified at model nodes along many of the rivers, streams, and ditches throughout the CTM basin. The locations of these river nodes are shown in Figure 4-14. The CTMRD model locates rivers nodes along the same surface water features as the MMA/Guyton model.

Figure 4-19 shows a conceptual figure of the river node functionality. The river boundary condition is equivalent to the River Package boundary condition documented for the MODFLOW modeling code by McDonald and Harbaugh (1988). Where the aquifer head exceeds the river stage, discharge from the aquifer to the stream is computed. If the aquifer head is less than the river stage, discharge from the stream to the aquifer is computed. Simulated rates of infiltration to and exfiltration from the streams and ditches will also be discussed in Section 6.3.

The specified values of river stage and streambed elevation were adapted from the MMA/Guyton model, with adjustments for the different computational grid structure. In general, these elevations are consistent with elevations indicated on USGS topographic maps. Initial values of streambed conductance, which accounts for the length, width, thickness and vertical hydraulic conductivity of the streambed

Table 4-4
Mountain Front Recharge Estimates

Year	***Precipitation / Recharge (Inches)***						
	Reno *measured*	**Mt. Rose** *measured*	**Mt. Rose*** *estimated*	**Mountain Front Recharge At SW Boundary Nodes** *15% of Mt. Rose**	**Stead** *measured*	**Stead**** *estimated*	**Mountain Front Recharge At NW and East Boundary Nodes** *15% of Stead***
1961	5.4		22.4	3.4		8.1	0.8
1962	9.1		37.8	5.7		13.6	1.4
1963	10.9		45.7	6.9		16.4	1.6
1964	7.9		33.1	5.0		11.9	1.2
1965	9.7		40.6	6.1		14.6	1.5
1966	3.3		13.7	2.1		4.9	0.5
1967	9.5		39.6	5.9		14.2	1.4
1968	5.5		22.8	3.4		8.2	0.8
1969	10.2	39.1	39.1	5.9		15.3	1.5
1970	7.0	33.6	33.6	5.0		10.4	1.0
1971	10.6	35.5	35.5	5.3		15.9	1.6
1972	5.5	16.2	16.2	2.4		8.3	0.8
1973	9.2	18.7	18.7	2.8		13.8	1.4
1974	5.4	25.5	25.5	3.8		8.1	0.8
1975	7.0	28.5	28.5	4.3		10.4	1.0
1976	5.1	32.3	32.3	4.8		7.6	0.8
1977	6.8	37.9	37.9	5.7		10.3	1.0
1978	7.9	52.1	52.1	7.8		11.9	1.2
1979	6.0	10.2	10.2	1.5		9.0	0.9
1980	9.2		38.5	5.8		13.8	1.4
1981	6.7		27.9	4.2		10.0	1.0
1982	11.1		46.4	7.0		16.7	1.7
1983	13.2		55.3	8.3		19.8	2.0
1984	4.3		17.9	2.7		6.4	0.6
1985	5.0		20.9	3.1	5.6	5.6	0.6
1986	8.9		37.4	5.6	18.9	18.9	1.9
1987	7.5		31.4	4.7	10.2	10.2	1.0
1988	5.3		22.2	3.3	6.7	6.7	0.7
1989	7.3		30.7	4.6	12.7	12.7	1.3
1990	5.3		22.0	3.3	6.7	6.7	0.7
1991	5.2		21.5	3.2	8.6	8.6	0.9
1992	5.4		22.4	3.4	8.9	8.9	0.9
1993	6.6		27.5	4.1	10.0	10.0	1.0
1994	5.2		21.7	3.3	7.5	7.5	0.8
1995	12.6		52.5	7.9	20.9	20.9	2.1
1996	12.2		51.0	7.7	23.6	23.6	2.4
1997	7.8		32.4	4.9	10.3	10.3	1.0
1998	12.0		50.3	7.5	15.0	15.0	1.5
1999	4.4		18.5	2.8	9.5	9.5	0.9
2000	5.7		23.9	3.6	7.6	7.6	0.8
Average	7.6	29.9	31.4	4.7	11.4	11.6	1.2

* The synthetic Mt. Rose record was created by multiplying the Reno record by 4.2. The 4.2 multiplier represents the average ratio of Mt. Rose rainall to Reno rainfall over the 1969-1979 period (e.g. Mt. Rose receives, on average, 4.2 times the rainfall that Reno receives).

** The synthetic Stead record was created by multiplying the Reno record by 1.5. The 1.5 multiplier represents the average ratio of Stead rainfall to Reno rainfall over the 1985-2000 period (e.g. Stead receives, on average, 1.5 times the rainfall that Reno receives).

associated with each node, were also adapted from the MMA/Guyton model. (Again, adjustments were made for different grid structure.) While the majority of conductance values were left at the initial values, some of the initial streambed conductance values were changed by factors varying from 5 to 10 in order to better represent observed water levels in shallow monitoring wells.

4.2.6.5 Evapotranspiration

Evapotranspiration (ET) is the process where groundwater is used by plants and then released to the atmosphere. Therefore, ET represents a net loss of water from the groundwater. ET depends on the water table depth and the depth of the root zone. The model determines the ET rate based on the simulated water table depth below land surface. Simulated ET varies linearly from the maximum ET rate when the water table is at ground surface to zero at the "extinction depth" (i.e. the depth at which ET is considered to no longer occur). An extinction depth of 10 feet and a maximum ET rate of 37 inches per year were specified. These values are the same as used in the MMA/Guyton model.

The potential for ET is assigned to the entire model area. However, if the water table does not fall within 10 feet (the extinction depth) of the ground surface ET is not invoked and an ET flux is not calculated. Only in portions of the model where the simulated water table is within 10 feet of the ground surface is ET calculated. Refer to Section 6.3 for a discussion of simulation results describing the areas where ET is simulated.

4.2.7 Temporal Discretization

During the entire long-term and historical transient simulations (1961-2001, refer to Section 5) the groundwater model was simulated using monthly time steps. The stresses applied to the model (pumping, recharge, etc.) were adjusted at differing intervals. Table 4-5 shows the frequency that groundwater stresses were updated in the long-term and historical transient model simulations.

Table 4-5
Frequency of Groundwater Stress Updates
Long-Term and Historic Transients

Groundwater Stress	*Dates*	*Frequency*
Pumping		
TMWA	1961-1995	Yearly
	1996-2001	Monthly
Domestic	1961-1969	1965 value assigned
	1970-1979	1975 value assigned
	1980-1989	1985 value assigned
	1990-2001	1995 value assigned
Remedial (SSFS)	1995-2001	Monthtly
Recharge		
MFR	1961-2001	Yearly
Agricultural Irrigation	1961-1995	Yearly
	1996-2001	1995 value assigned
Urban Return Flow	1961-1964	1961 value assigned
	1965-1971	1965 value assigned
	1972-1979	1972 value assigned
	1980-1989	1984 value assigned
	1990-2001	1995 value assigned
Adjacent Valley Inflow/Outflow		
Chalf Bluff	1961-2001	Constant
Spanish Springs Valley	1961-2001	Constant
Vista Canyon	1961-2001	Constant

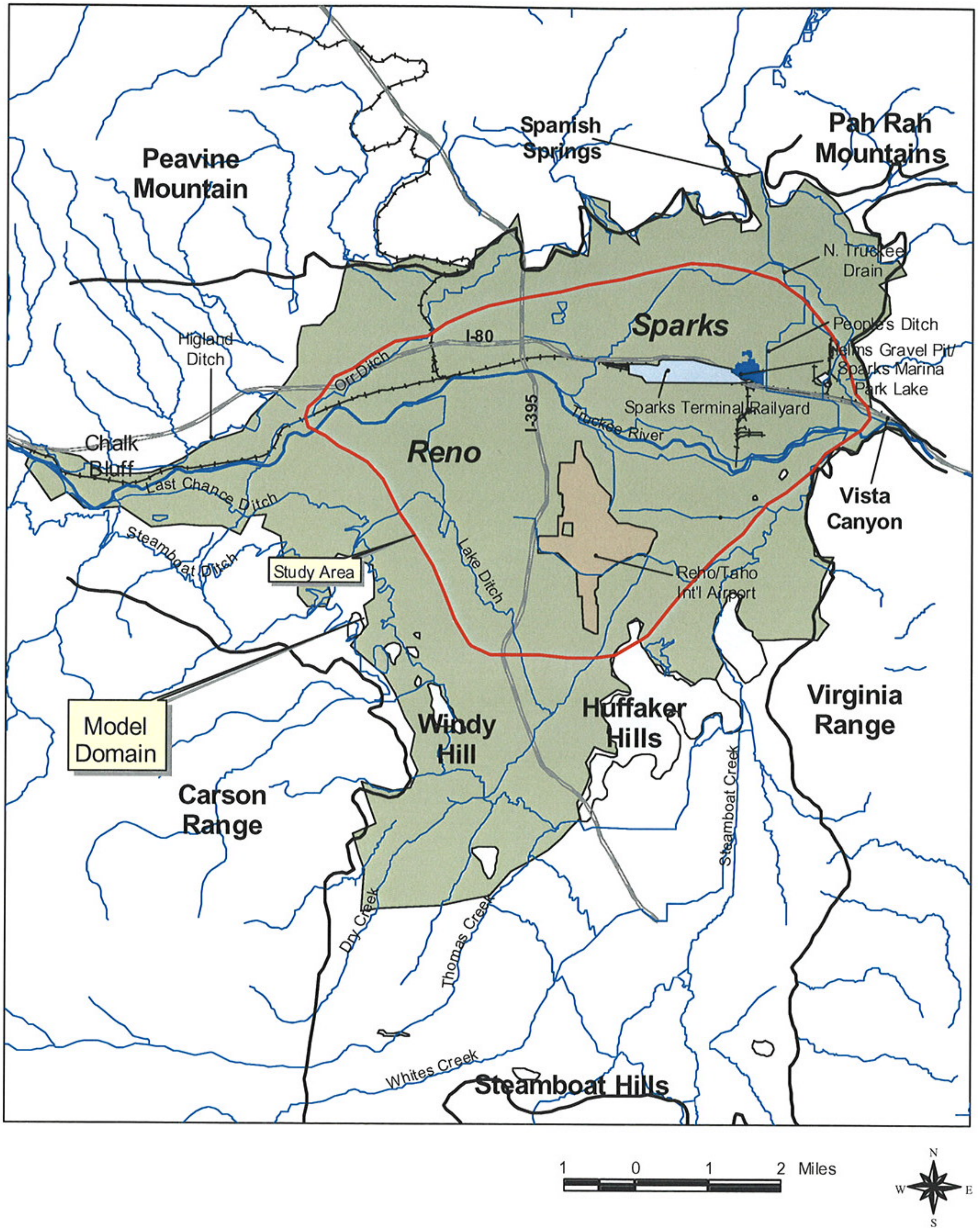


Figure 4-1
Model Domain
Central Truckee Meadows Remediation District

CDM

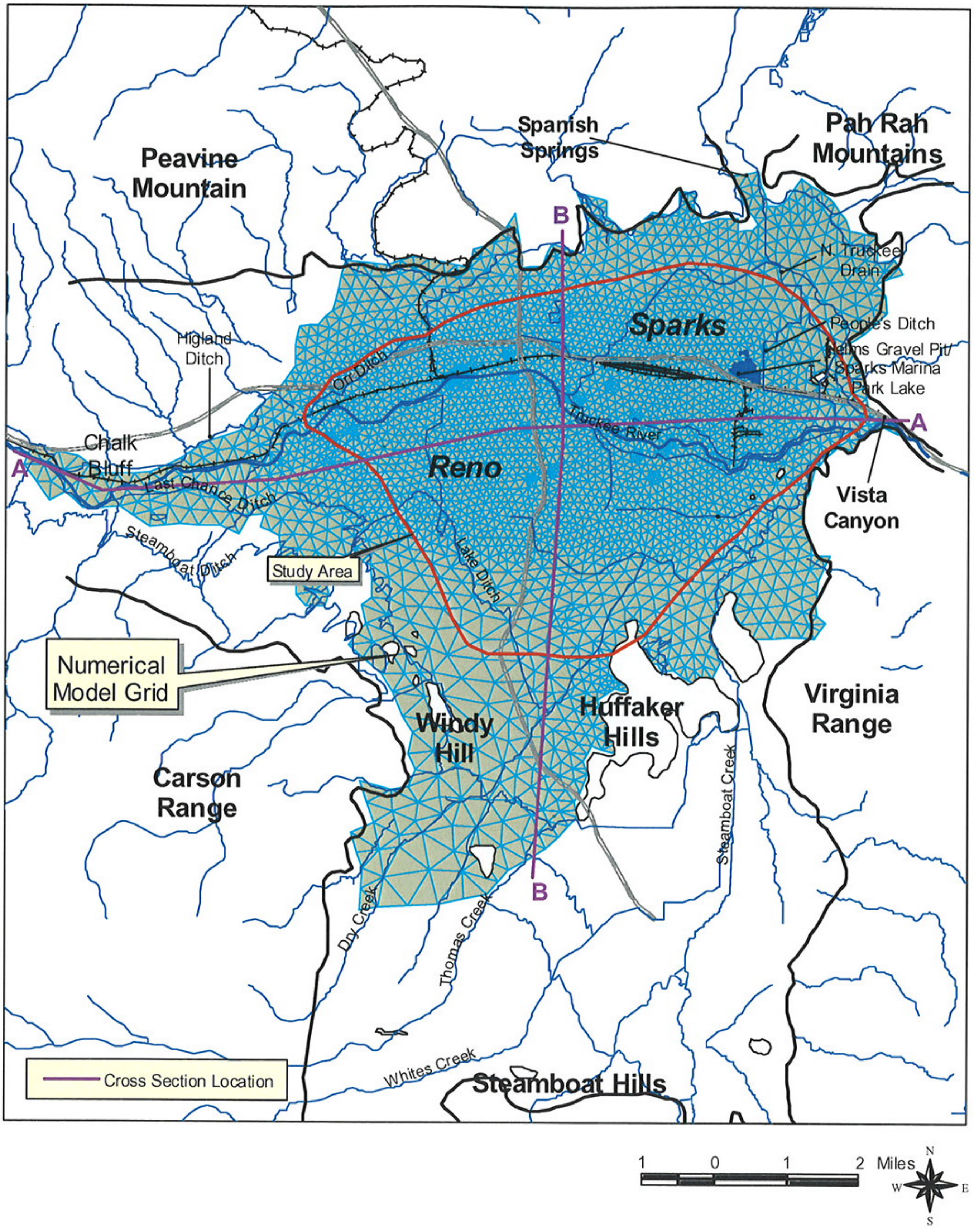
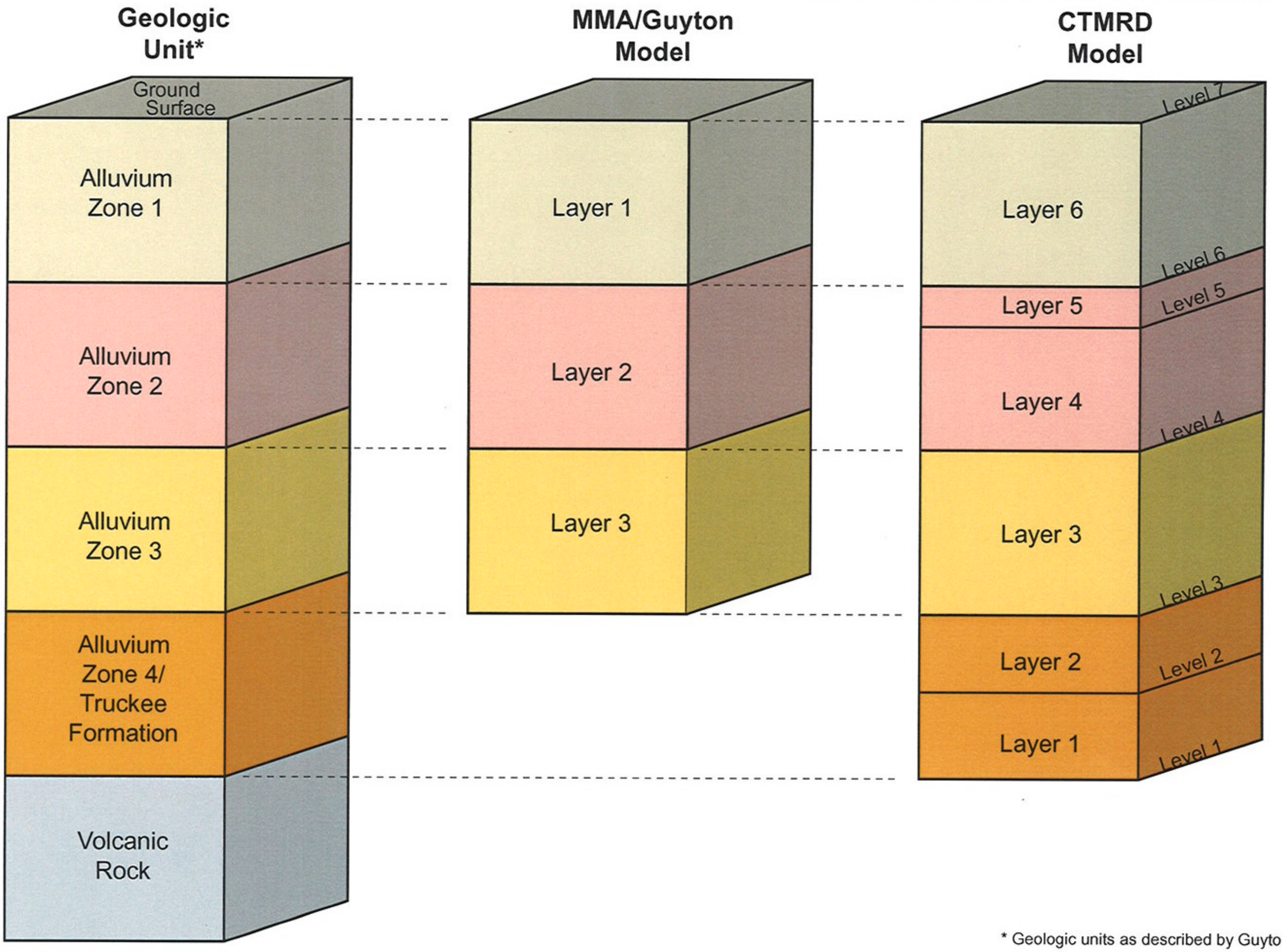


Figure 4-2
Numerical Model Grid
Central Truckee Meadows Remediation District

CDM



* Geologic units as described by Guyton (1997).

Figure 4-3
Conceptual Diagram of Model Layering and Geologic Units
Central Truckee Meadows Remediation District

CDM

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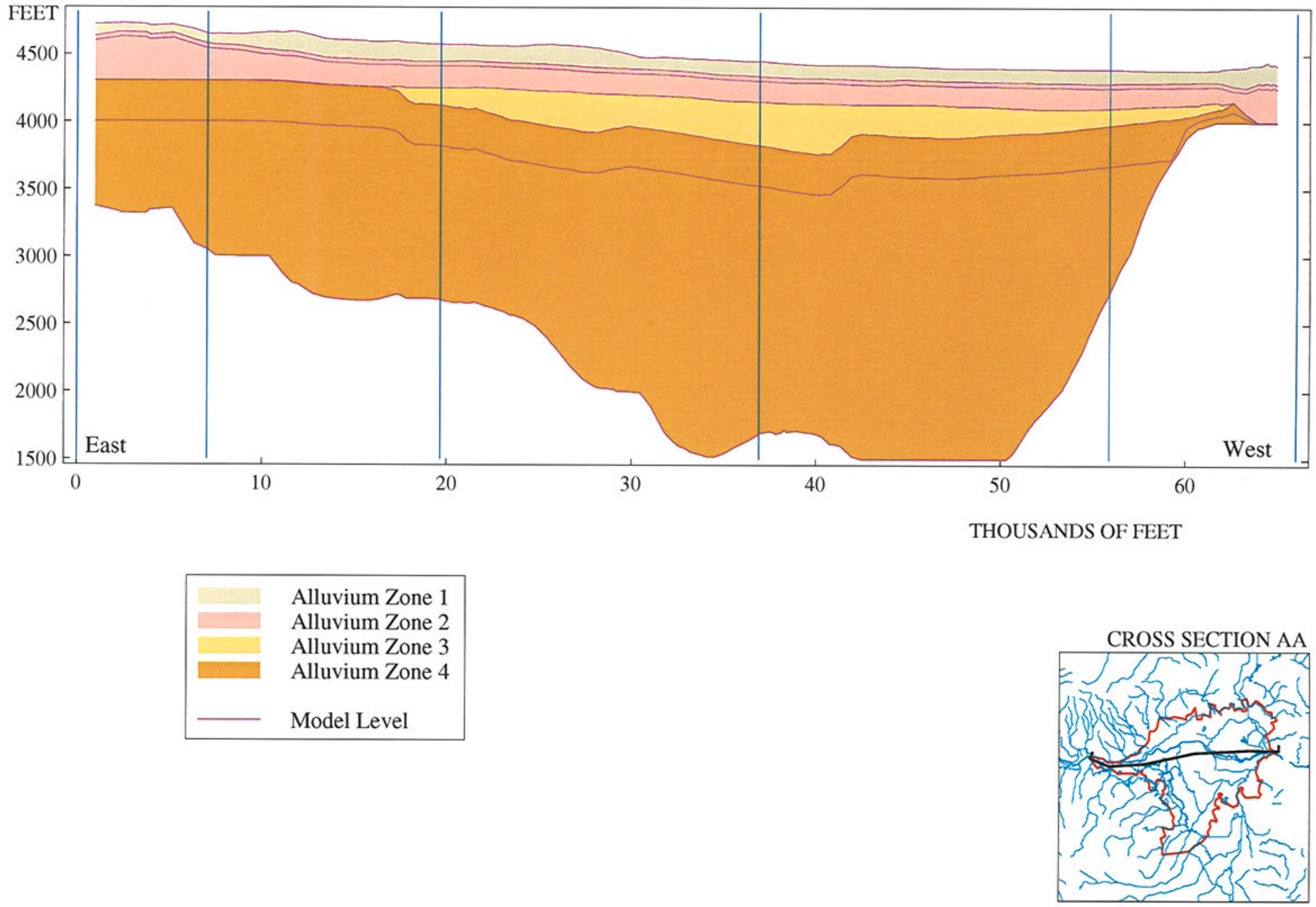

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FIGURE
4-4

Typical East-West Cross Section
Geologic Units Shown with Model Layers

Central Truckee Meadows Remediation District

CDM

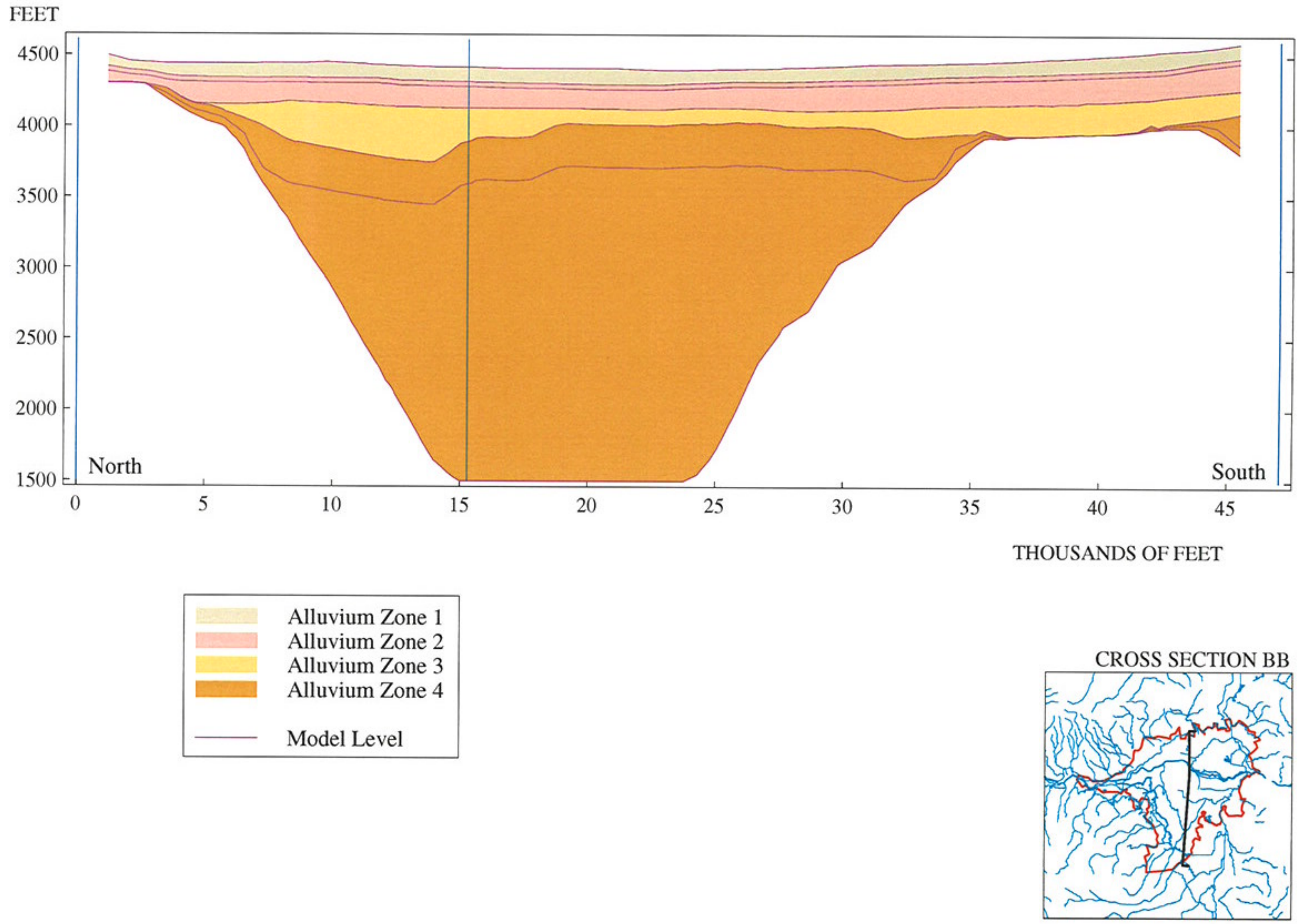

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FIGURE
4-5

Typical North-South Cross Section
Geologic Units Shown with Model Layers

Central Truckee Meadows Remediation District

CDM

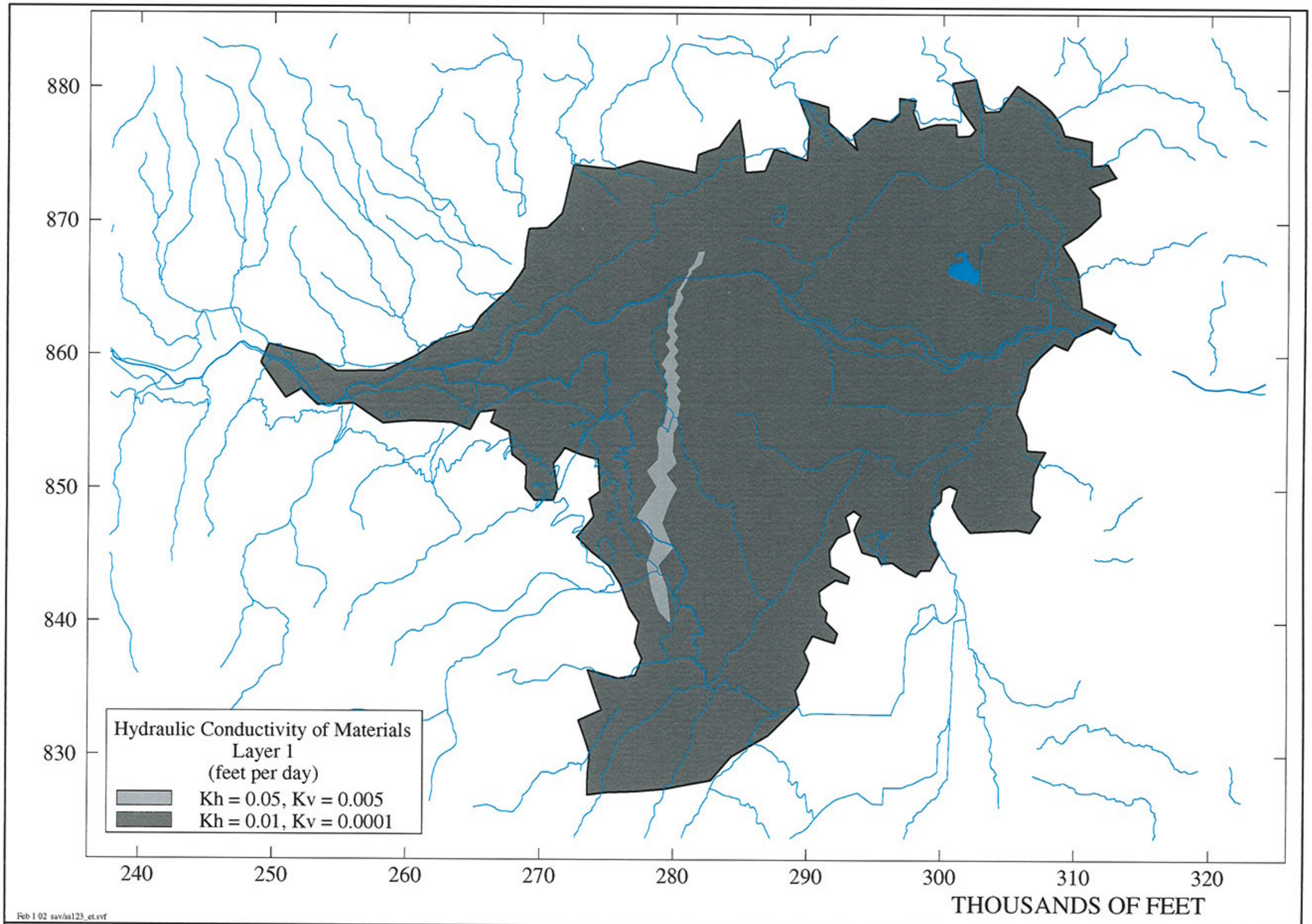

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FIGURE
4-6

Simulated Hydraulic Conductivity Distribution
Layer 1

Central Truckee Meadows Remediation District

CDM

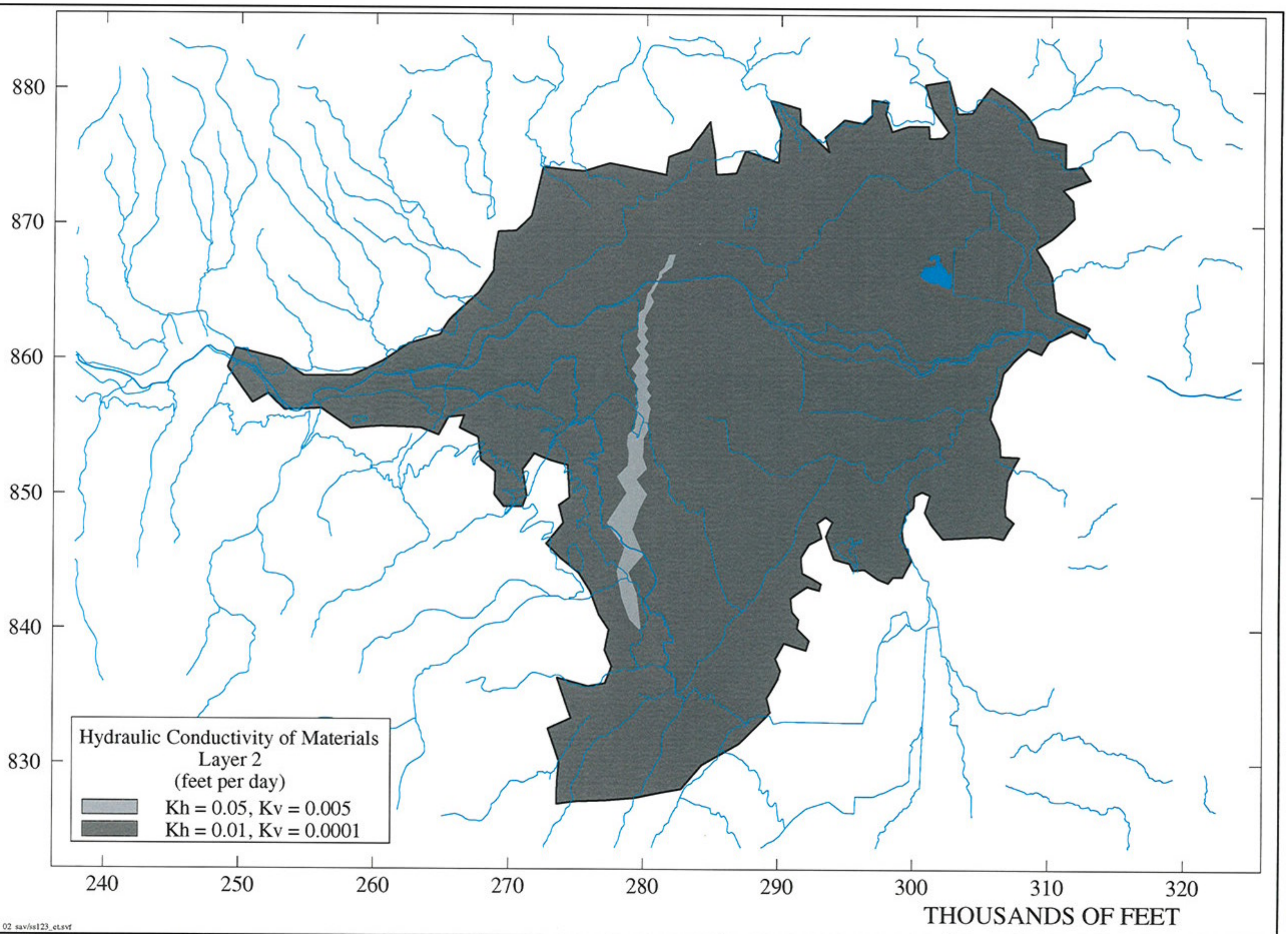

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FIGURE
4-7

Simulated Hydraulic Conductivity Distribution
Layer 2

Central Truckee Meadows Remediation District

CDM

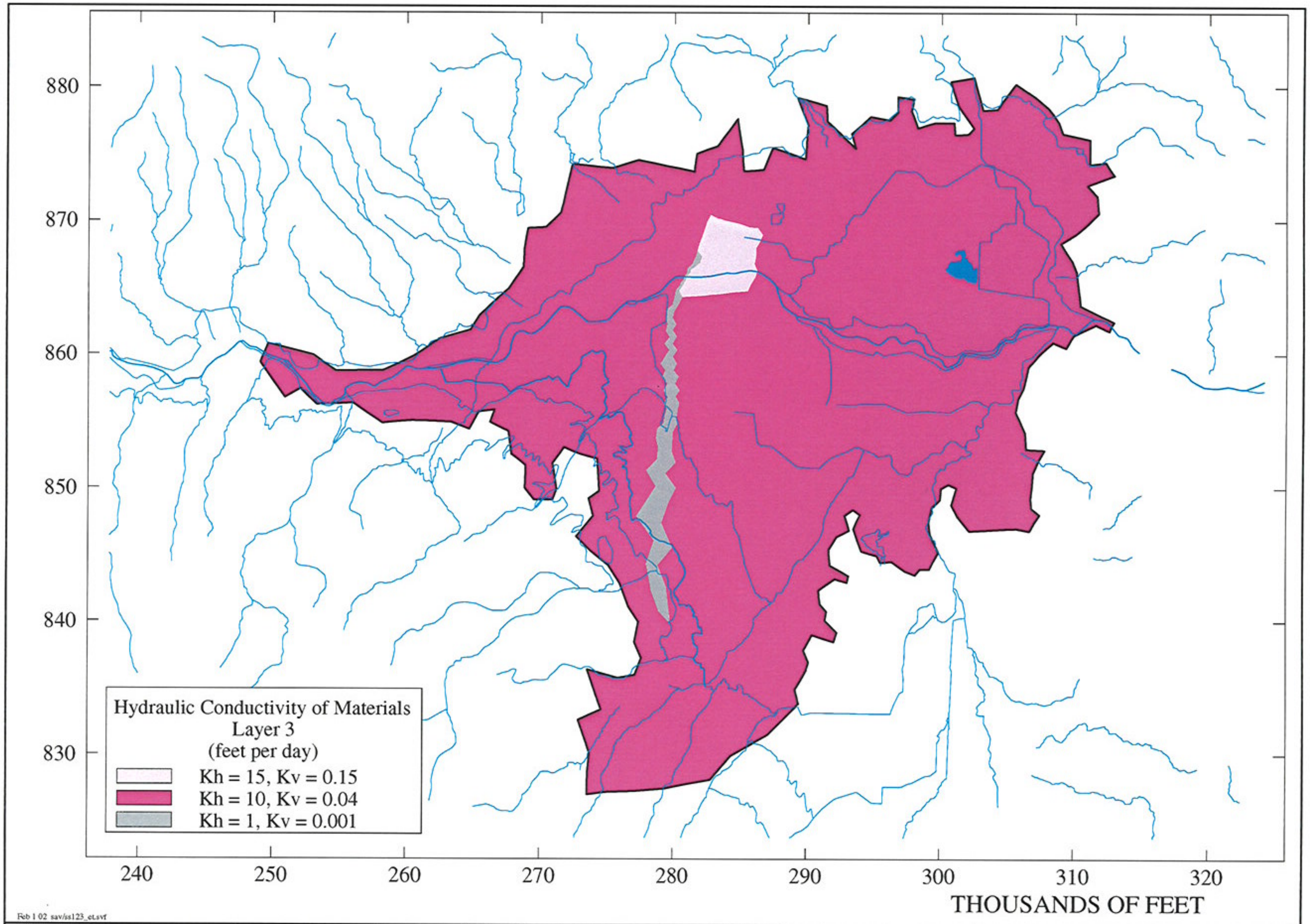

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FIGURE
4-8

Simulated Hydraulic Conductivity Distribution
Layer 3

Central Truckee Meadows Remediation District

CDM

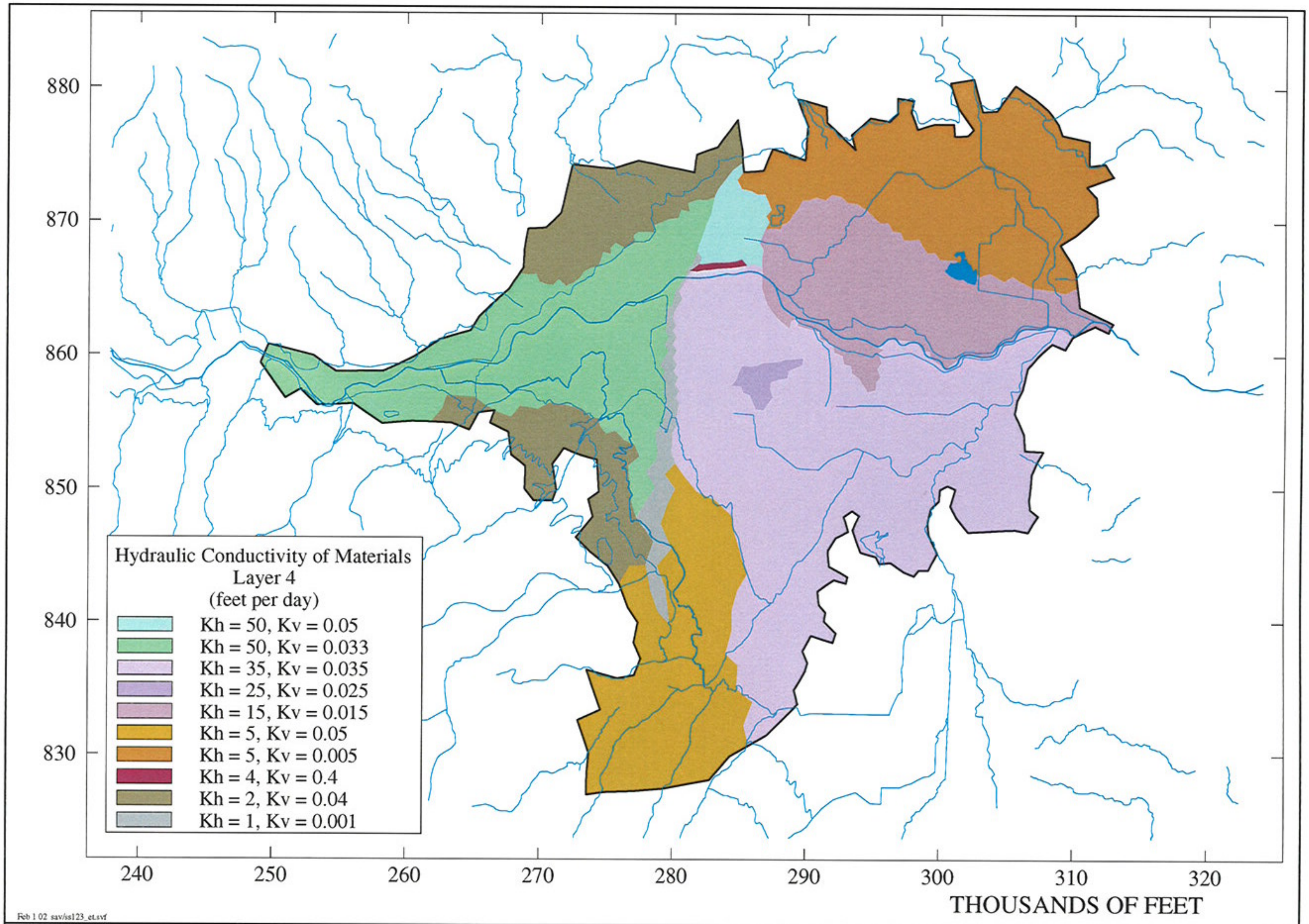

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FIGURE
4-9

Simulated Hydraulic Conductivity Distribution
Layer 4

Central Truckee Meadows Remediation District

CDM

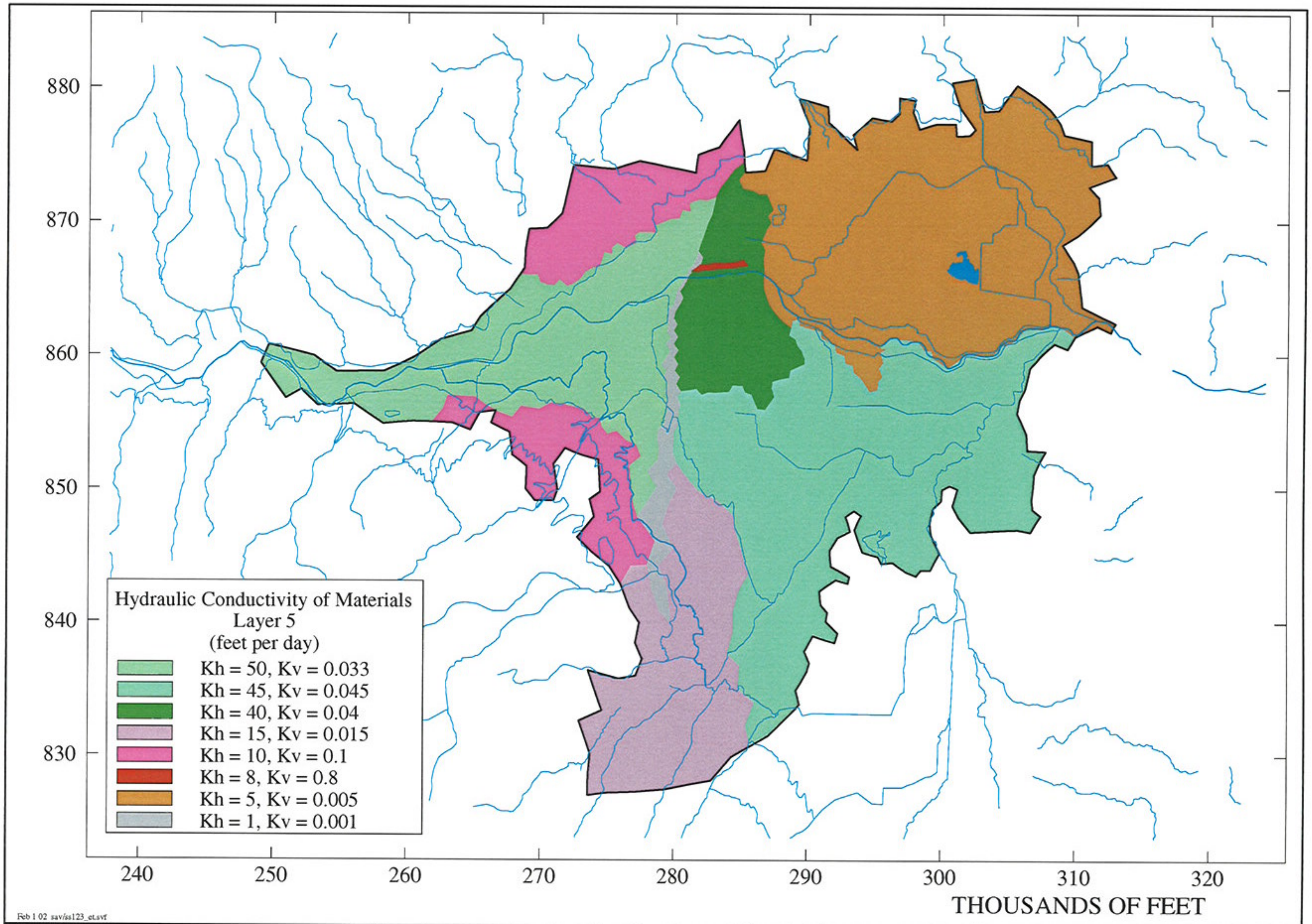

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FIGURE
4-10

Simulated Hydraulic Conductivity Distribution
Layer 5

Central Truckee Meadows Remediation District

CDM

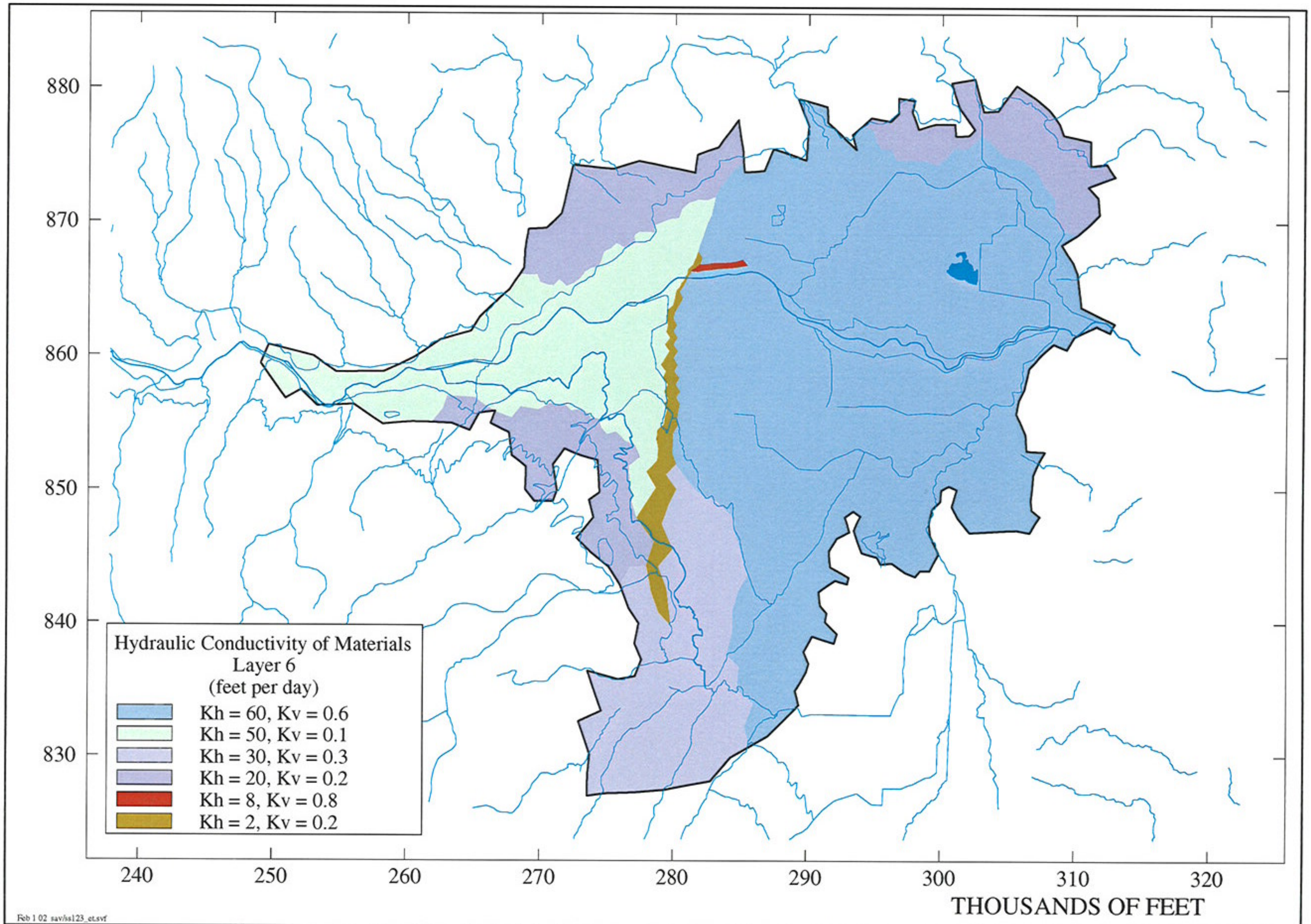

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FIGURE
4-11

Simulated Hydraulic Conductivity Distribution
Layer 6

Central Truckee Meadows Remediation District

CDM

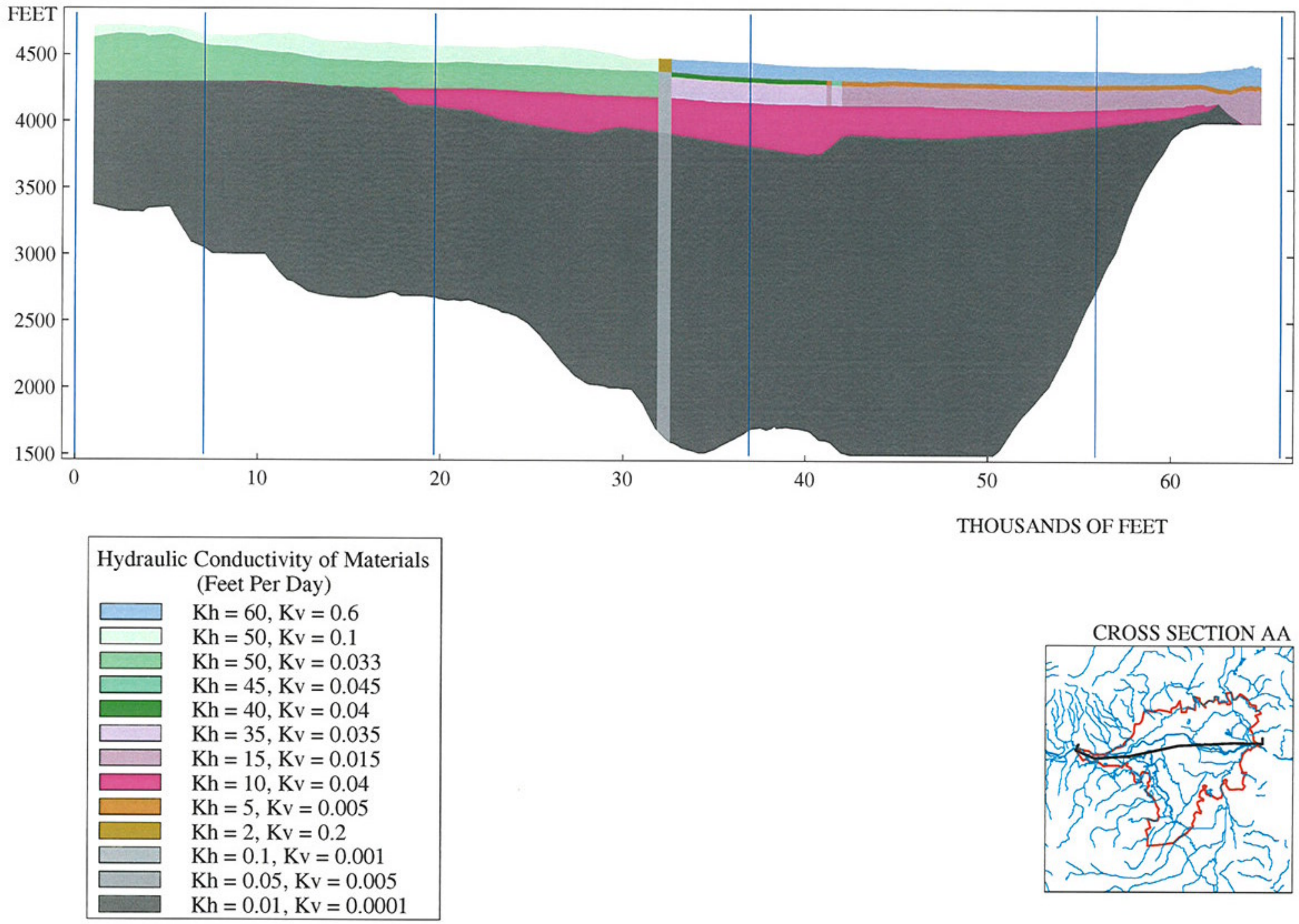

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FIGURE
4-12

Simulated Hydraulic Conductivity Distribution
Typical East-West Cross Section

Central Truckee Meadows Remediation District

CDM

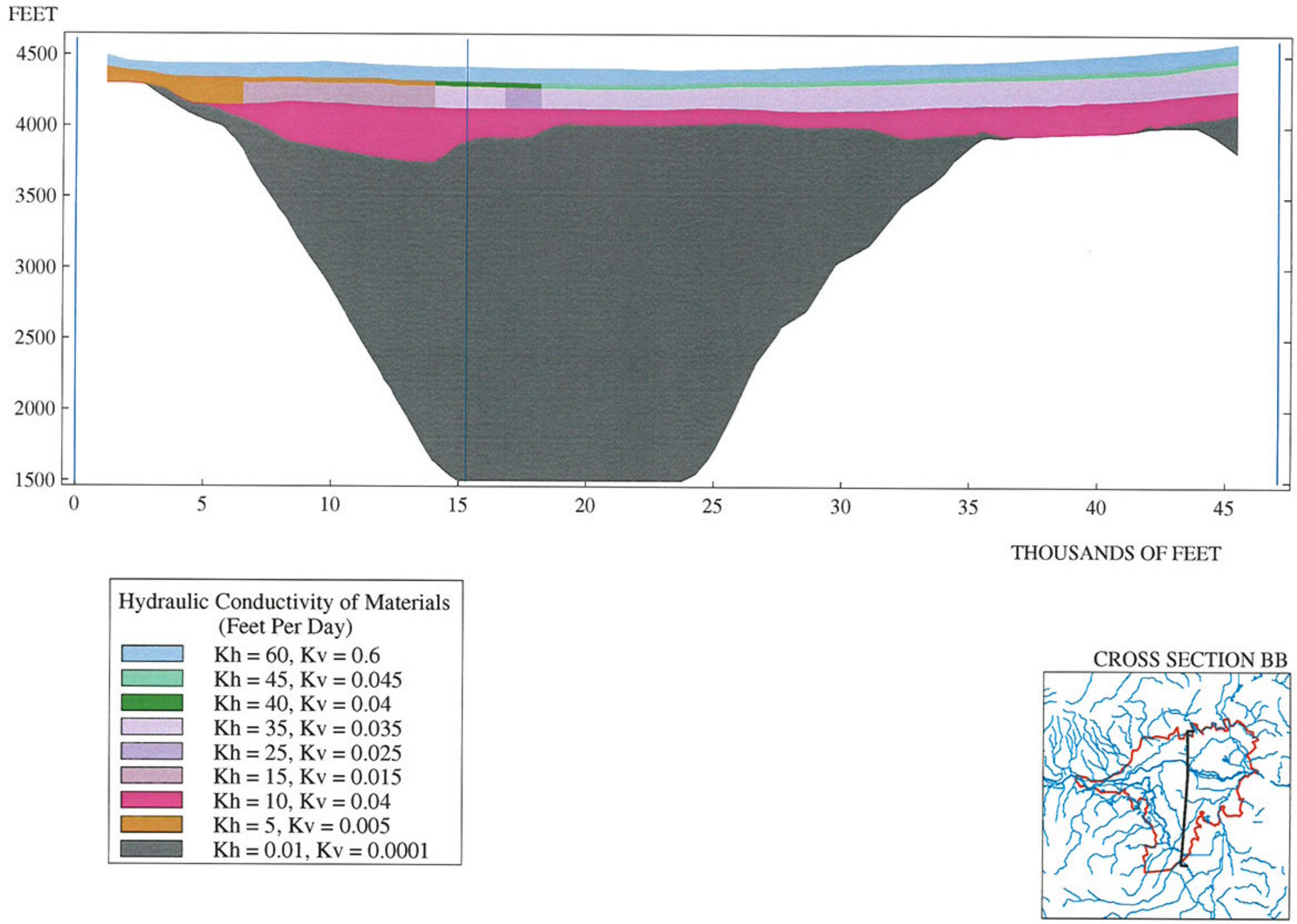

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FIGURE
4-13

Simulated Hydraulic Conductivity Distribution
Typical North-South Cross Section

Central Truckee Meadows Remediation District

CDM

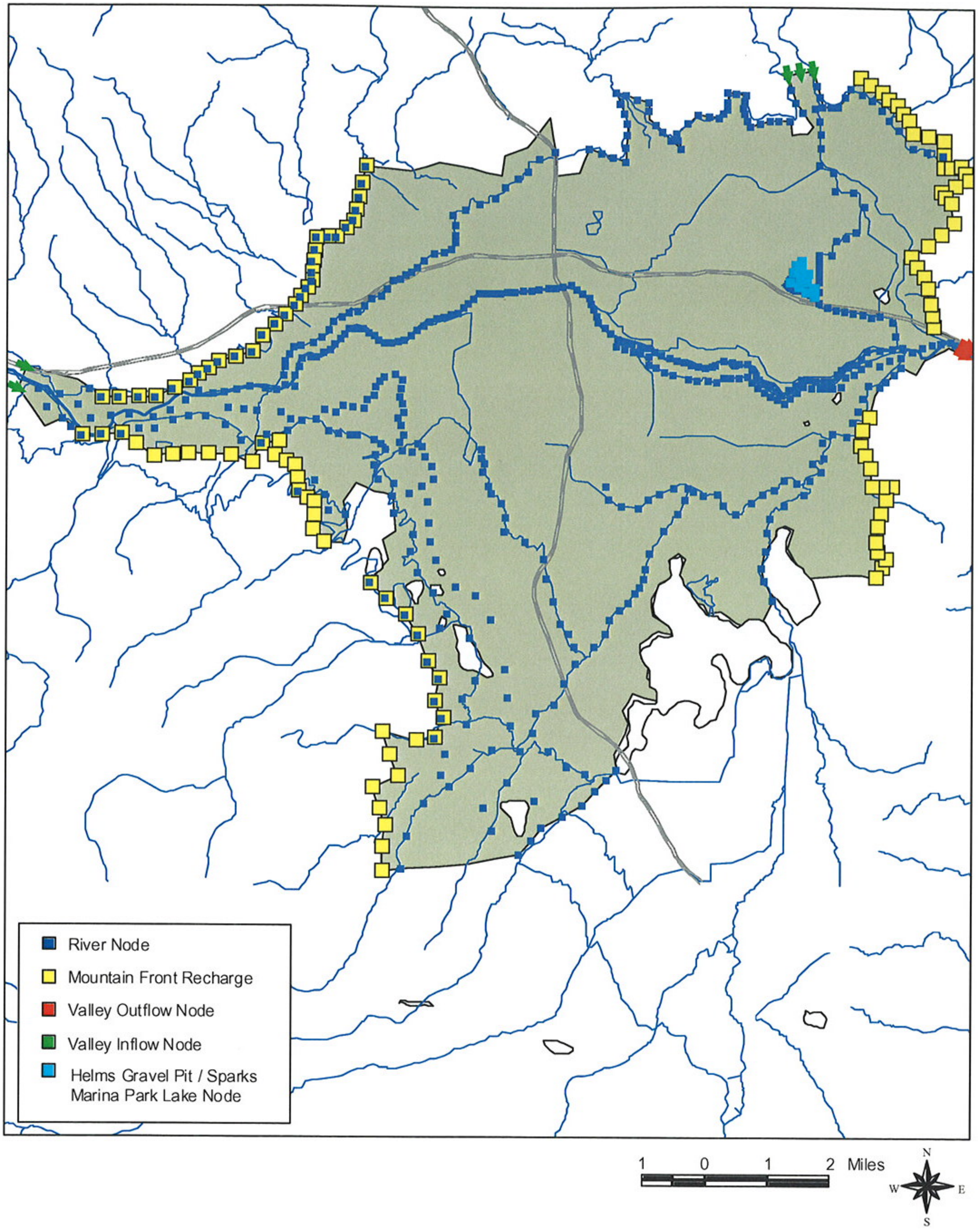
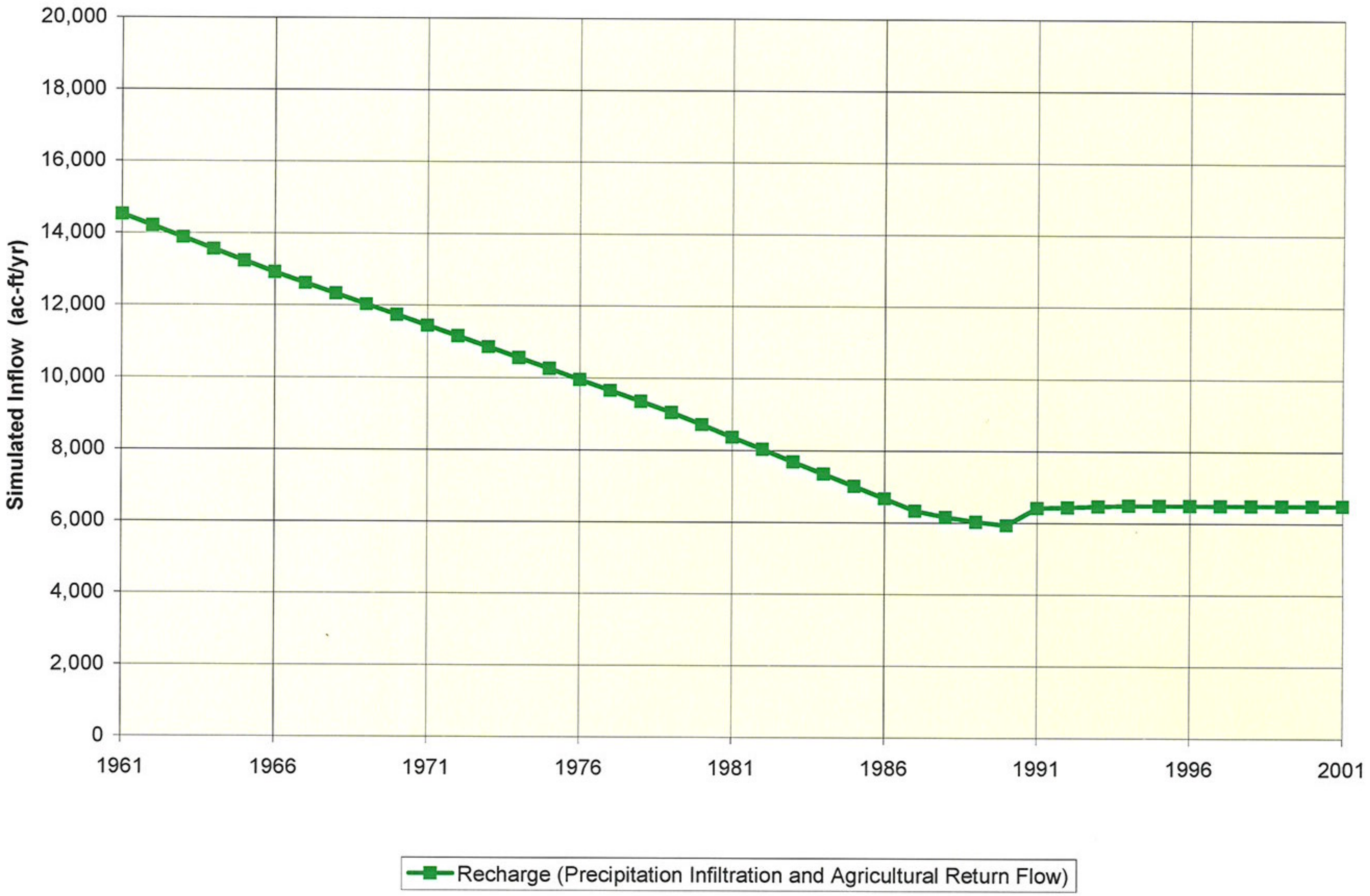


Figure 4-14
Boundary Conditions for CTMRD Model
Central Truckee Meadows Remediation District

CDM



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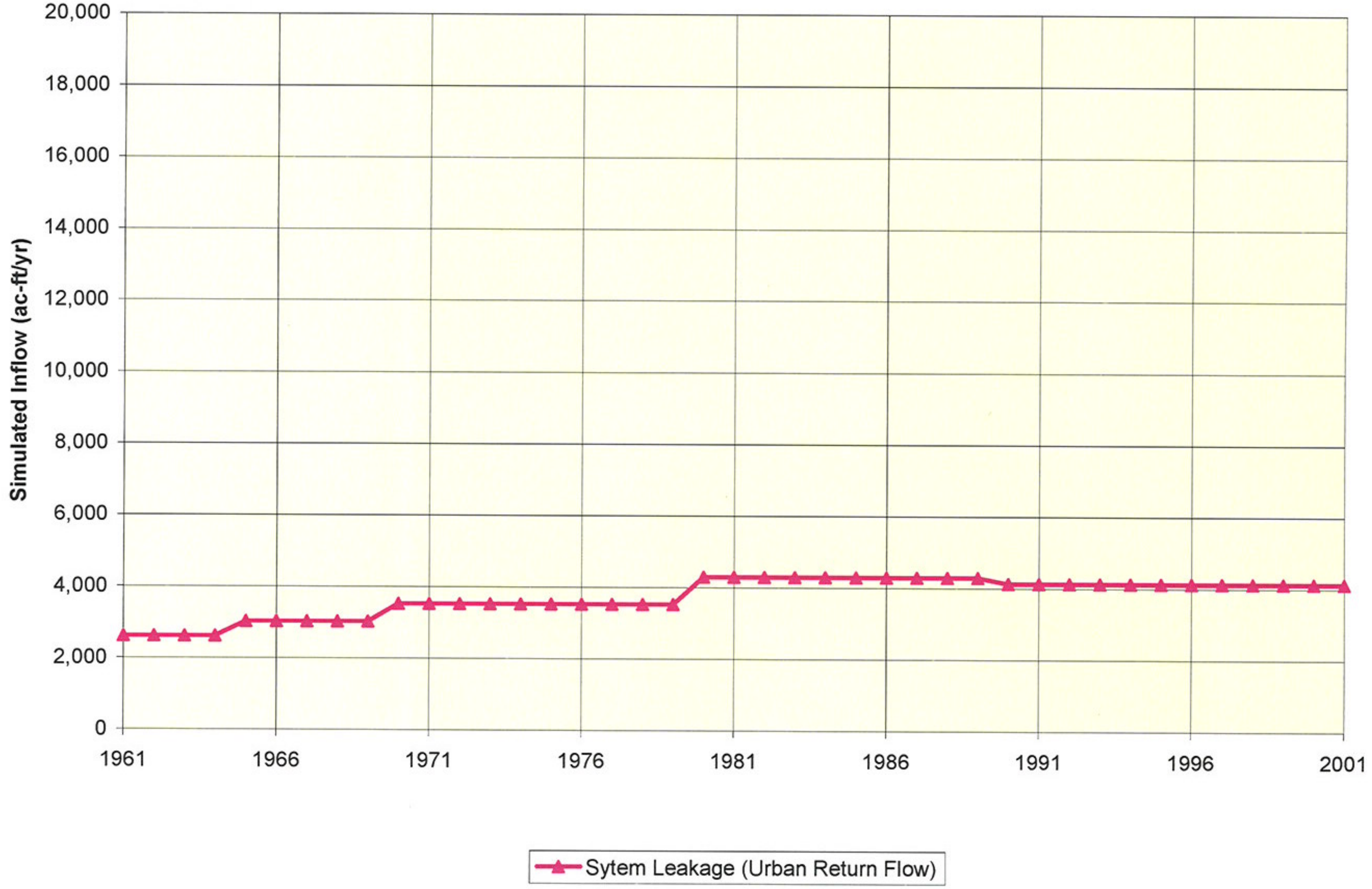
06/25/2002

Figure 4-15
Applied Areal Groundwater Recharge
Central Truckee Meadows Remediation District



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06/25/2002

Figure 4-16
Applied System Leakage/Urban Return Flow Rates
Central Truckee Meadows Remediation District

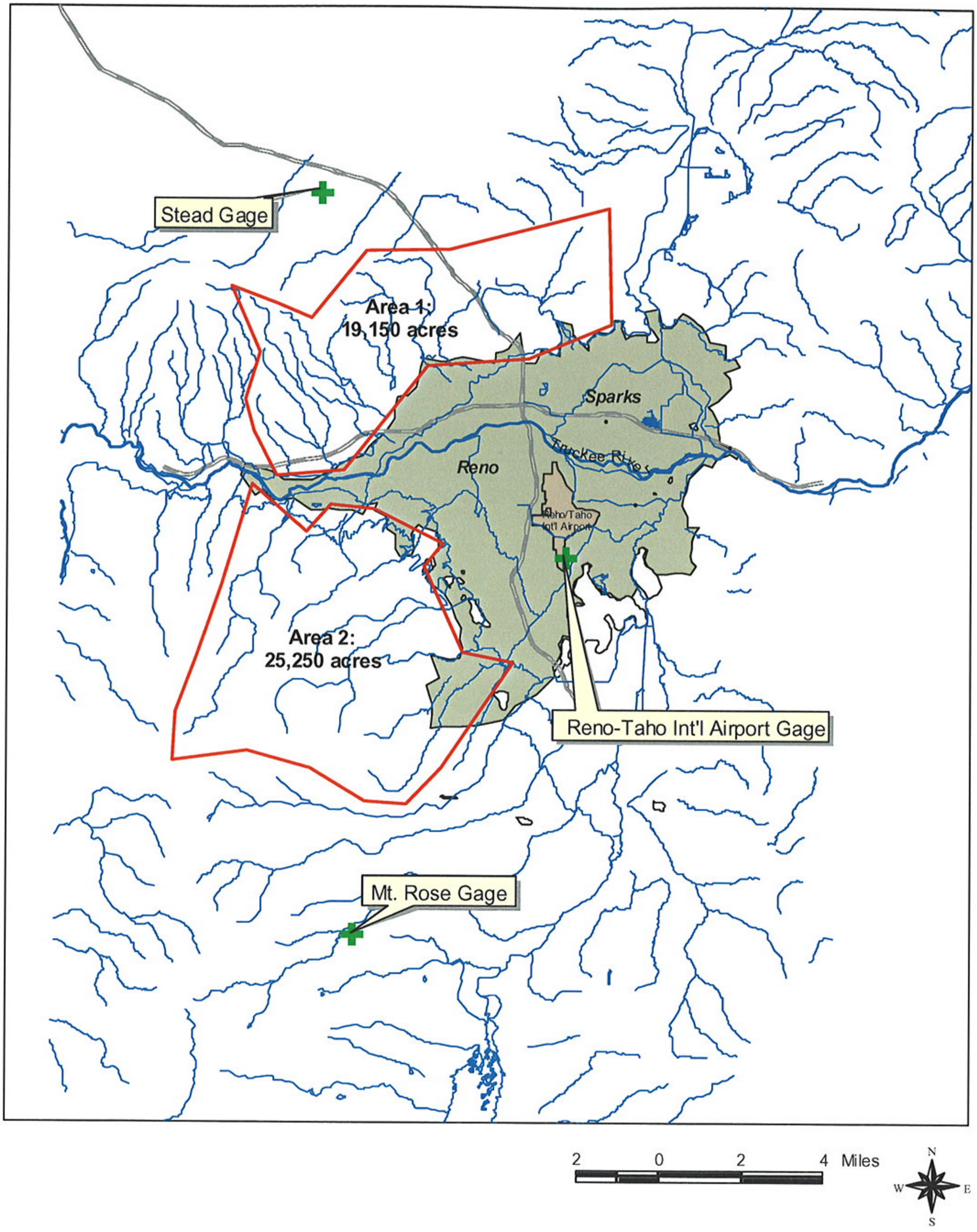

Figure 4-17
Areas Used to Establish MFR Rates
Central Truckee Meadows Remediation District

CDM

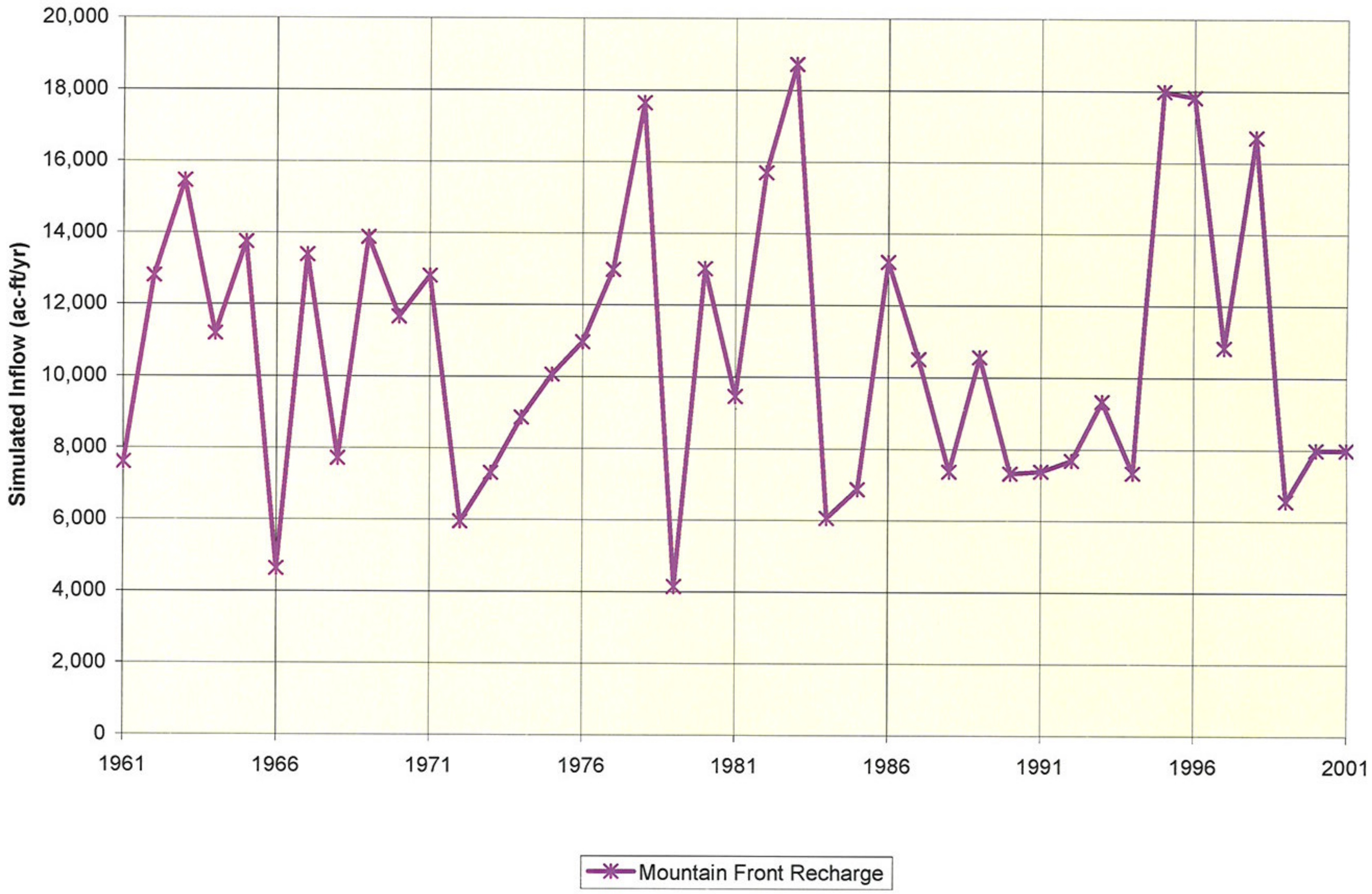

Figure 4-18
Applied Mountain Front Recharge Rates
Central Truckee Meadows Remediation District

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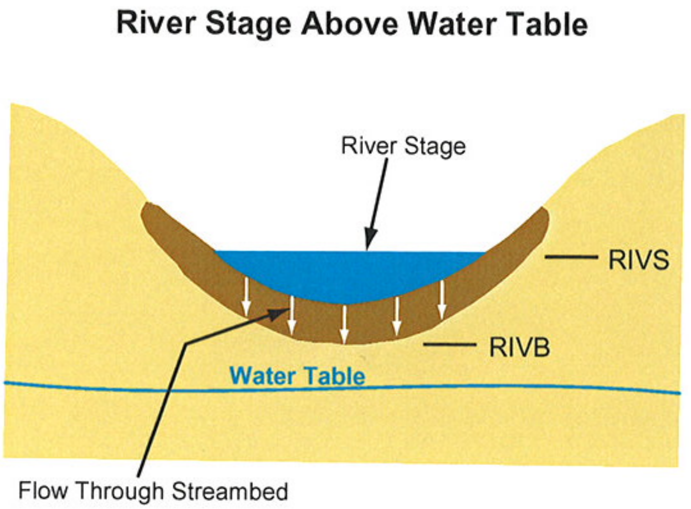
06/25/2002



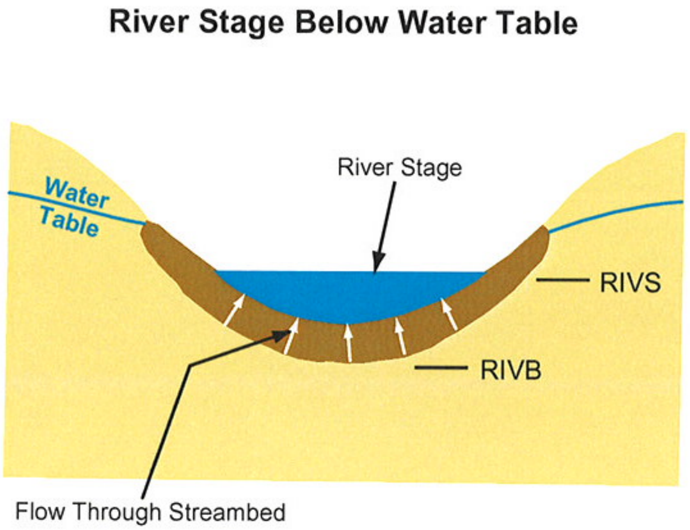


Figure 4-19
Conceptual Diagram of River Node Functionality
Central Truckee Meadows Remediation District

Section 5
Calibration and Transient Simulation

This section discusses the calibration of the CTMRD flow model. Calibration consisted of two transient events, a short-term and a long-term event.

5.1 Calibration Periods

Investigation of water levels in the CTM basin indicated that the groundwater system is not typically in a steady-state condition. Rather, groundwater levels in the CTM basin vary greatly during a typical year. The most significant changes in water levels occur in the deep monitoring wells. These changes are primarily caused by the seasonal pumping fluctuations at the TMWA wells.

As an example of the transient nature of the basin, Figure 5-1 shows water levels at 4 representative wells within the basin. This figure indicates the wide range of water levels encountered within a fairly short time period. Figure 5-2 shows the total TMWA pumping rates within the basin. TMWA rates vary from heavy pumping in the summer months to reinjection during the winter. This information indicated that the CTMRD model needed to be calibrated under transient conditions.

The following time periods were selected for transient calibration of the CTMRD flow model.

- Short-term Transient Calibration (August 2001): The configuration of CDM's field program did not allow traditional pumping tests to be performed. However, monitoring of water levels in response to the cyclic nature of TMWA pumping allowed for an analysis similar to a pumping test.

- Long-term Transient Calibration (1999-2001): As mentioned above, a suitable steady-state flow condition does not appear to exist in the CTM basin. The 1999-2001 period was chosen for calibration because this period contains sufficient quantity of water level data (both temporally and spatially).

- Historical Transient Simulation (1961-2001): The historical transient simulation results were used to check the model against other, longer-term data. For example, the historical results were compared to water levels at 2 USGS wells that had older data records and to the dewatering pumping rates at Helms Gravel Pit/Sparks Marina Park Lake (HGP/SMPL).

Calibration efforts focused on adjusting the model parameters to achieve a match between simulated and measured water levels at monitoring wells screened within the model domain. The parameters that were adjusted during the calibration process included horizontal and vertical conductivity, storage parameters, and river conductance.

An initial head condition was required in order to begin each of the transient flow simulations. A steady-state simulation for 1961 was used to start the historical transient. This 1961 steady-state used the groundwater stresses for 1961 as well as the other 1961 inflows and outflows.

The initial heads for the long-term transient were taken directly from the results of the historical transient for the appropriate time. The simulated long-term transient heads for August 2001 were saved and used as starting heads for the short-term transient simulation.

5.2 Short-Term Transient Calibration (August 2001)

As discussed in Section 2.4.3, 11 continuous recording data loggers were installed in monitoring wells between August 17, 2001 and September 14, 2001. These data loggers recorded the changes in water levels in the monitoring wells in response to pumping at TMWA wells close to the monitoring wells. The data loggers in the deeper monitoring wells responded quickly to periods when the TMWA well were shutdown and subsequently restarted. The shallower monitoring wells did not respond significantly to the shutdowns.

5.2.1 Simulation Characteristics

The period from August 27 through August 31, 2001 was chosen as the simulation time period. Figures 5-3 through 5-6 show the pumping rates and water levels from the deeper data logger expanded for this time period. The pumps at the High Street, Morrill Avenue, Mill Street, Corbett School, and Kietzke Lane wells were shut off at approximately 1:00 pm on August 27. These pumps remained off for approximately 7 hours, after which they were restarted (see Figures 5-3 through 5-6). These figures also show the data logger record for the corresponding monitoring wells.

The starting head condition used for these simulations is based on the simulated August 2001 water levels from the long-term transient (Section 5.4). At the start of the short-term simulation the pumping rates at the High Street, Morrill Avenue, Mill Street, Corbett School, and Kietzke Lane TMWA wells are adjusted to the average value recorded between midnight on August 27 and the beginning of the pump shutdown. In addition to the pumping wells that were actually shut off, actual pumping rates were also simulated at the 4th Street, 21st Street, Galletti Way, Terminal Way, and View Street TMWA wells. These wells are close enough to the data loggers to potentially cause interference during the test. The pumping rates in the other TMWA wells were not adjusted during this simulation. These rates were left at average August values.

The pumping rates used in these simulations were somewhat simplified based on the pumping rate data provided by TMWA. TMWA provided hourly average rates for the pumping wells. However, instead of adjusting pumping rates hourly within the simulation, the short-term transient simulations used average pumping rates during pumping periods. For example, at the Mill Street well, a rate of 1,188 gpm was used prior to the August 27 shutdown and a rate of 1,230 gpm was specified after the August 27 shutdown. The data shown in Figure 5-4 indicate that the pumping rate at Mill Street actually fluctuated slightly during these time periods. These slight fluctuations did not impact the results obtained from the short-term transient calibration simulations.

5.2.2 Results

The results of the short-term transient simulations are shown in Figure 5-7. These figures show a comparison of the measured and simulated change in water level at four deeper monitoring wells, where data loggers were installed, due to changes in TMWA pumping. A figure for the results at CTM-23D, near the Peckham well is not shown because the Peckham well was not pumped during the period of the data logger record. Comparisons are not shown at the shallow monitoring wells because water levels (simulated or measured) did not significantly respond to pumping shutdowns. Given that the primary goal of these simulations was to match the relative response to pump shutdown, the water levels on these figures are plotted as changes from average water levels on August 27 prior to the pump shutdowns.

General observations are listed below:

- There is generally good agreement between the simulated and measured aquifer response to TMWA pumping changes. This agreement was achieved primarily by adjusting the hydraulic conductivity (both horizontal and vertical) and specific storativity of units near the monitoring/pumping locations.

- The lack of response at the shallow monitoring wells indicates a strong degree of hydraulic separation between the shallow and deeper alluvium.

- As discussed in Section 2.4.4, the rapid water level response of the deep monitoring wells is consistent with a generally confined aquifer condition.

- Simulations indicated a degree of hydraulic isolation was required between the Kietzke Lane and 4th Street wells to adequately characterize the aquifer response in this region. Initial model configurations did not contain sufficient isolation between these two wells. As a result of this initial configuration, the direct impact of the 4th Street well was evident in the simulated response at CTM-22D. This response was visible because the 4th Street well shut down two hours before and turned back on two hours later than the Kietzke Lane well. The calibration process led to the incorporation of a slightly lower conductivity unit between these two wells. This feature was incorporated in the shallow and deep aquifer units (model layers 4, 5, and 6).

5.3 Long-Term Transient Calibration (1999-2001)

In addition to calibration to short-term transient events, the groundwater model was calibrated to a longer-term transient. This longer-term transient calibration time period was chosen to be June 1999 through August 2001. This period was chosen due to availability of monthly water levels at a large number of wells monitored by Washoe County DWR. This time period also encompasses water levels collected at the new CTM wells that were installed in May 2001. Of key importance to the calibration effort was the availability of water levels in the deep CTM wells. It is important to note that little piezometric head data from the deeper portions of the aquifer were available before the new CTM wells were installed.

5.3.1 Simulation Characteristics

The starting head condition used for this simulation is based on the flow conditions simulated in a historic transient (refer to Section 5.4). Model inputs are varied temporally as discussed in Section 4. Model simulations for the long-term transient calibration were conducted for the period of June 1999 to August 2001.

5.3.2 Results

Given the large number of wells available as calibration targets in the CTM basin, a set of wells was selected to represent flow conditions throughout the basin. Figure 5-8 shows the locations of these selected wells.

Wells were chosen in order to get a good spatial distribution, both horizontally and vertically, across the basin. Shallow wells are much more numerous than the deeper wells. Where deeper wells were available, a shallow well in the same vicinity was also chosen, if possible, so as to assess the ability of the model to reproduce vertical head differences.

Figure 5-9 shows the calibration results at the selected wells for the long-term transient. To assist in the understanding of this figure, various color-coding is employed to differentiate the depth of the wells. As a reference, Figure 5-10 provides example calibration graphs for shallow and deep wells and for a shallow/deep well pair. Table 5-1 also provides a key to Figure 5-9.

Table 5-1
Key to Figure 5-9

Background Color	
Yellow	Shallow Well
Blue	Deep Well
Green	Shallow/Deep Well Pair
Line Color	
Dark Blue	Observed Water Levels
Magenta	Simulated Water Levels
Line Type	
Solid	Water Level in Shallow Well
Dashed	Water Level in Deep Well

In addition to the calibration shown in Figure 5-9, snap-shots of the flow field were taken during the calibration simulation were taken and compared to available water levels. Figure 5-11 shows the calibration results in March and August 2001, respectively. These two time periods represent the extremes in terms of TMWA pumping and observed water levels in the basin. This figure plots the simulated versus observed heads on the same plot. Figure 5-11 indicates a good match between the simulated and observed heads because the data points are generally centered on the diagonal line. The diagonal line indicates a perfect match for all data points (e.g. a simulated value of 4,450 ft and an observed value of 4,450 ft would plot on the diagonal line).

Figure 5-12 presents this same calibration information spatially. This figure shows "+", "-", and "o" symbols representing the difference between simulated and observed water levels. The "+" symbol indicates the simulated value is higher than the observed value and the "-" symbol indicates that the simulated value is lower than the observed value. The "o" symbol indicates the simulated heads are within 10 feet of the observed data at that well. The characters are color-coded based on the ranges shown in the figure legend.

The calibration yields a mean difference between the observed and simulated water levels of 1.3 feet and a standard deviation of 4.9 feet during March 2001. The mean and standard deviation are 0.8 and 8.4 feet, respectively, for August 2001. The range of calibration heads across the model area is almost 175 during March 2001 and over 200 feet during August 2001. Therefore, the standard deviation represents less than 3% of the head range found in the model during March 2001 and about 4% during August 2001. Likewise the mean differences represent less than 1% of the range of water levels during both March and August 2001. These results indicate an adequate match of model results to field data. Based on this comparison of simulated and observed water levels elevations, it is concluded that the model adequately simulates groundwater flow patterns and is a useful tool for decision making processes involving groundwater contamination.

The majority of locations indicate simulated water levels within 10 feet of the observed water levels. These values are reasonable values based on the ranges of water levels observed across the model area.

Two features of the calibration results in Figure 5-9 should be noted. First, the model adequately represents the overall water levels in the basin. The model represents the water levels in both the shallow and deep aquifers. Of particular note is that the model adequately represents the vertical difference in water levels at well pairs. Second, the model represents the seasonal water level fluctuations well. These fluctuations are primarily observed in the deeper monitoring wells and are believed to be a result of seasonal pumping variations at the TMWA wells.

Basin-wide simulated groundwater flow directions are discussed in Section 6.1.

5.4 Historic Transient (1961-2001)

Transient simulations over the period 1961 to 2001 were performed to check that the CTMRD model could reasonably reproduce water level changes in the basin during this period. This transient simulation was performed to provide further verification of the model calibration discussed in sections 5.2 and 5.3. Additional verification was possible by comparing simulated results to observed data prior to 1999 (the beginning of the longer-term transient simulation discussed in Section 5.3).

CTMRD model simulation results were evaluated by comparing time histories of simulated and observed water level elevations at 2 USGS wells with available historical data records and selected monitoring wells in the basin. In addition, simulated groundwater fluxes at Helm's Pit were compared with measured groundwater withdrawal rates for 1995 through 2001.

The data records for the USGS wells span the early years of the historical transient simulation. Figure 5-13 shows simulated and observed water level elevations at USGS-1 and USGS-2. The slope of the simulated and observed time history curves are generally similar, although the simulated change in heads is greater at USGS-1.

Figure 5-14 shows simulated and observed water level elevations from the historical transient simulation for a broad range of wells (as used in Figure 5-9 as well).

Groundwater withdrawal rates at HGP/SMPL, including the effects of the 1997 flood event, were available from 1995 to August 2001. These data were used as a calibration target for the historical transient calibration. A comparison of simulated and observed groundwater fluxes at HGP/SMPL is shown in Figure 5-15. The results generally represent an adequate match between simulated and observed data. The simulated pumping rate prior to the 1997 was higher than the actual rate but within an acceptable range. After the flood, the construction of Sparks Marina Park Lake required many changes in the lake water level. These changes were necessary in order to perform the required earthwork. Therefore, the pumping rates from lake were extremely variable during this period. Model simulations represent a constant water level in the lake because exact lake water levels were not available. After the construction was finished water levels were maintained at a more constant value. During this time the simulated flux rates are an excellent match to actual pumping rates.

5.5 Simulated Water Budget

Calculations were performed to determine the rates of flow into and out of the CTM basin during the transient simulations. These flows include pumping, recharge, evapotranspiration, exfiltration from rivers, etc. The simulated water budget is presented in Section 6.3.

5.6 Steady-State Simulations

Even though no steady-state simulation was chosen for calibration, steady-state simulations were conducted using the calibrated CTMRD model. As discussed above, one of the steady-state simulations consisted of average 1961 conditions. This simulation was used as the starting conditions for the historical transient simulations.

Another steady-state condition that was simulated represented "pre-development" conditions in the basin. This simulation was performed with no pumping stresses, system leakage, agricultural recharge, or irrigation ditches. The only recharge represented in this simulation MFR and areal recharge from precipitation. The creeks and rivers in the area remained in the simulation. This simulation confirmed that the model was able to produce a reasonable solution, in terms of water levels and flow rates, for this condition. No calibration targets were available for this time period.

5.7 Model Limitations

The groundwater flow model developed during this project was created to represent flow directions and rates in the study area for this project. The model provides a fully 3-dimensional representation that has been tested under different hydrologic conditions. Primarily, the model development has focused on the downtown Reno area where the highest levels of PCE contamination have been detected and near the five TMWA wells with wellhead treatment. The calibration results presented earlier in Section 5 indicate that, within the study area, the flow model adequately represents:

- Observed water levels
- Flow directions
- Aquifer response to pumping stresses

While the model is sufficient for the scope of this project, as with any model representing a complex natural system, there are some limitations to model application. These limitations are presented below.

- The model calibration was not sensitive to some of the basin inflow/outflow parameters (e.g. mountain-front recharge). There also was not available data to attempt to calibrate groundwater/surface water interaction with all the ditches and streams in the area. Therefore, the model calibration did not significantly improve the reliability of the overall basin water balance implicit in the model. Also, analysis using the model should focus on the central part of the basin. The relative accuracy of the hydraulic model in predicting observed water levels under various hydrologic conditions (e.g., Winter 2000, Summer 1999, etc.) supports the use of the model to evaluate TMWA well capture zones for different seasonal conditions, given that the TMWA wells are significantly removed from whatever inaccuracies exist in the simulations at the margins of CTM. To this end, the literature values available to characterize the water budget of CTM were relied upon to support the modeling effort, without compromising the model's integrity.
- There is a large portion of the model area for which data did not exist to be used in calibration. For example there were no observed water levels in the southern part of the basin, south of Plumb Lane. There are also limited data in and around the Reno-Tahoe Airport, and south and east of the Airport. Given that TMWA does not have production wells in these areas that have detectable concentrations of PCE (with the except of Peckham), rigorous simulations of well capture zones were not needed in these areas to support development of the Remediation Plan. Therefore, the model results presented in this report are not compromised by the limits of data in these areas. However, if predictions of well capture zones and/or contaminant migration pathways are needed in these areas, additional data will be needed to support model enhancement and re-calibration.

5.8 Supplemental Data

Additional data would be useful in supporting model refinements, especially if more TMWA well capture zones need to be characterized and predicted. Those data that would benefit model enhancements include the following.

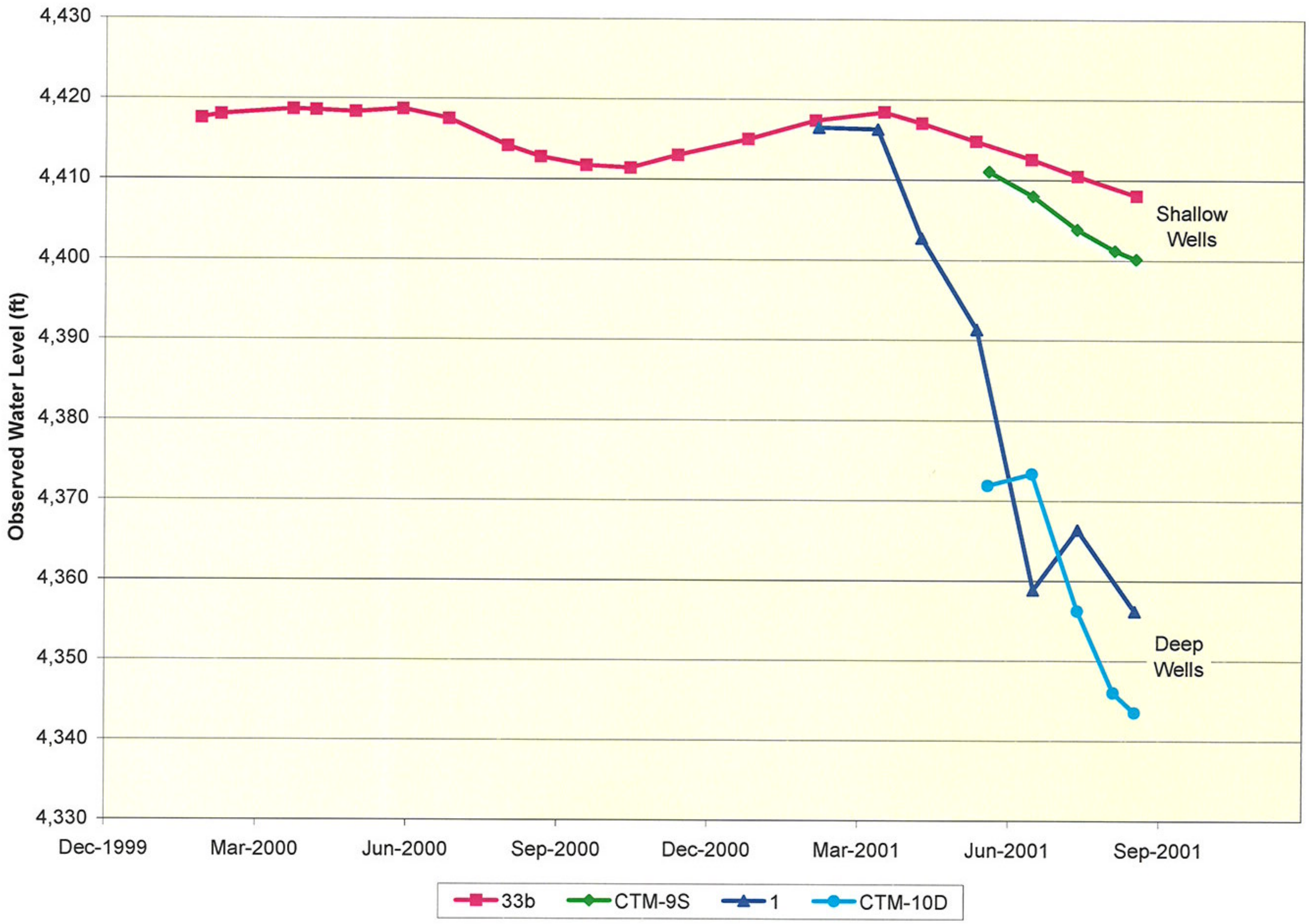
- Spatial Distribution of Water Levels: In order to more completely understand the flow pattern in the full CTM basin it would be useful to have additional monitoring wells installed in locations where limited, or no, water level data is currently available. The choice of these locations would be made with understanding that the measurement of water levels would be the primary data collected at these locations. This monitoring should include wells to monitor both the shallow and deep aquifers. The existing model can be used to aid in identifying the placement of additional monitoring points. New monitoring well sites should be evaluated for multi-level completions, especially in areas near TMWA production wells. Potential areas for siting of new monitoring wells includes, but is not limited to:

  - South of Plumb Lane and east of Lakeside Dr. to McCarran Blvd.
  - Around, and adjacent to, the airport
  - Along 4th St. and/or 5th St. east of Wells Ave.
  - North of Mill St., east of Kietzke Lane, south of the Truckee River and west of Rock Blvd.
  - Along the Truckee River, east of Rock Blvd. to McCarran Blvd.
  - North of I-80 in Sparks
  - In areas around the perimeter of the basin

- Faulted Zone: As mentioned earlier, there appears to be a faulted zone in the vicinity of the High St. and Morrill Ave. wells. The primary evidence for this faulted zone is observed water levels. However, there are only two sets of wells (145/34 and 122a/CTM-15S) that serve this purpose. A more complete characterization of this feature would be useful in refining the representation in the model. This characterization could be done by identifying locations for east-west transects of monitoring points similar to those identified earlier.

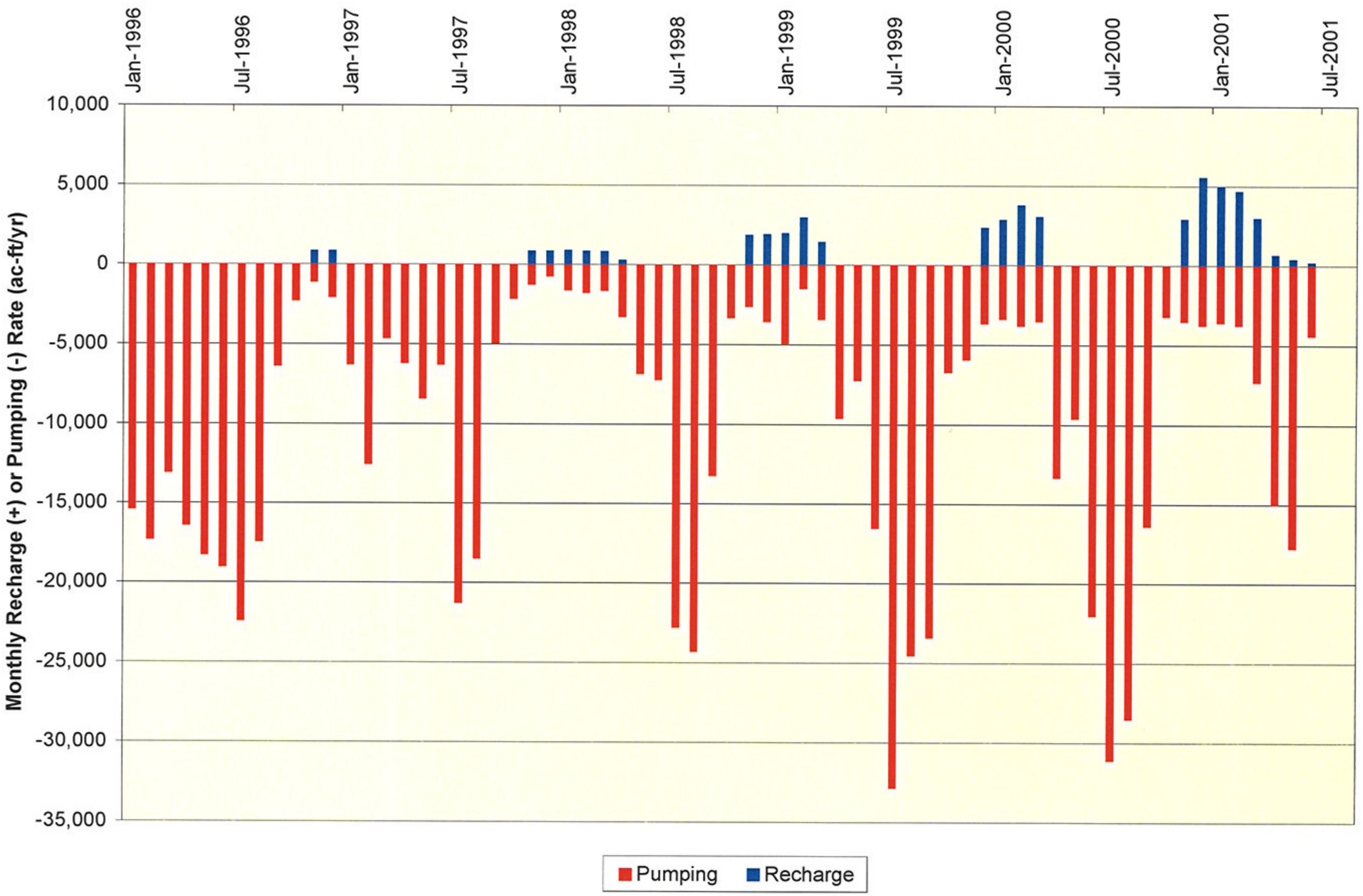
- Historical Pumping Rates: The data used to represent groundwater pumping in the model for the period 1961 to 1995 was taken from the MMA/Guyton model data files. This pumping was assigned on a yearly-average basis. There may be merit to determining, or constructing, a seasonal pattern to superimposed on the total yearly pumping. This additional information could be used in establishing a more complete long-term historical transient simulation to assess past flow and contaminant transport issues.

- Historical Water Levels: Monthly water levels were available for a large number of shallow monitoring wells starting in January 2000. However, a long-term record of water levels in the deeper aquifer does not exist. Continued monitoring of the existing monitoring wells (both shallow and deep) can be used to increase the robustness of the database characterizing groundwater flow in the CTM.



Representative_WLs.xls: Sample WLs
06/25/2002

Figure 5-1
Time History of Water Levels at 4 Representative Wells
Central Truckee Meadows Remediation District



pump_rch_th.xls: Chart-Montly TMWA
06/25/2002

Figure 5-2
Total Pumping and Recharge at TMWA Wells in Project Area
Central Truckee Meadows Remediation District

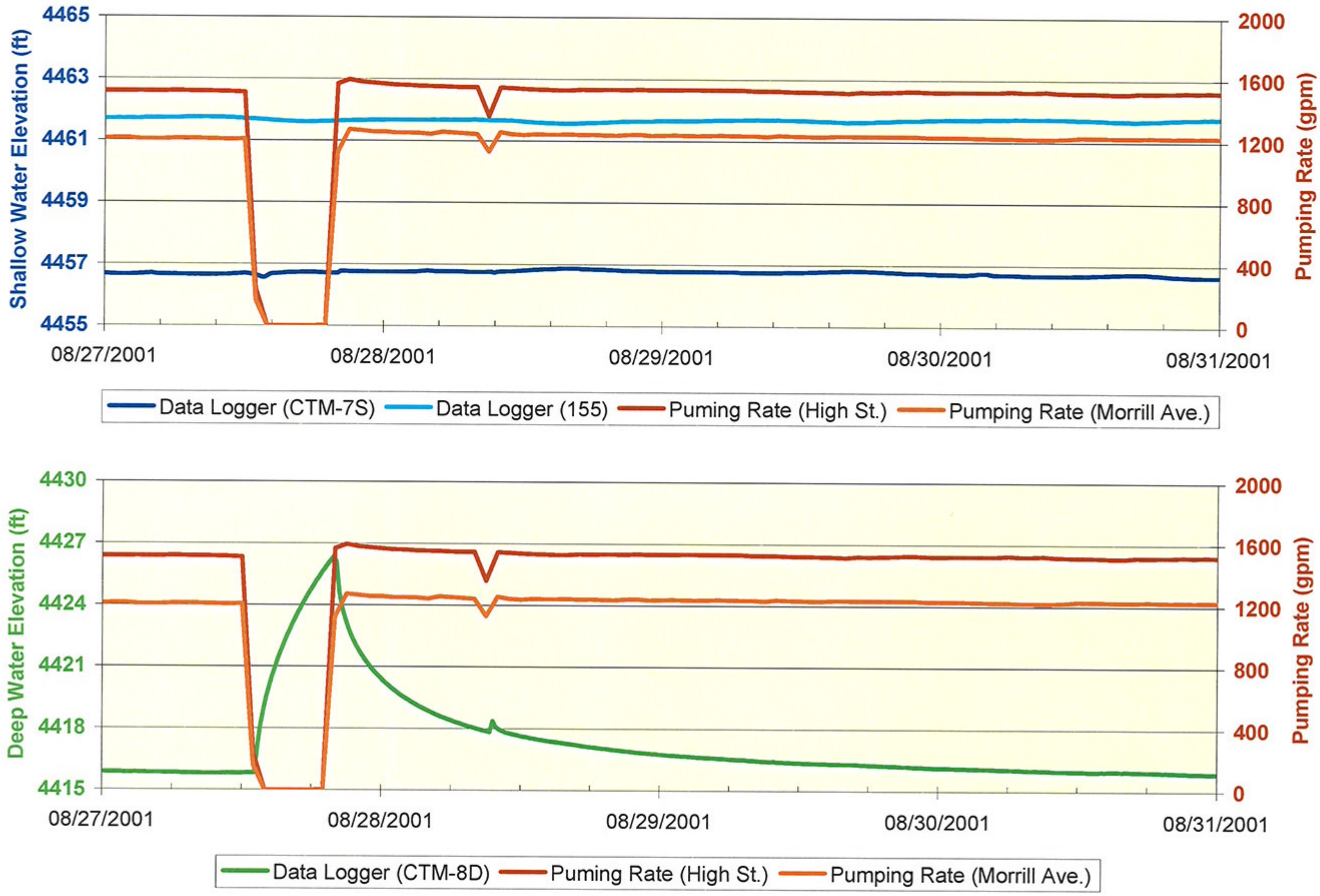
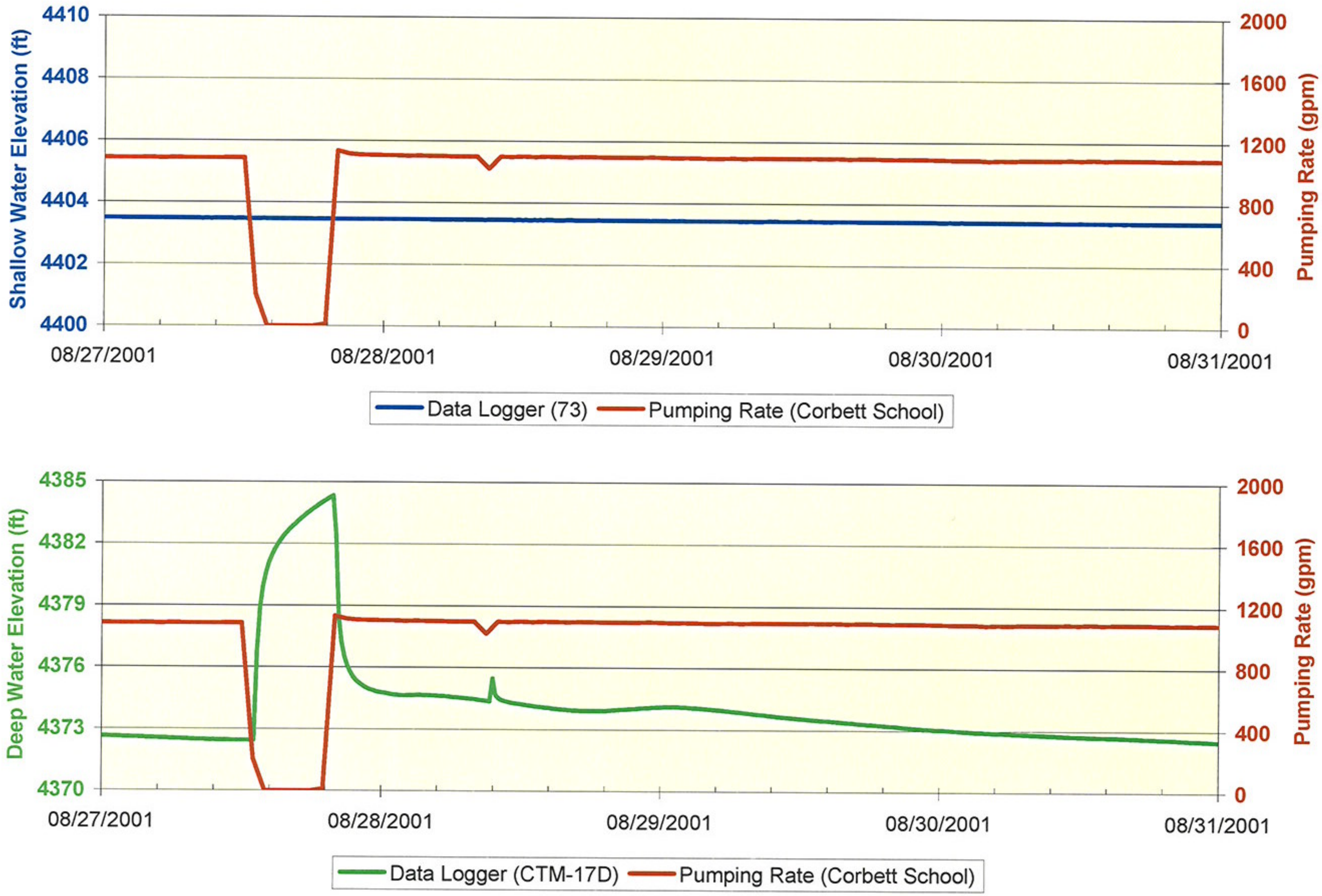


Figure 5-3
Time Period of Short-Term Transient Calibration
Data Logger Results Near High St. and Morrill Ave. Wells
Central Truckee Meadows Remediation District

Logger Results-Model TM.xls: High-Morrill-Test
06/25/2002

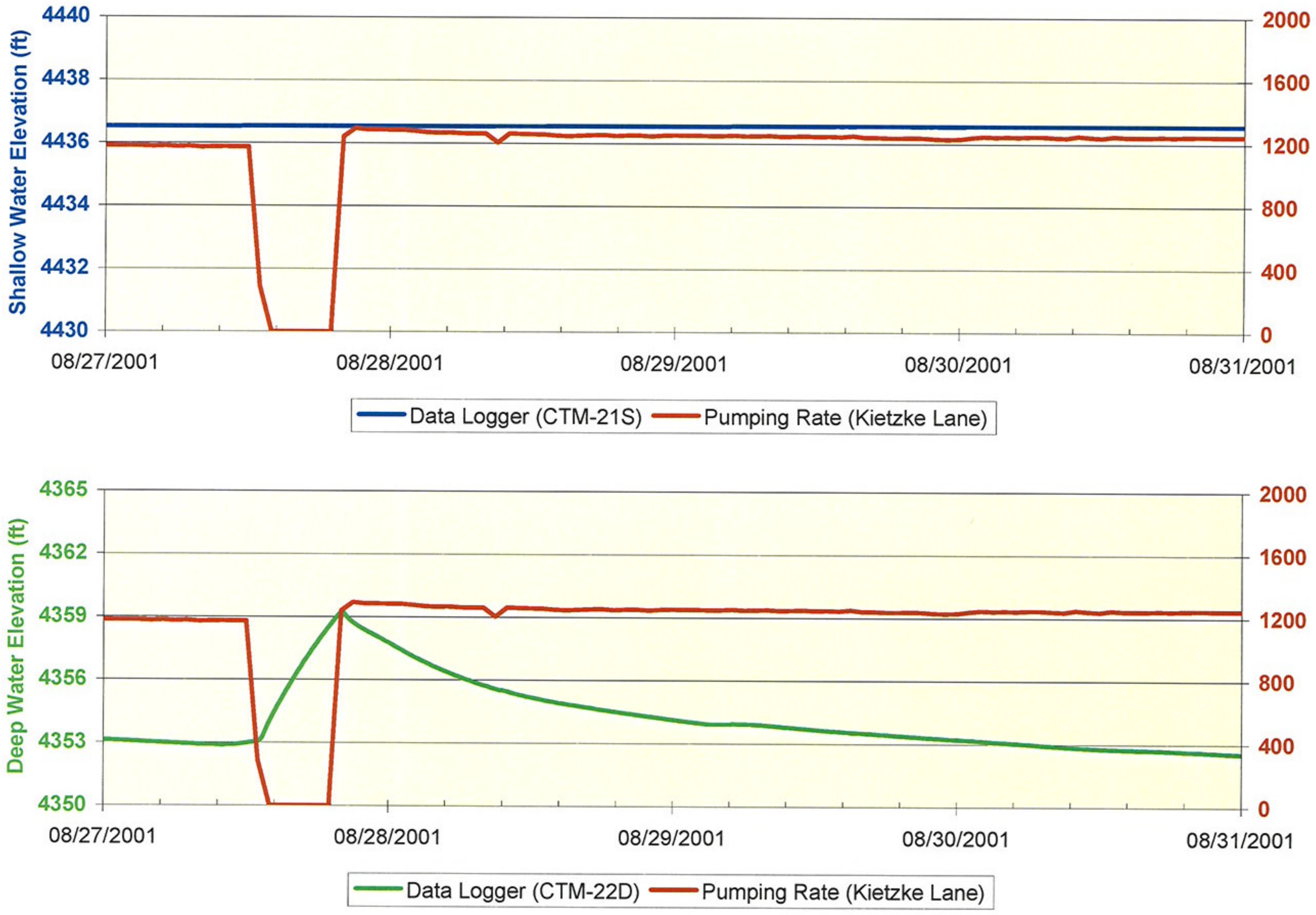
Logger Results-Model TM.xls: Mill-Test
06/25/2002

Figure 5-4
Time Period of Short-Term Transient Calibration
Data Logger Results Near Mill St. Well
Central Truckee Meadows Remediation District



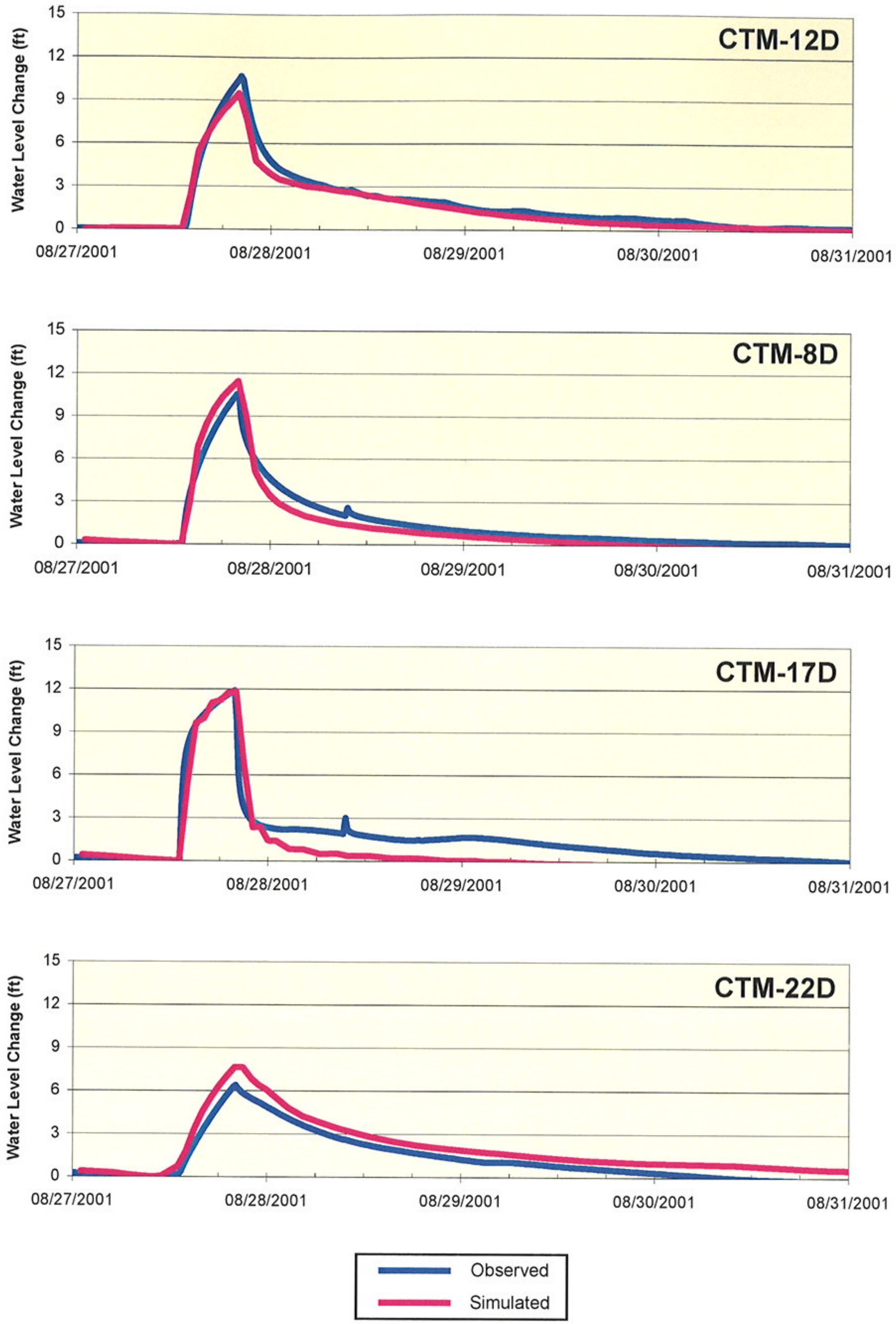
Logger Results-Model TM.xls: Corbett-Test
06/25/2002

Figure 5-5
Time Period of Short-Term Transient Calibration
Data Logger Record Near Corbett School Well
Central Truckee Meadows Remediation District



Logger Results-Model TM.xls: Kietzke-Test
06/25/2002

Figure 5-6
Time Period of Short-Term Transient Calibration
Data Logger Record Near Kietzke Lane Well
Central Truckee Meadows Remediation District



Datalogger Simulations - 5.xls: Results-4Panel
06/25/2002

Figure 5-7
Simulated Results for Short-Term Transient
Central Truckee Meadows Remediation District

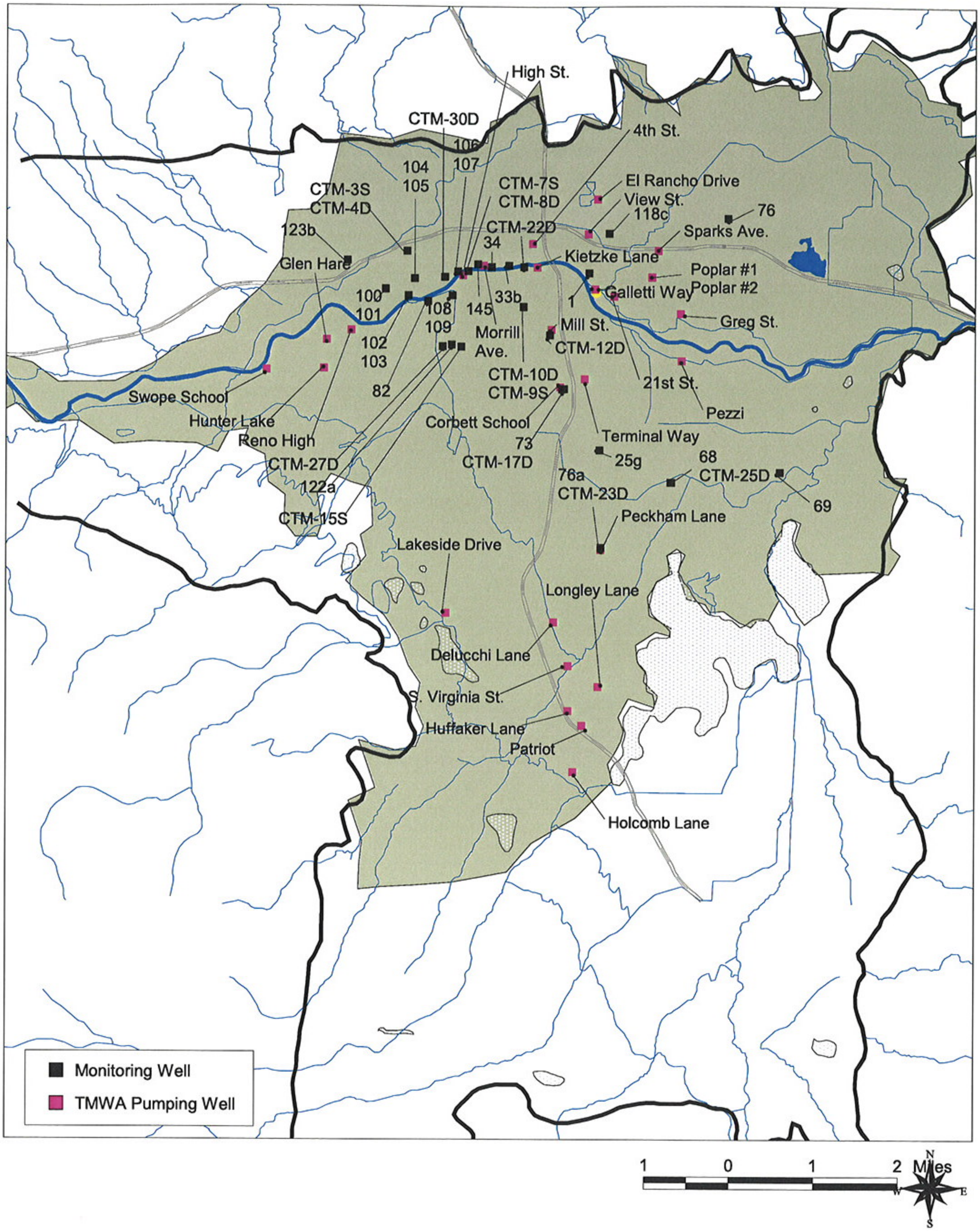


Figure 5-8
Location of Selected Calibration Wells and TMWA Wells
Central Truckee Meadows Remediation District

CDM

Figure 5-9 is located in a map pocket
at the end of the document.

1 0 1 2 Miles

N W E S

CDM

Figure 5-9
Calibration Results at Selected Monitoring Wells
Central Truckee Meadows Remediation District

\\ntsv3\files9\ctm\docs\GW Model TM\Figures\Example Calibration Graphs.ai

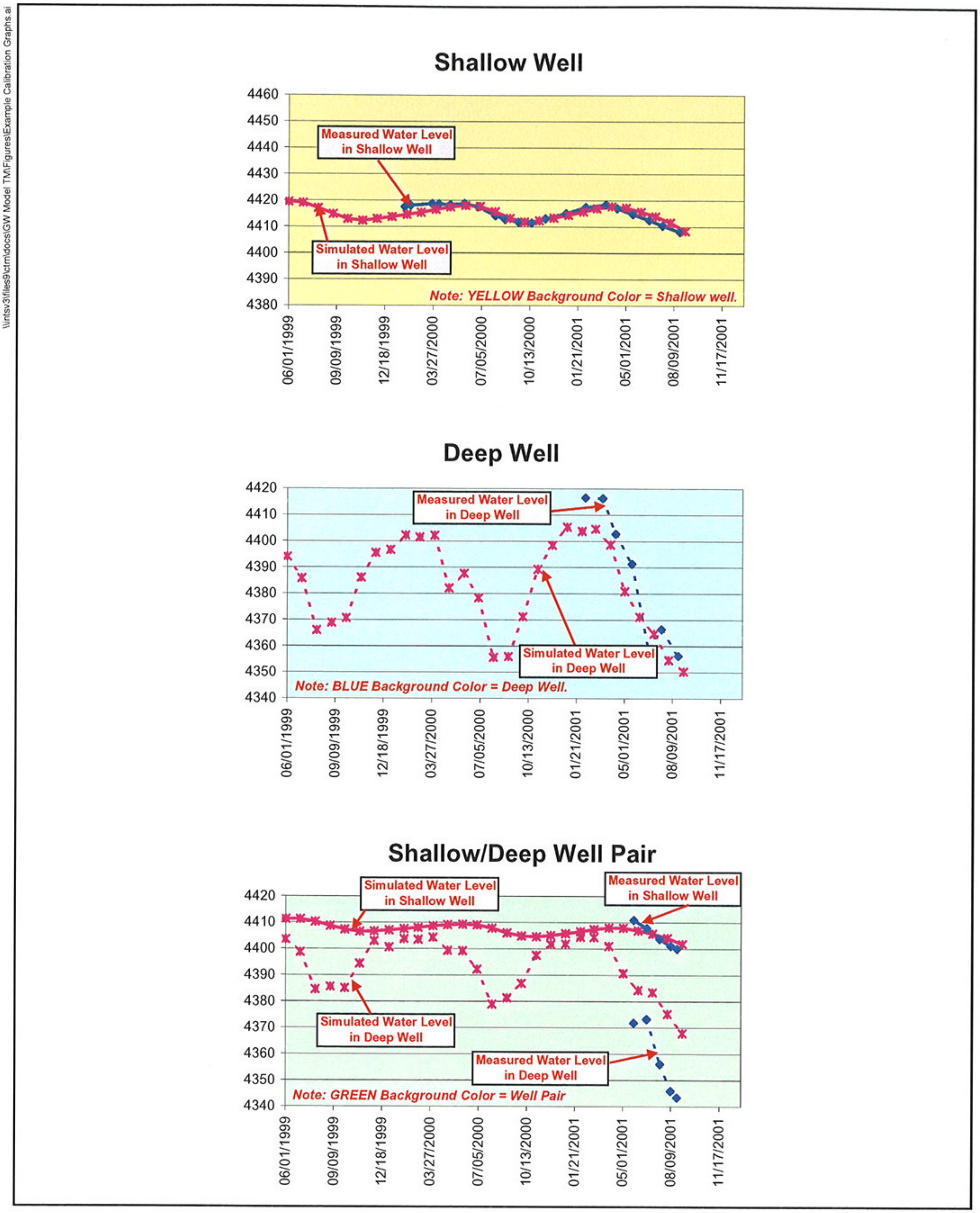


Figure 5-10
Example Calibration Graphs
Central Truckee Meadows Remediation District

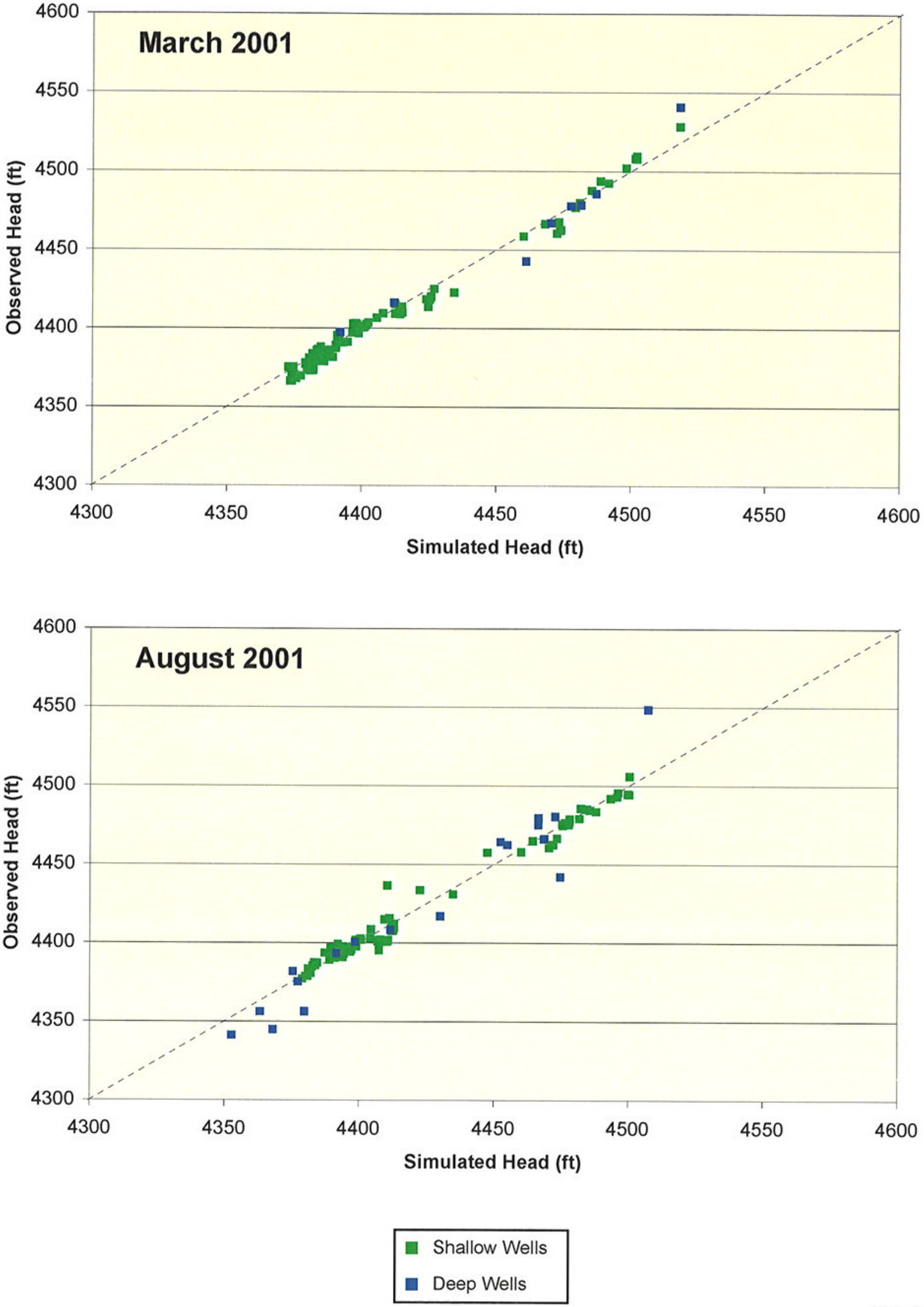
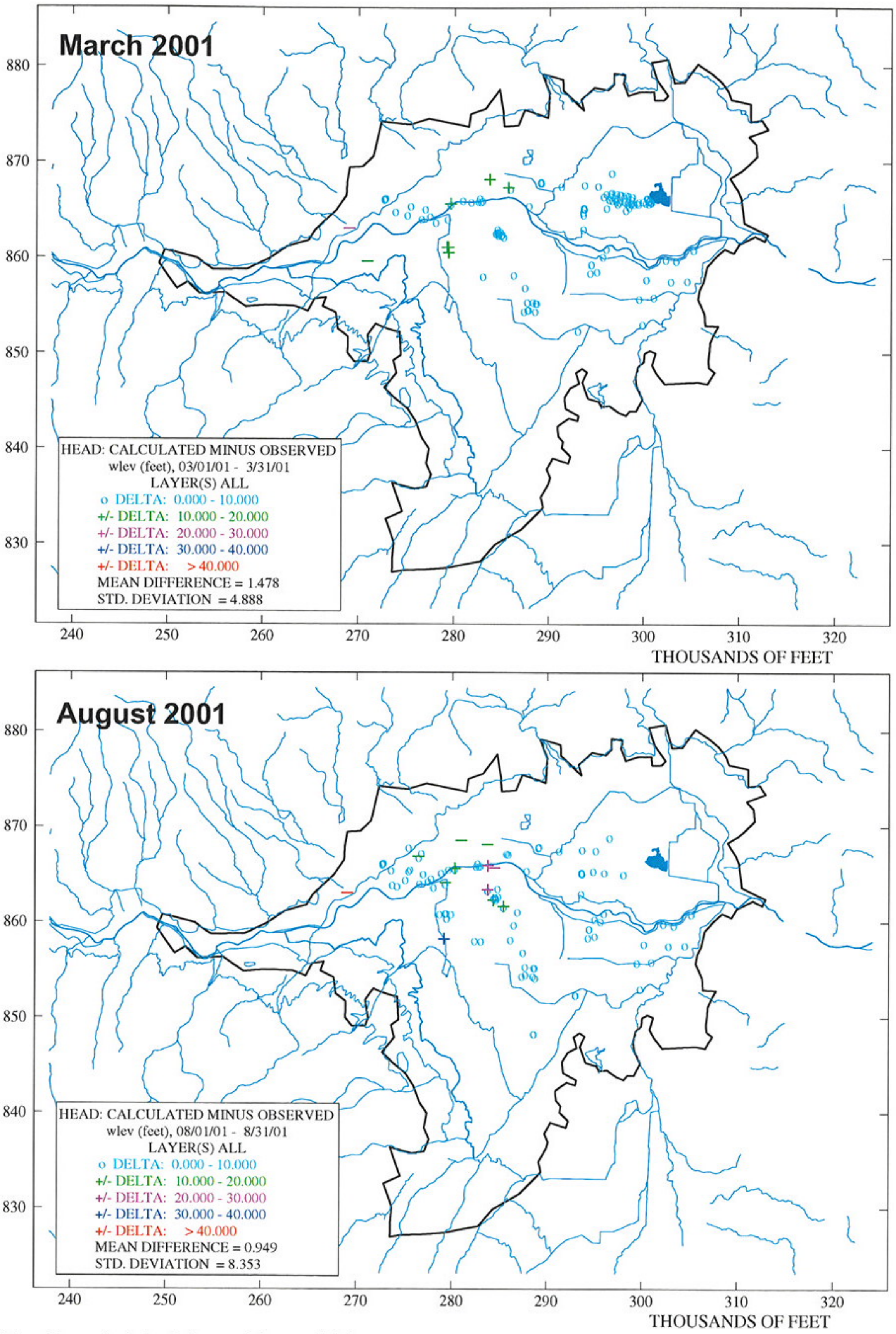


Figure 5-11
Comparison of Simulated and Observed Heads
Central Truckee Meadows Remediation District

trans61_hdck.xls: Obs_Sim Chart
06/25/2002



Notes: Figures include shallow and deep well data.

Figure 5-12
Model Calibration: Simulated Water Levels Minus Observed Water Levels
Central Truckee Meadows Remediation District

CDM

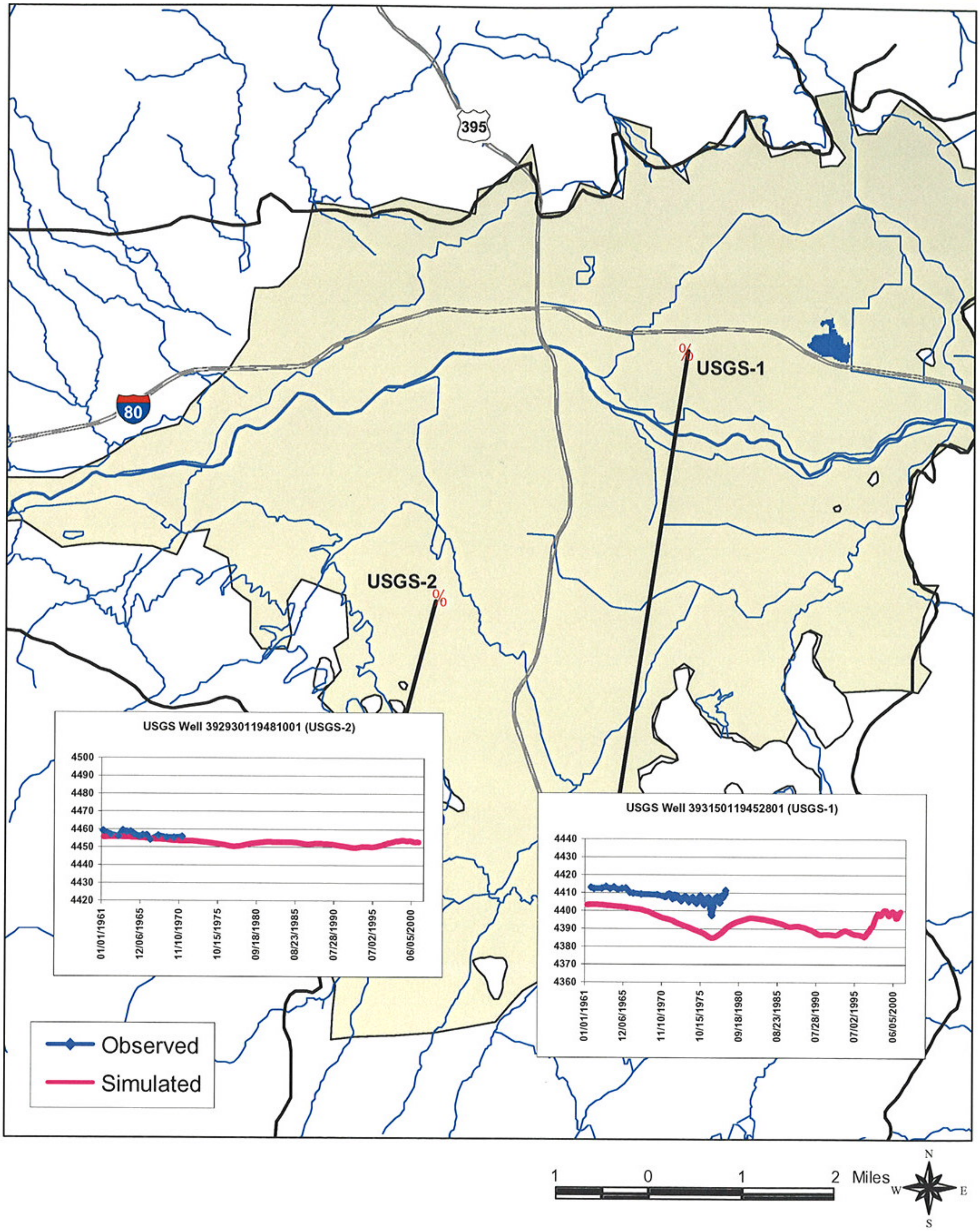
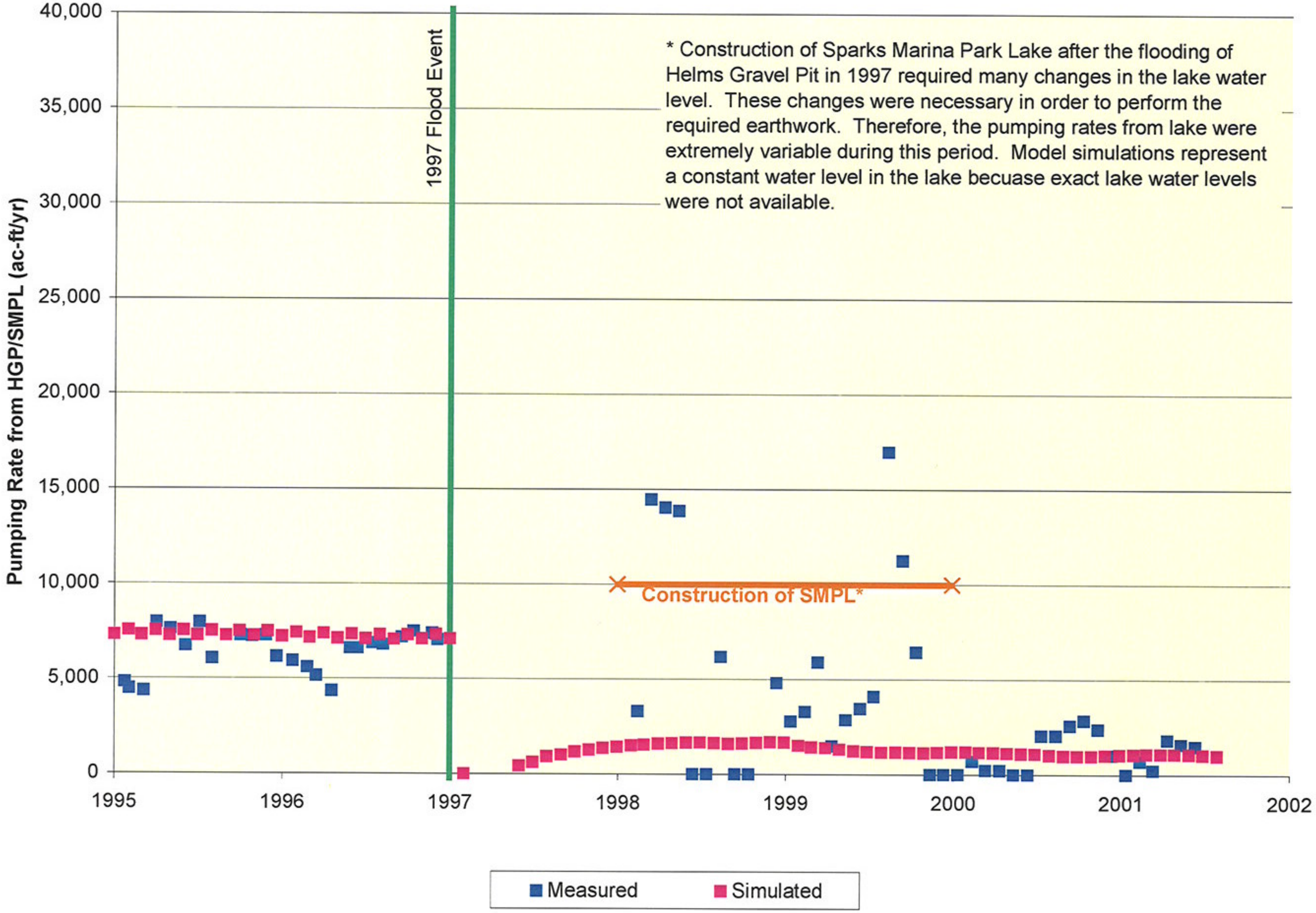


Figure 5-13
Model Calibration Results at USGS Wells
Central Truckee Meadows Remediation District

CDM

Figure 5-14 is located in a map pocket
at the end of the document.

Figure 5-14
Results of Historic Transient at Selected Monitoring Wells
Central Truckee Meadows Remediation District



* Construction of Sparks Marina Park Lake after the flooding of Helms Gravel Pit in 1997 required many changes in the lake water level. These changes were necessary in order to perform the required earthwork. Therefore, the pumping rates from lake were extremely variable during this period. Model simulations represent a constant water level in the lake becuase exact lake water levels were not available.

lt_trans19_check.xls: Chart-Helms Pit
06/25/2002

Figure 5-15
Comparision of Measured and Simulated Pumping Fluxes at HGP/SMPL
Central Truckee Meadows Remediation District

Section 6
Groundwater Flow Model Results and Analyses

This section presents a summary of the relevant flow modeling results developed through the process of flow model configuration and calibration. Section 7 will discuss the impact of simulated flow directions on the potential migration of contaminants within the groundwater system.

6.1 Groundwater Flow Direction

The direction of flow, both horizontally and vertically, within the CTM basin is a primary result of interest from the groundwater model. The model was used to simulate both current and historic flow directions.

6.1.1 Current Conditions

An analysis of current flow conditions is necessary to understand the dynamics of the flow regime within the CTM basin. Horizontal and vertical flow directions, as well as seasonal impacts, are discussed below.

6.1.1.1 Horizontal Flow Direction

The general flow direction through the center of the CTM is from west to east. The predominant groundwater discharge features in the basin are the TMWA pumping wells and the basin outlet at Vista Canyon in the east. The Truckee River primarily acts as a source of water to the shallow aquifer in the western half of the basin. Helms Gravel Pit/Sparks Marina Park Lake (HGP/SMPL) also influences groundwater flow direction by serving as a discharge location for groundwater.

Figure 6-1 shows contours of the simulated water table elevation at a 20 ft interval. This figure shows the simulated water table at the end of March and August 2001. Note that the flow directions in the shallow aquifer do not vary greatly between the two seasons. There is a reduction is water levels during the summer, but the general flow directions are quite similar. Figure 6-1 also indicates the influence of SMPL on the shallow groundwater flow system. The water level at SMPL was maintained at approximately 4,375 feet since the completion of SMPL in late 1999.

Figure 6-2 shows contours (20 ft interval) for the simulated heads in the deeper aquifer, approximately 150 ft below ground surface. This figure shows the simulated results for March and August 2001. Again, the predominant flow direction through the center of the basin in west to east. However, TMWA pumping exerts sufficient influence during the summer months to significantly alter the horizontal flow directions. The summer pumping regime also sets up higher horizontal gradients.

6.1.1.2 Vertical Flow Direction

The information in Figures 6-1 and 6-2 can also be used to draw conclusions about the vertical direction of groundwater flow.

The vertical direction of groundwater flow can be visualized basin-wide. Figure 6-3 shows the differences between the elevation of the water table and the heads at the base of the shallow aquifer. This figure indicates a combination of areas showing an upward direction and areas showing a downward direction. However, the majority downtown Reno shows a downward direction. The area near the SMPL/HGP shows an upward flow direction as a result of the local pump-and-treat remediation system in place there. This figure also shows the impact of seasonal fluctuation is water levels in the deeper aquifer. The summer pumping regime results in a more substantial area with downward flow directions that can cause recharge to the deeper aquifer. Figure 6-4 shows the difference between the elevation of the simulated water table and heads in the deeper aquifer. Figure 6-4 indicates that the potential for downward flow to the deeper aquifer exists during both March and August 2001 in the Reno area. The area of potential downward flow expands to cover most of the model area during the summer flow regime.

Simulated model results can be viewed in cross-section. Figure 6-5 shows the simulated heads on an east-west cross section CC through the model. This figure, again, shows the simulated results for March and August 2001. This cross section passes through the 10 TMWA wells. The significant impacts of the TMWA wells can be seen during the summer pumping condition. The summer conditions sets up a condition allowing more downward flow than the winter conditions. Figure 6-6 shows the same information for north-south cross section DD. Both of these figures indicate that primary change in flow directions occurs in the center of the CTM near the main TMWA wells.

6.1.1.3 Seasonal Impacts

TMWA pumping is a major stress on groundwater levels in the CTM basin. As shown previously in Figures 5-1 and 5-2, the TMWA pumping rates vary seasonally, with the highest rates pumped during the summer. Winter months see low (or zero) pumping rates from some wells and reinjection at other wells.

Principally, increased summer pumping rates cause a significant drop in water levels in the deeper aquifer. This drop is most prominent in the center of the CTM basin, near a number TMWA pumping wells (see Figures 6-5 and 6-6). As evident in the contours of simulated heads, the flow directions in some portions of the basin change between the winter and summer periods.

Figure 6-7 shows simulated flow directions in the deeper aquifer during March 2001 and August 2001. The velocity vectors in this figure represent the simulated direction of groundwater flow during March and August 2001. This figure indicates that the direction of flow within the deeper aquifer can vary due to the influence of TMWA pumping. These results indicate that the area contributes to one of the TMWA pumping wells differ between the summer and winter months. Therefore, the full area that is tributary to a TMWA well would need to include areas that are upgradient of the well in either the summer or winter months.

6.1.2 Historic Conditions

In order to understand the historic behavior of the aquifer system, snap shots of the flow field were take every five years during the historic transient simulation discussed in Section 5.4. Figures 6-8 through 6-15 present simulated shallow and deep water level contours every five years starting in December 1965. One of the more significant features that can be seen in these figures is the impact of dewatering at gravel pits. Dewatering operations during the construction and operation of HGP caused a significant drop in water levels in the vicinity of HGP (approximately 1967 – 1997). Likewise, the flood of 1997 caused water levels in the area to rise significantly as shown in the lower gradients around HGP between 1995 and 2000.

The frequency of changes in input data should be noted when reviewing these figures. As discussed in Section 4, TMWA pumping was varied annually from 1961 – 1995. Starting in 1996, TMWA pumping was varied monthly. Therefore, seasonal effects are not captured during the simulation years 1961-1995. Instead, during this period, the simulation represents annual average conditions.

6.2 TMWA Well Capture Zones

The impact of TMWA pumping on the overall (advective) groundwater flow directions and the capture zones for the TMWA wells are of particular interest within the CTM basin. Five TMWA wells are currently fitted with facilities to treat PCE contamination in the pumped water (i.e. wellhead treatment). These wells are: High St., Morrill Ave., Kietzke Lane, Mill St., and Corbett School. Pumping at these wells is maintained at prescribed rates based on a pumping plan set up by Sierra Pacific Power Company (now operated by TMWA) (SPPCo 2000).

To better understand the flow system and its relationship to TMWA pumping, capture zone simulations were made for the five TMWA wells with wellhead treatment. Capture zones depict the areas that are tributary to a groundwater discharge point (e.g. a pumping well). A capture zone is simulated by placing a grid of computational particles over a specified area. The particles are then tracked along the average advective flow path through the simulated flow field the duration of the simulation. The starting locations for particles that were extracted a groundwater discharge points are recorded and can be shown on a figure.

Figure 6-16 shows the simulated capture zones for these five TMWA wells. To assess the vertical extent of the capture zone, simulations were run for three different depths in the aquifer. Capture zone were run for the simulated water table, the bottom of the shallow aquifer (approx. 100 ft below ground), and for the deep aquifer (approx. 200-250 ft below ground).

The capture zones were simulated to represent long-term flow paths (e.g. an "eventual" flow path). In order to generate these capture zones the flow field from the simulations discussed in Section 5 was used. The simulated flow field from August 1999 to August 2001 was repeated through the length of the transport simulation. Therefore, the simulated flow field used in these simulations accounts for seasonal variations in TMWA pumping, but at 1999-2001 levels.

These simulations indicate that the majority of the downtown area west of I-395 and between the Truckee River and I-80 is tributary to the High Street, Morrill Avenue, and Kietzke Lane wells. Therefore, these wells would likely receive the majority of the contamination emanating from those known and unknown sources in these areas. The Mill Street and Corbett School wells appear to produce water that is tributary from the South Virginia Street area. It should be noted that the TMWA wells also draw water up from below the wells screens (i.e. not all the water pumped from the TMWA wells has passed downward to get to the well screen).

Figure 6-17 shows the same capture zones as shown in Figures 6-16 with color-coding to indicate travel time. These figures present the 10, 20, 30, and 40-year capture zones for the TMWA wells. For these simulations, an effective porosity of 0.15 and a retardation factor of 1 were used. These values are the same as used in CDM's work at the Sparks Solvent/Fuel Site.

Figure 6-17 indicates that it takes less than 10 years for particles started at the water table to reach the High Street, Morrill Avenue, Kietzke Lane, and Corbett School wells. At the bottom of the shallow aquifer, travel time to the TMWA is quicker because these wells are screened the deeper aquifer.

6.3 Water Balance

Figure 6-18 presents the simulated water inflows and outflows for the entire historical transient simulation. This figure indicates the following:

- TMWA Pumping: On average, TMWA pumping has remained fairly constant.
- Recharge: Surface recharge has declined with time. This decline is primarily to due to the decline in recharge from agricultural operations. Areal recharge from precipitation was simulated as constant during this period.
- Mountain Front Recharge: The application of MFR to the model is directly proportional to rainfall in the area. The applied MFR rates value greatly, from approximately 4,000 ac-ft/yr to almost 19,000 ac-ft/yr.

- Evapotranspiration: The rate of ET generally decreased throughout the majority of the simulation. Figure 6-19 shows the areas where ET has been "invoked" during 1965 and 1995. ET is "invoked" because the simulated water table comes within 10 feet (the extinction depth) of the ground surface. In general, the water table is lower in 1995. This lower water table results in lower ET rates and smaller ET areas. This change in water table elevation is due, in part, to higher pumping rates and reduced recharge from agricultural irrigation in 1995 compared to 1965.

Table 6-1 shows a comparison of estimated and simulated inflows and outflows. The estimated values consist of data from references and data from the previous MMA/Guyton model.

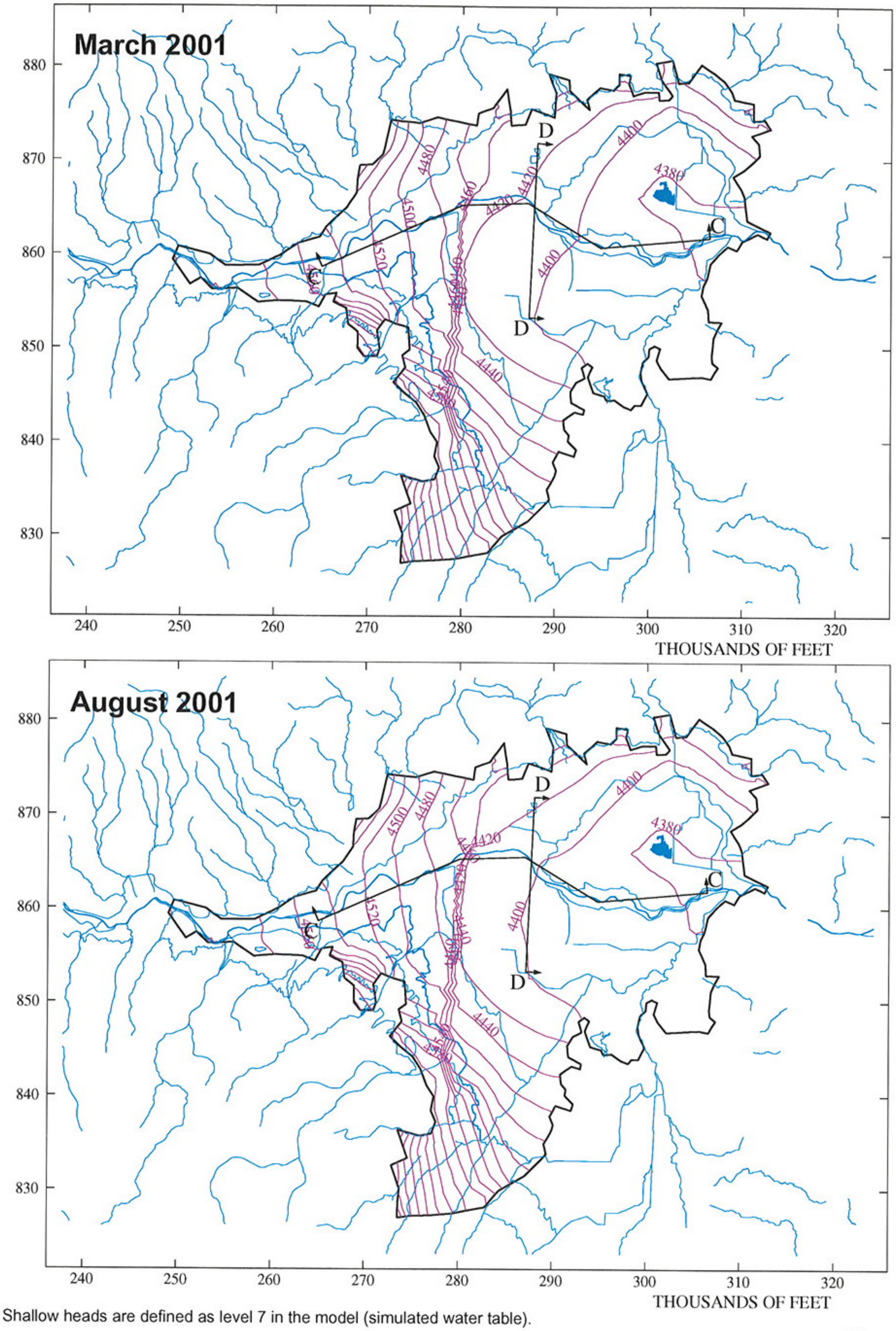
Table 6-1
Comparison of Basin Inflows and Outflows

Inflows	***Estimated Value/Range(1)***	***CTMRD Value/Range***
Mountain Front Recharge (MFR) / Canal Leakage	10,000-15,000 *(LGB/Guyton, 1993);* 13,000 afy** *(MMA 1993)*	4,000-19,000 afy *(MFR only)*
Truckee River Leakage	4,000 afy *(Cohen and Loeltz 1964)*	2,200-4,200 afy
River/Stream/Ditch Leakage(2)	6,000 afy (irrig. ditches), 1,000 afy (other streams) *(Cohen and Loeltz 1964, MMA 1993);*	4,300-10,500 afy
Excess Agricultural Irrigation Recharge	7,000-20,000 afy *(MMA 1993)*	7,000-20,000 afy *(MMA values used)*
Water System Leakage	2,500-4,400 afy *(MMA 1993)*	2,500-4,400 afy *(MMA values used)*
Infiltration from Precipitation	2,000 afy *(MMA 1993)*	1,500 afy
Outflows	***Estimated Value/Range(1)***	***CTMRD Value/Range***
Municipal/Industrial Pumping	6,000-19,000 afy *(MMA 1993)*	6,000-19,000 afy
Domestic Pumping	390-1,060 afy *(MMA 1993)*	390-1,060 afy *(MMA values used)*
Evapotranspiration	8,000-15,000 afy *(MMA 1993)*	3,300-21,000 afy
Helms Gravel Pit(3)	4,400 afy (prior to flood) *(MMA 1993)*	7,800 afy (prior to flood) 1,200 afy (after flood)

Units: afy = acre-feet per year
(1) Note that these estimates are for both Central and South Truckee Meadows
(2) Excluding Truckee River
(3) Not including construction period

Figure 6-20 shows the simulated groundwater inflows and outflows to/from surface water streams and ditches. This figure indicates the relative influence on the groundwater budget from each of these features. Note that the Orr Ditch line indicates a large addition of water to the groundwater system. This large inflow is related to the combined representation of Orr Ditch and MFR (refer to section 4.2.6.3). Essentially, any exfiltration from Orr Ditch to the groundwater and inflow of MFR are combined and represented as a flux from the ditch.

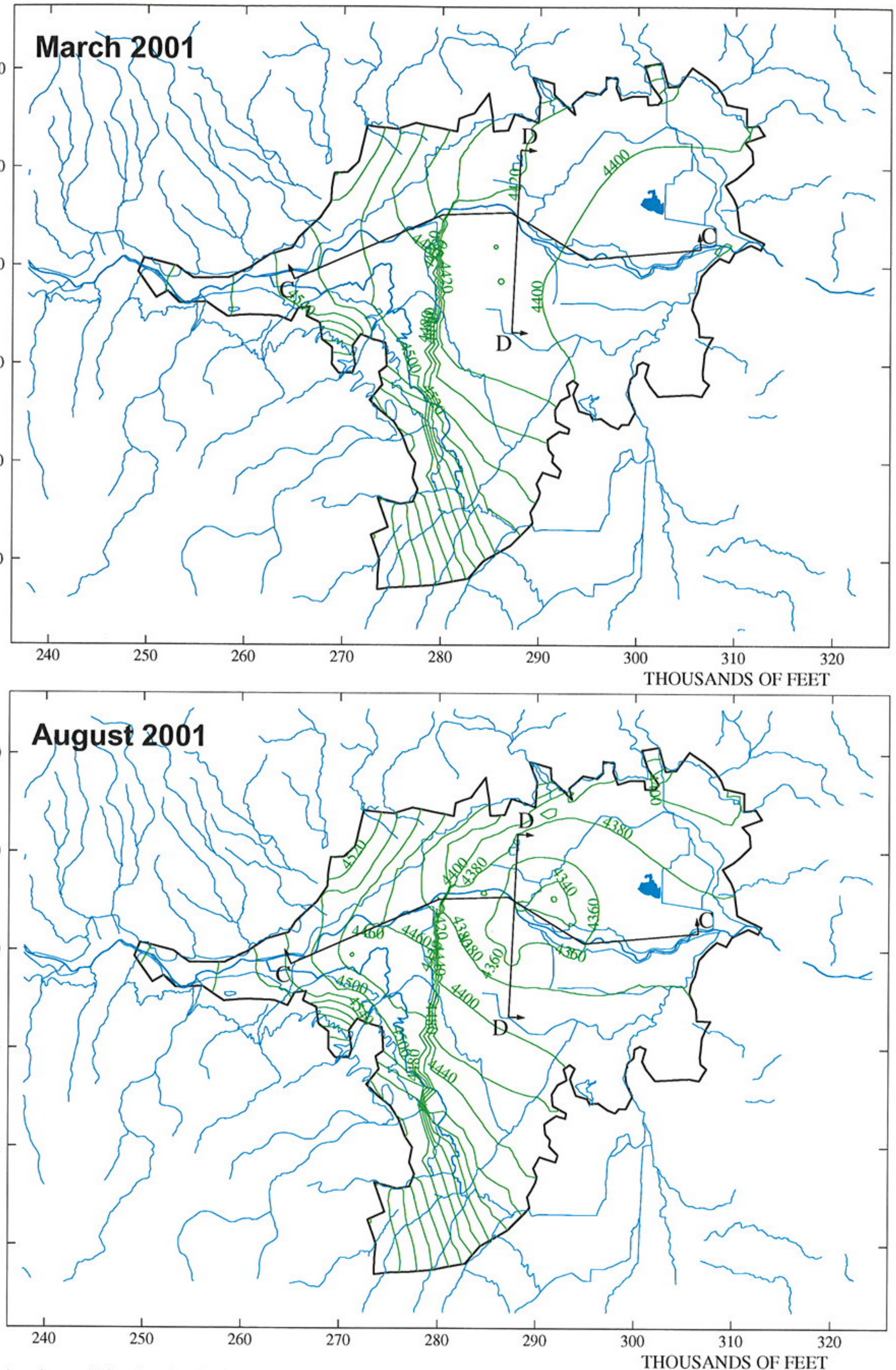
While the river node boundary condition allows for calculation of stream flows within reaches of the surface water features, this functionality was not used for the CTMRD model during this work. Flow rates were not available for the many ditches and streams in the model area. Figure 6-20 was used to verify that the general trends seen in simulated river inflows/outflows appeared reasonable. As discussed earlier, Orr Ditch appears to have the greatest inflow to the groundwater system. This high rate is due to the combination of Orr Ditch exfiltration and MFR where Orr Ditch runs along the northern model boundary. Except for Orr Ditch/MFR inflow, the Truckee River provides the largest simulated input of surface water to the groundwater system, as expected. This result agrees with the fact that the Truckee River is the largest surface water feature in the area. The North Truckee Drain also represents a relatively large single inflow of surface water to the groundwater. Some of this inflow may be induced by the dewatering operations that occurred at Helms Gravel Pit prior to the 1997 flood. After the flood, the higher water table elevation causes groundwater to discharge to the North Truckee Drain. Note that all the streams and ditches underwent changes in inflow/outflow rates after the 1997 flood. In general, the flood resulted in less inflow to the groundwater from surface water.



Note: Shallow heads are defined as level 7 in the model (simulated water table).

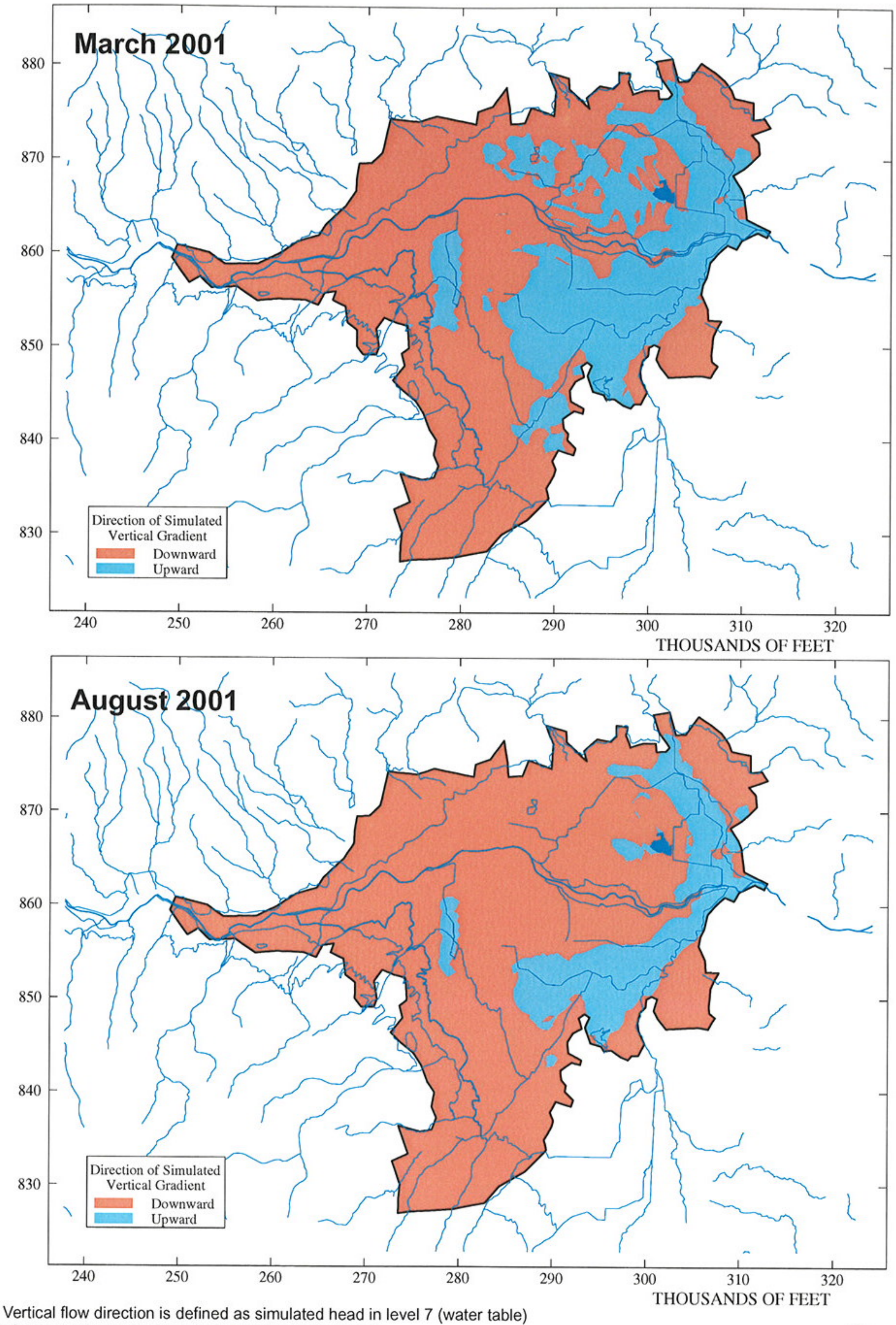
Figure 6-1
Simulated Water Level in Shallow Aquifer
Central Truckee Meadows Remediation District

CDM



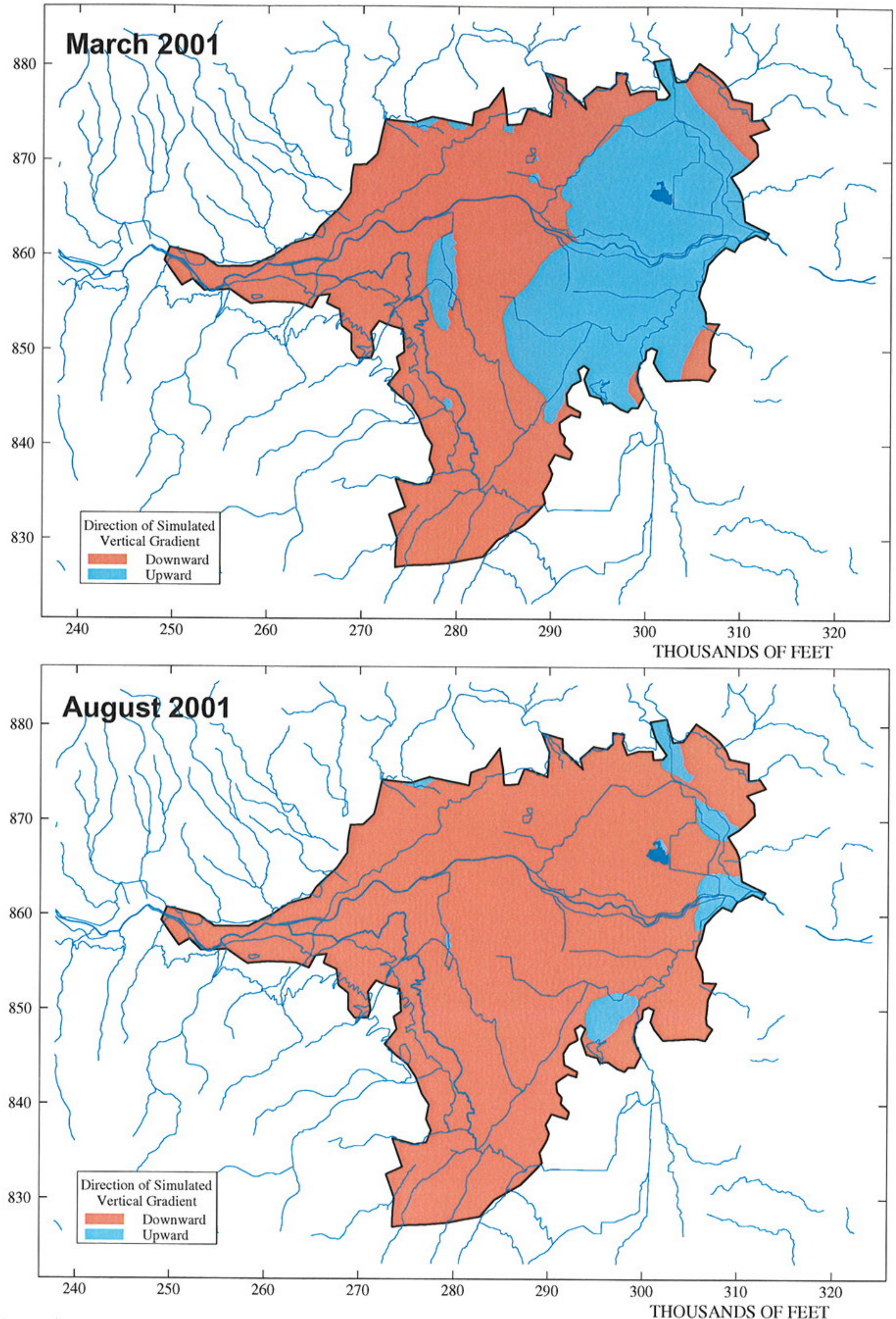
Note: Deep heads are defined as level 4 in the model (approx. 200-250 ft bgs).

Figure 6-2
Simulated Water Level in Deep Aquifer
Central Truckee Meadows Remediation District



Note: Vertical flow direction is defined as simulated head in level 7 (water table) minus simulated head in level 6 (bottom of shallow aquifer).

Figure 6-3
Direction of Simulated Vertical Flow within Shallow Aquifer
Central Truckee Meadows Remediation District



Note: Vertical flow direction is defined as simulated head in level 7 (water table) minus simulated head in level 4 (deep aquifer).

Figure 6-4
Direction of Simulated Vertical Flow Between Water Table and Deep Aquifer
Central Truckee Meadows Remediation District

CDM

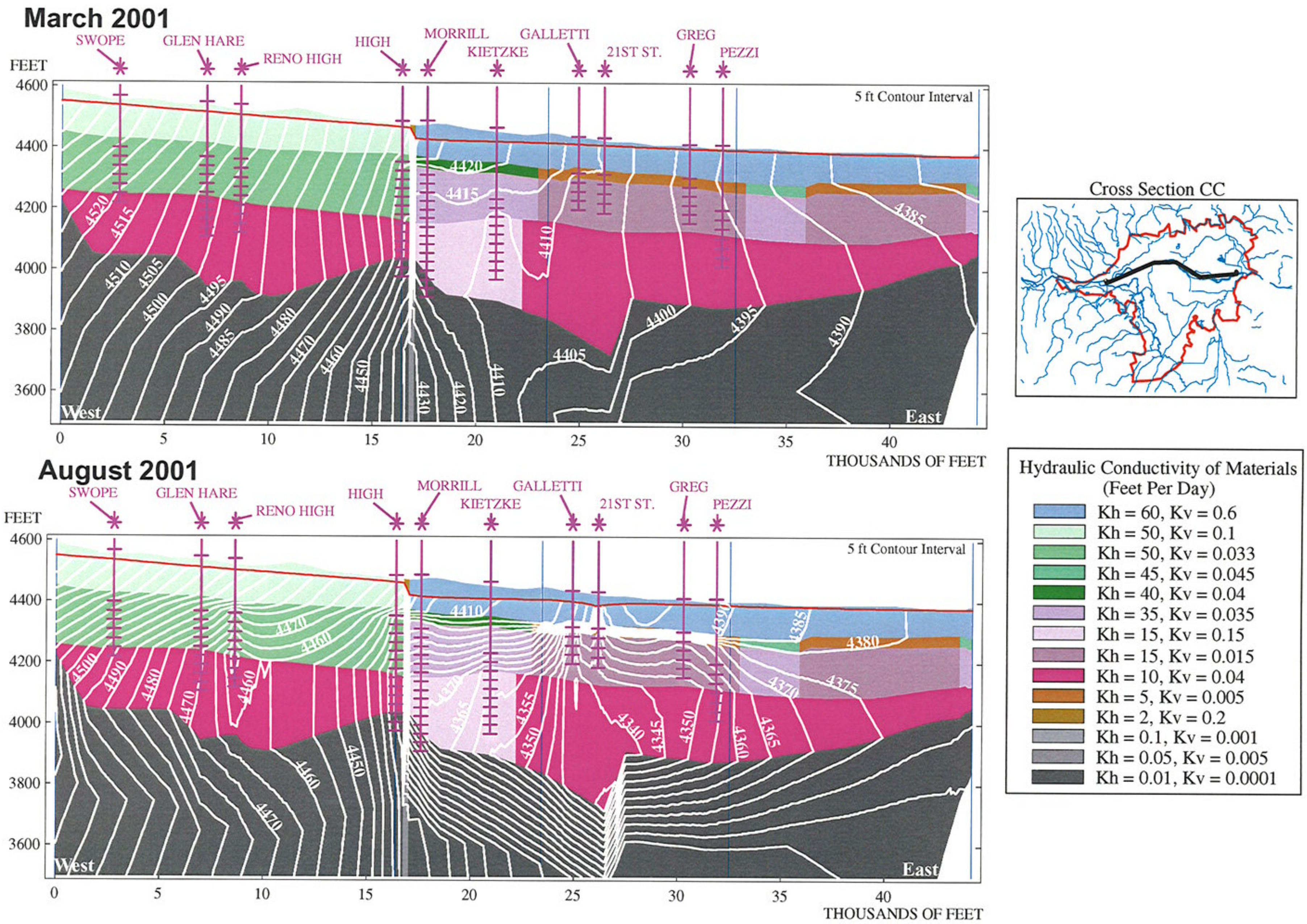


Figure 6-5
Simulated Water Level in East-West Cross Section CC
Central Truckee Meadows Remediation District

CDM

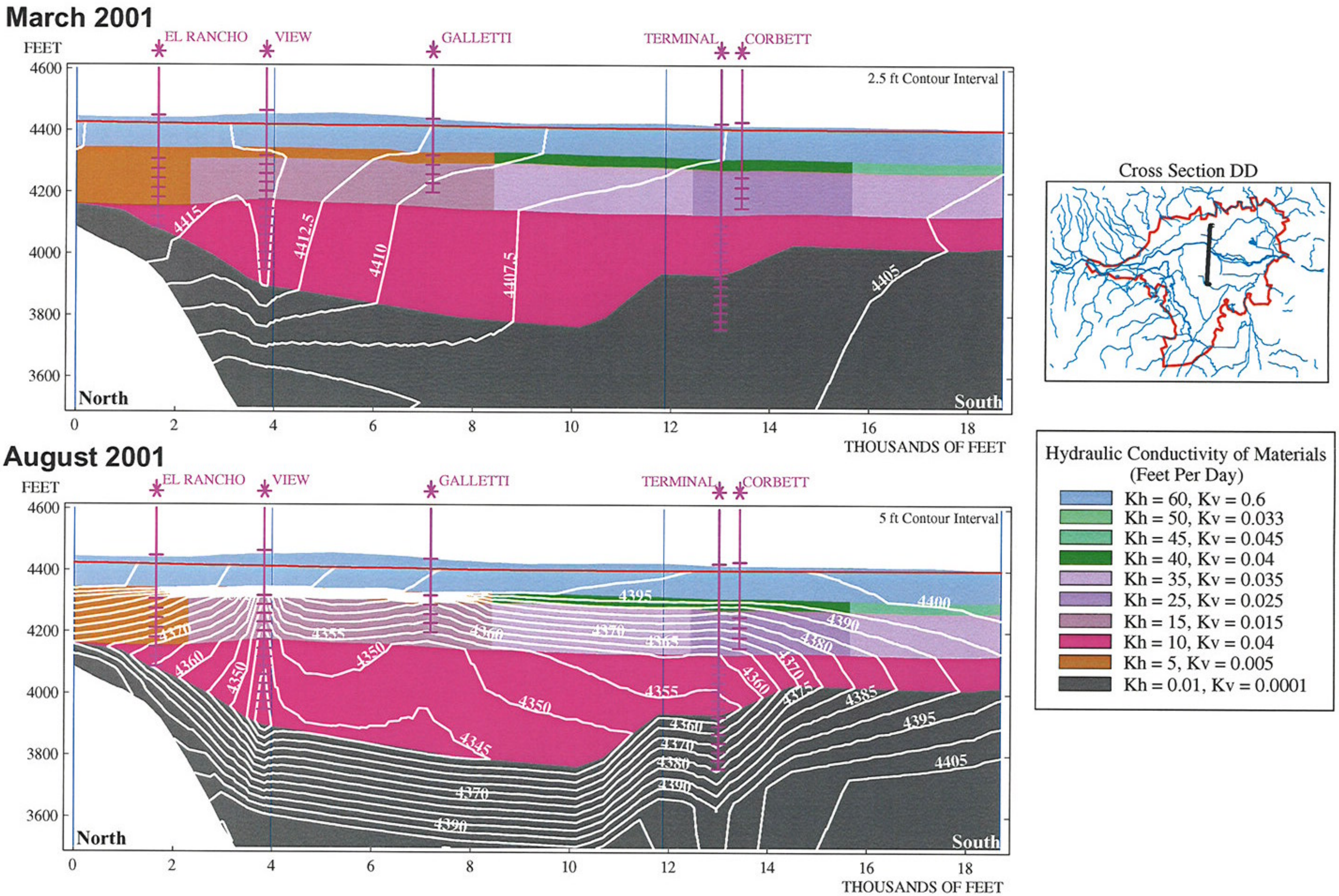
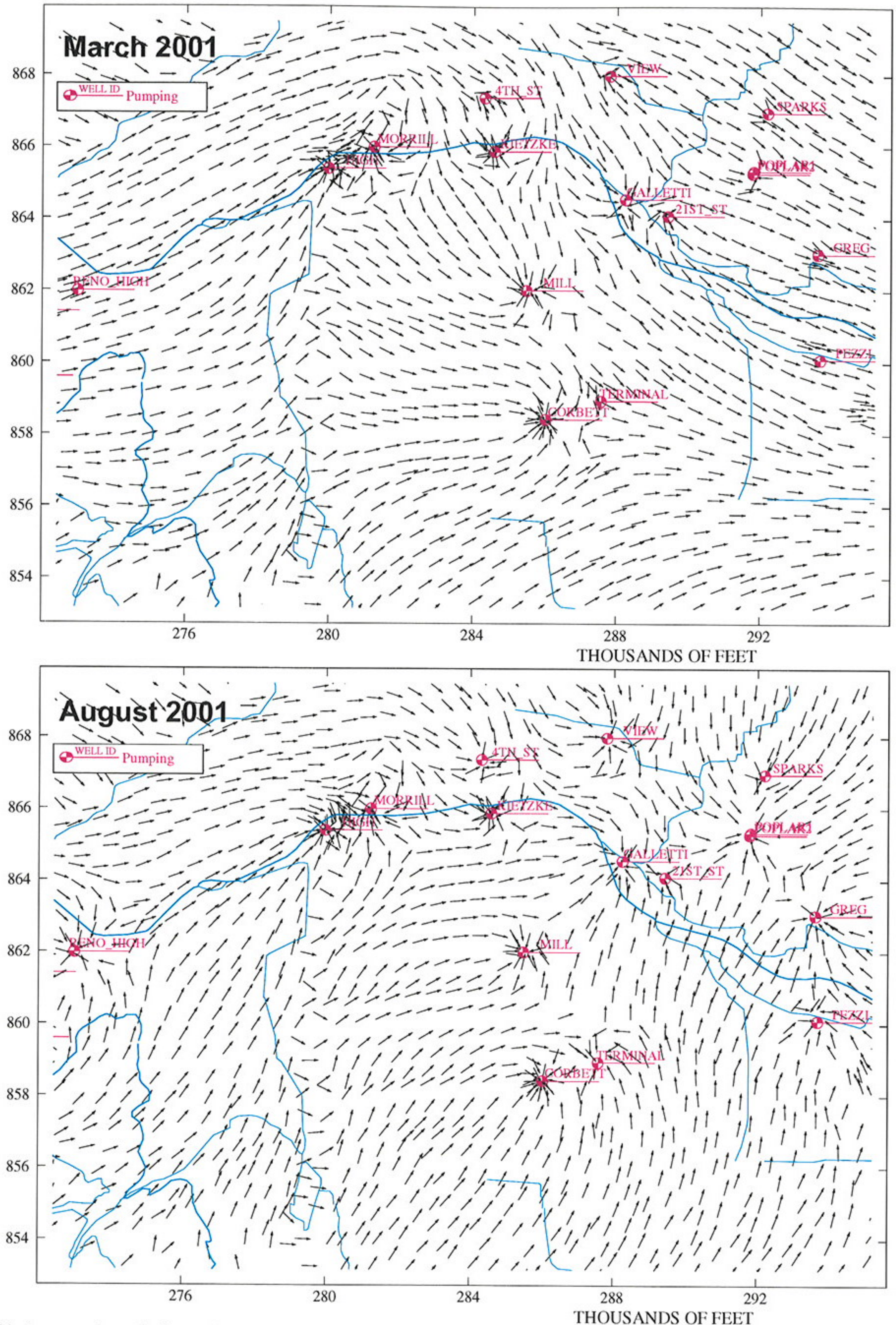
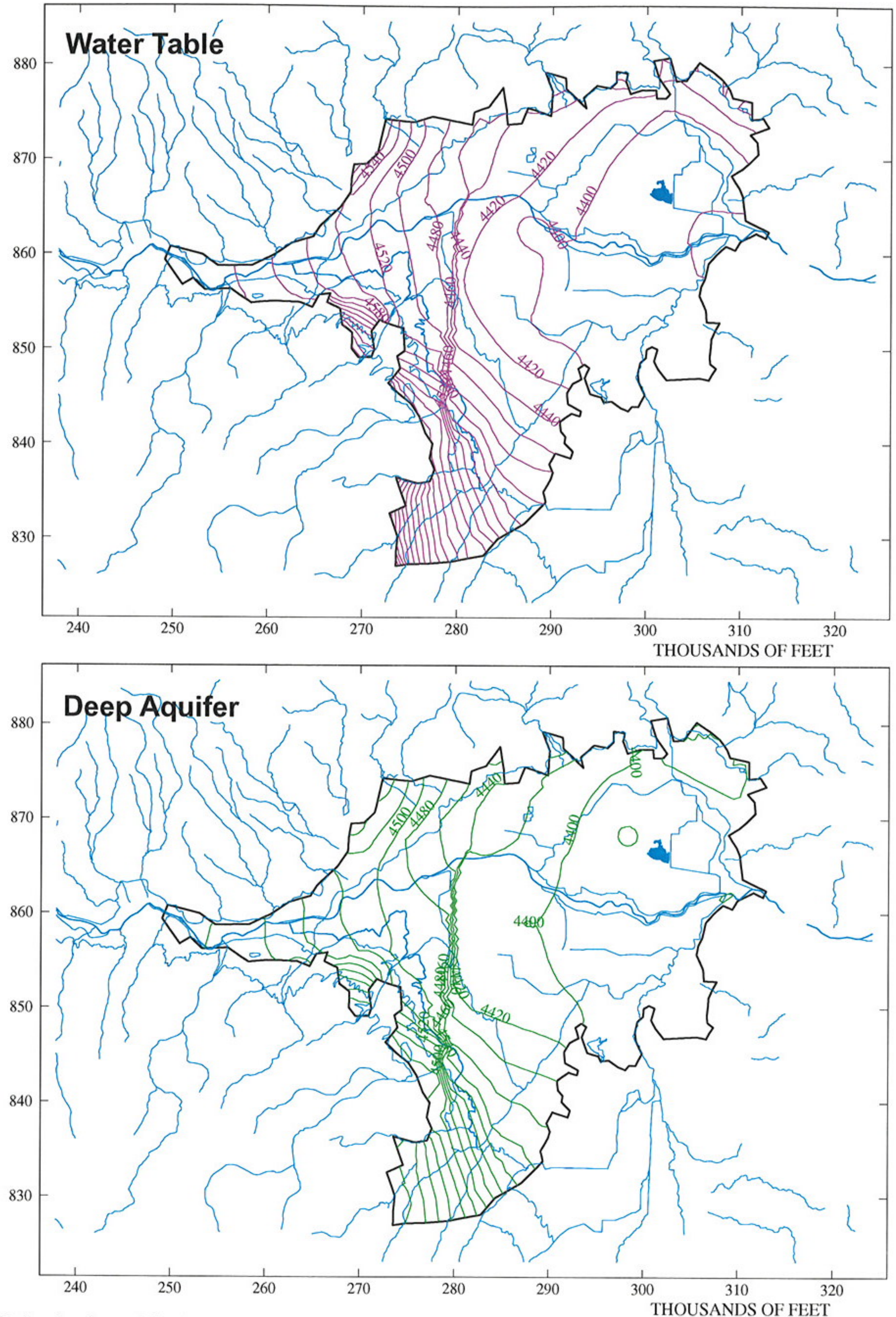


Figure 6-6
Simulated Water Level in North-South Cross Section DD
Central Truckee Meadows Remediation District



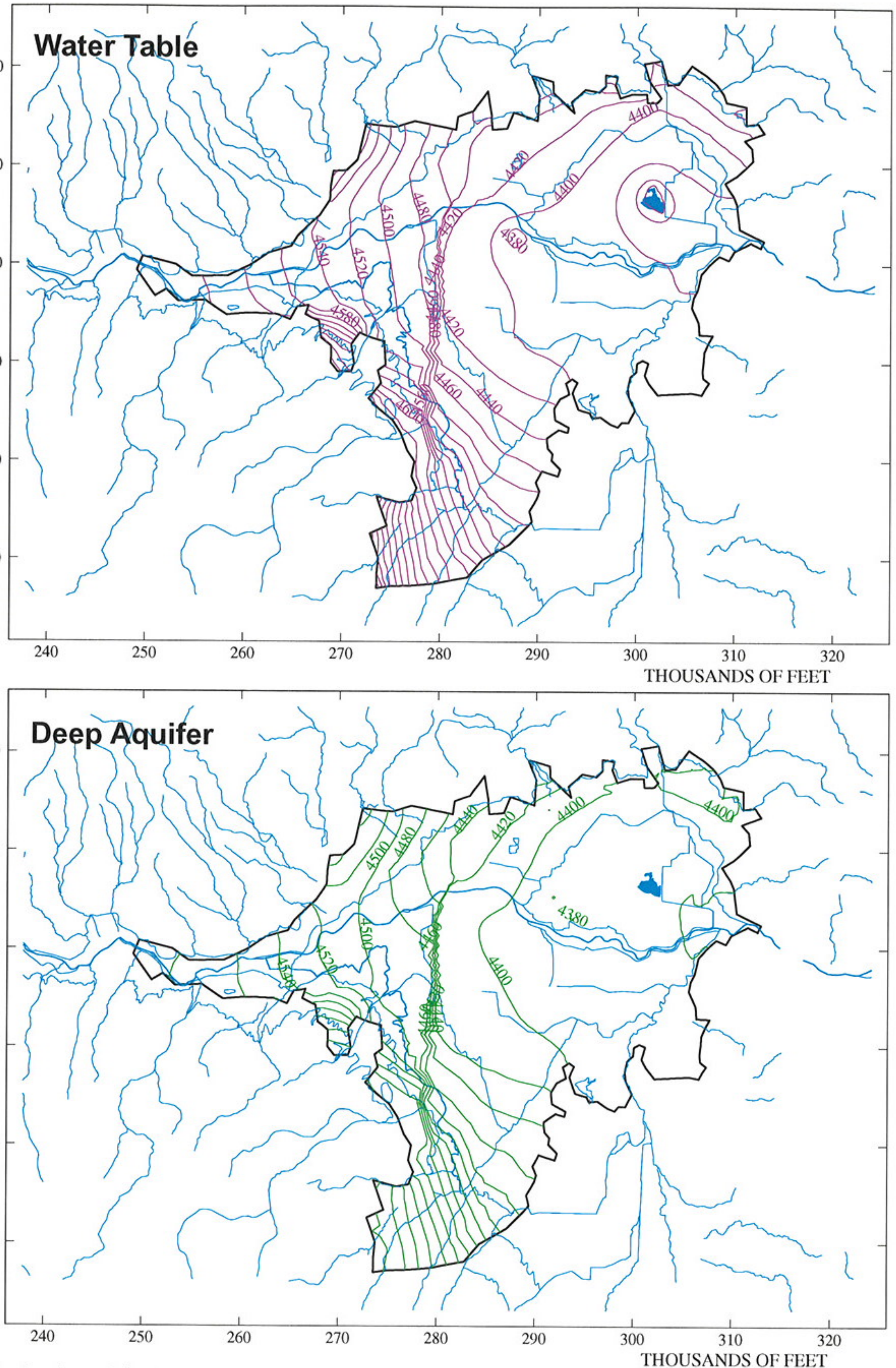
Notes: Vectors are shown for Layer 4.
Vectors are not scaled.

Figure 6-7
Simulated Flow Directions in Deeper Aquifer
Central Truckee Meadows Remediation District



Note: Shallow heads are defined as level 7.
Deep heads are defined as Level 4.

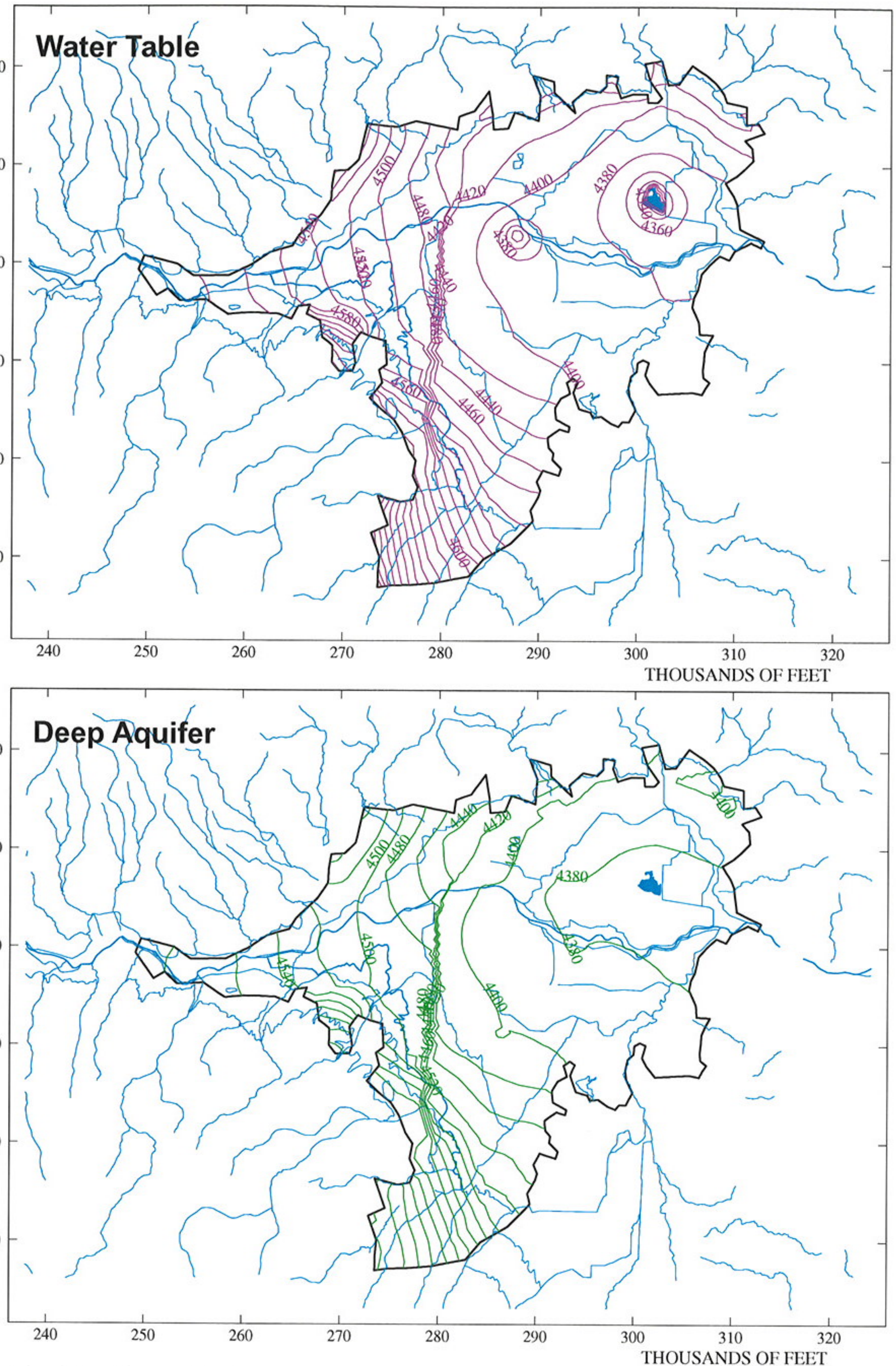
Figure 6-8
Simulated Water Levels, December 1965
Central Truckee Meadows Remediation District



Note: Shallow heads are defined as level 7.
Deep heads are defined as Level 4.

Figure 6-9
Simulated Water Levels, December 1970
Central Truckee Meadows Remediation District

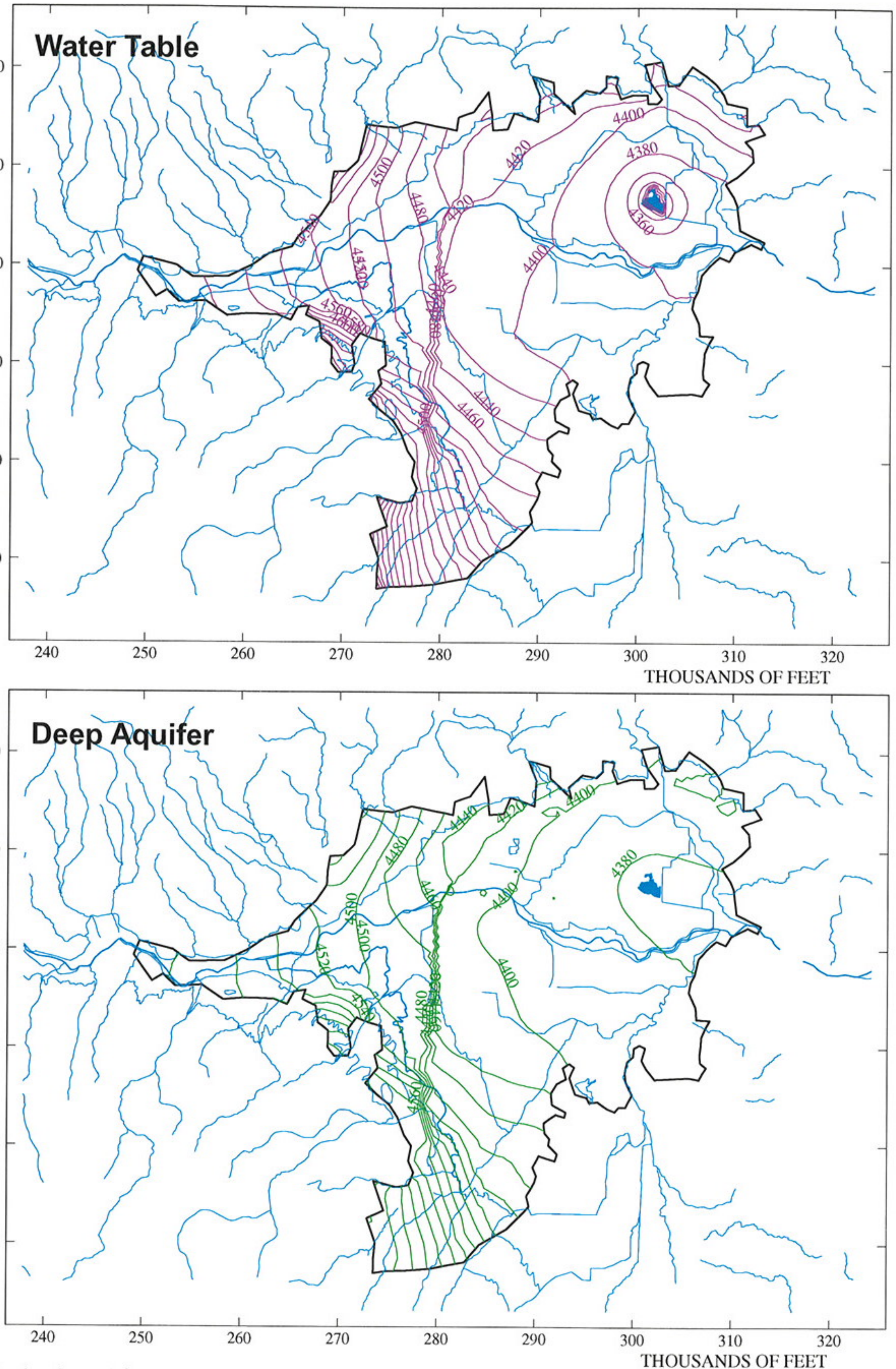
CDM



Note: Shallow heads are defined as level 7.
Deep heads are defined as Level 4.

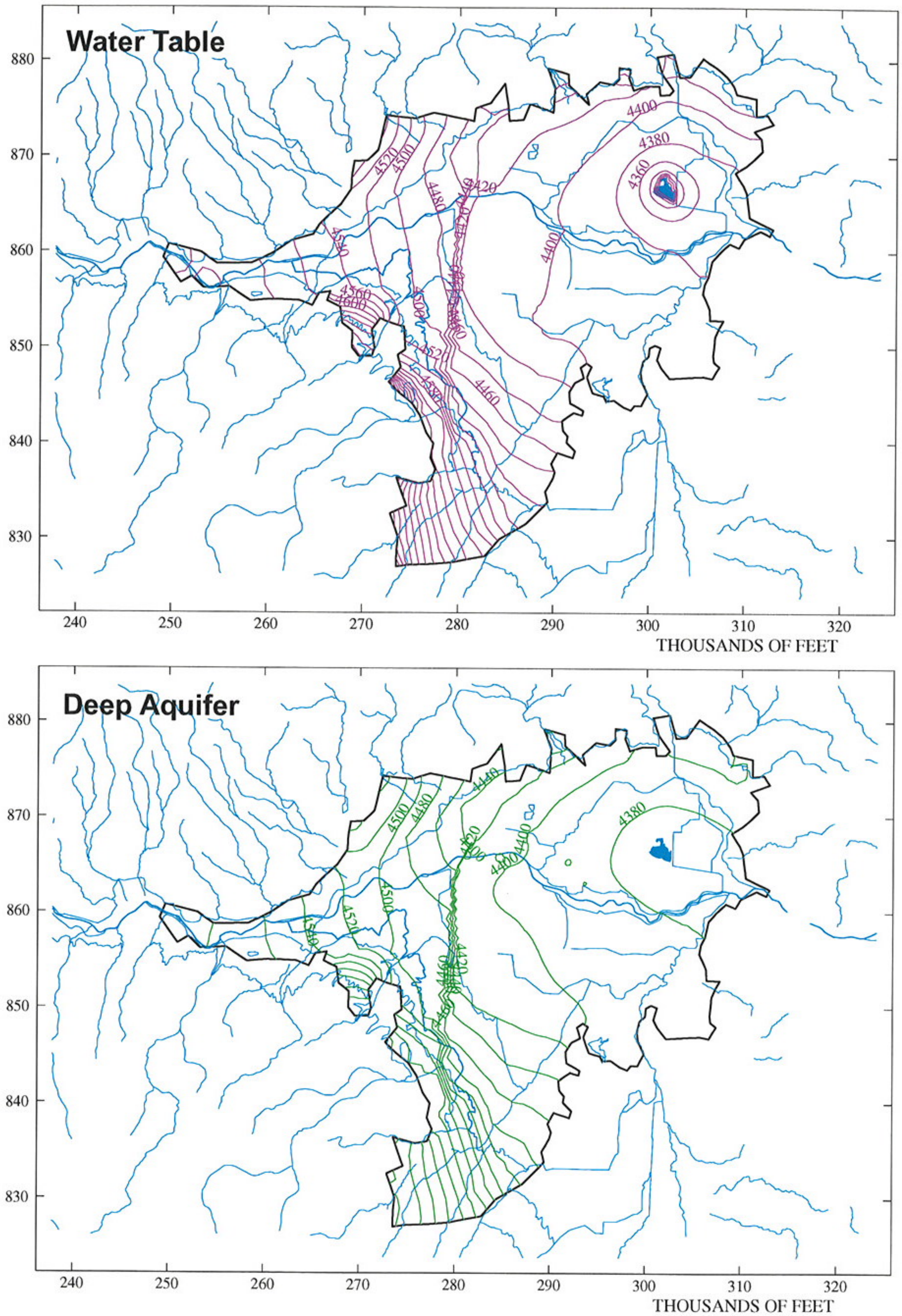
Figure 6-10
Simulated Water Levels, December 1975
Central Truckee Meadows Remediation District

CDM



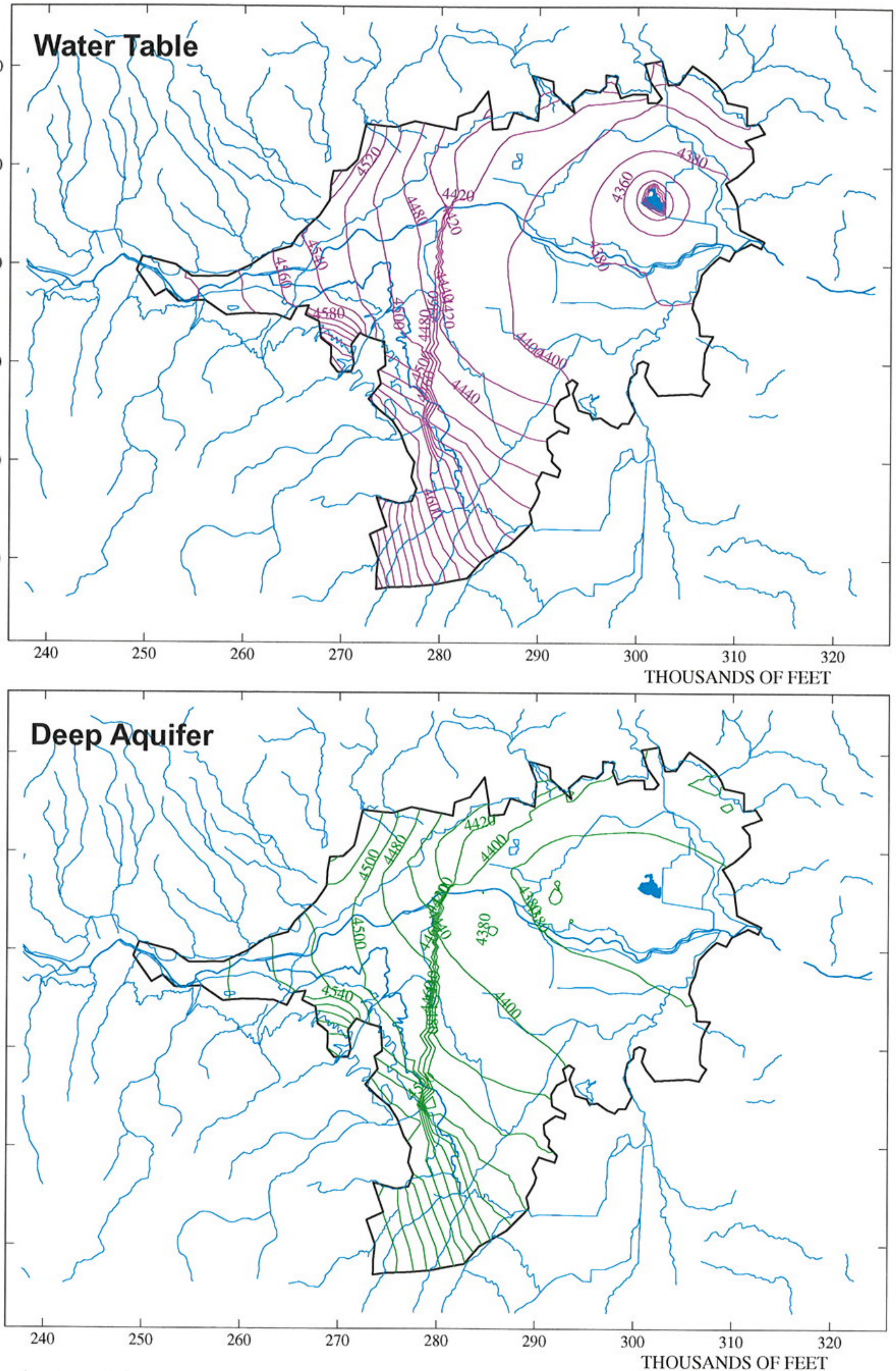
Note: Shallow heads are defined as level 7.
Deep heads are defined as Level 4.

Figure 6-11
Simulated Water Levels, December 1980
Central Truckee Meadows Remediation District



Note: Shallow heads are defined as level 7.
Deep heads are defined as Level 4.

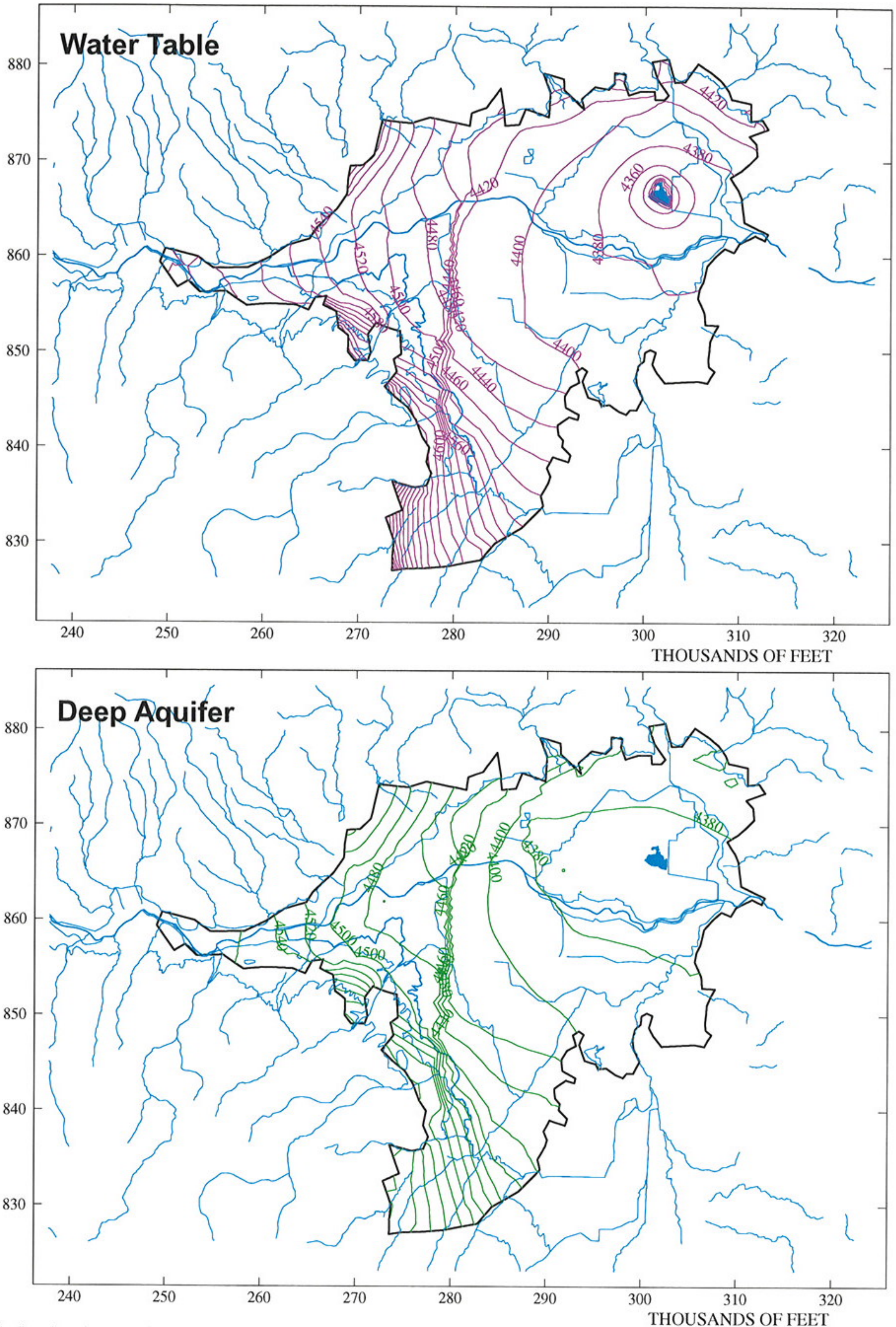
Figure 6-12
Simulated Water Levels, December 1985
Central Truckee Meadows Remediation District



Note: Shallow heads are defined as level 7.
Deep heads are defined as Level 4.

Figure 6-13
Simulated Water Levels, December 1990
Central Truckee Meadows Remediation District

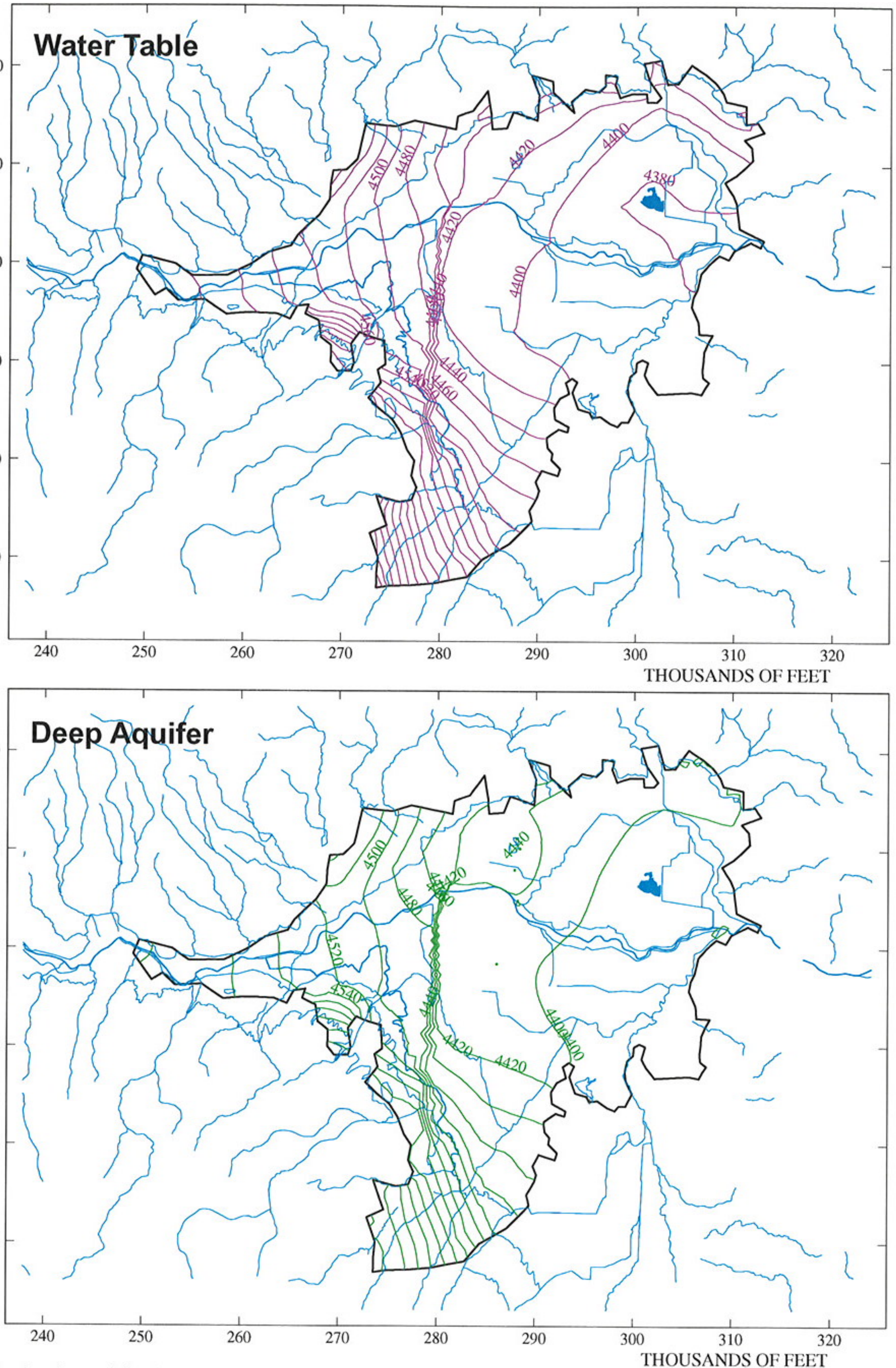
CDM



Note: Shallow heads are defined as level 7.
Deep heads are defined as Level 4.

CDM

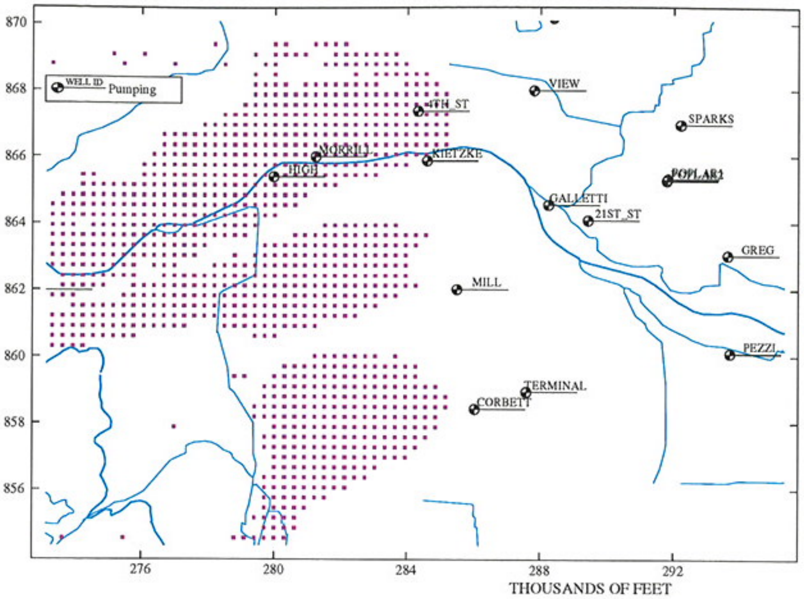
Figure 6-14
Simulated Water Levels, December 1995
Central Truckee Meadows Remediation District



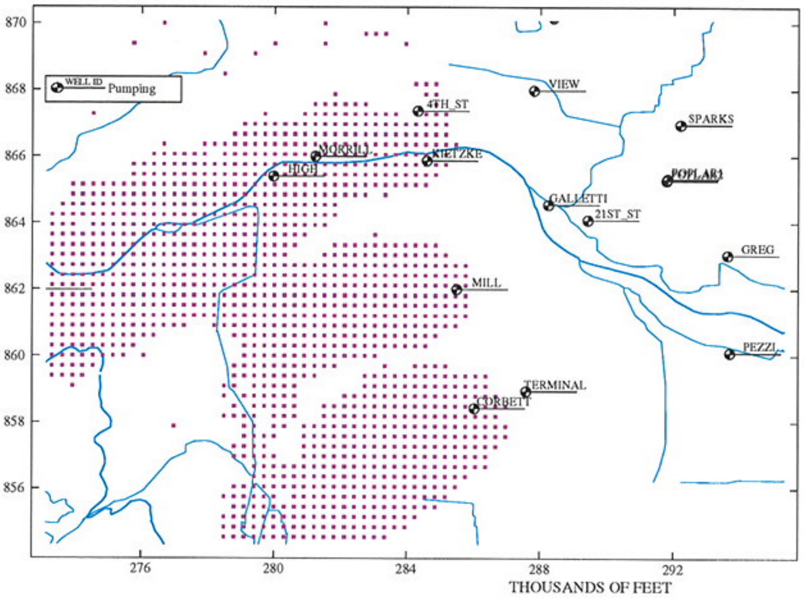
Note: Shallow heads are defined as level 7.
Deep heads are defined as Level 4.

Figure 6-15
Simulated Water Levels, December 2000
Central Truckee Meadows Remediation District

Water Table
(simulated)



Bottom of Shallow Aquifer
(approx. 100 ft bgs)



Capture Zones for:
High St.
Morrill Ave.
Kietzke Lane
Mill St.
Corbett School

Deeper Aquifer
(approx. 200-250 ft bgs)

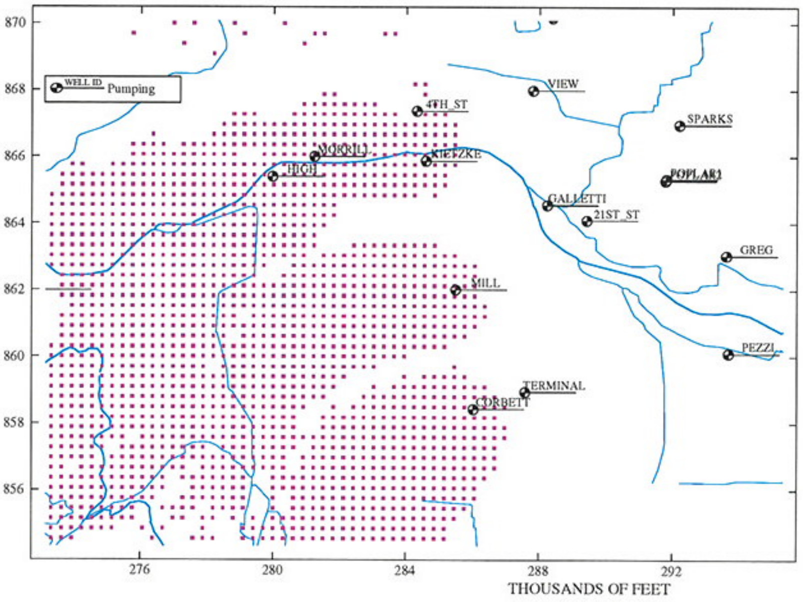


Figure 6-16
Simulated Capture Zones for TMWA Wells with Wellhead Treatment
Central Truckee Meadows Remediation District

Water Table
(simulated)

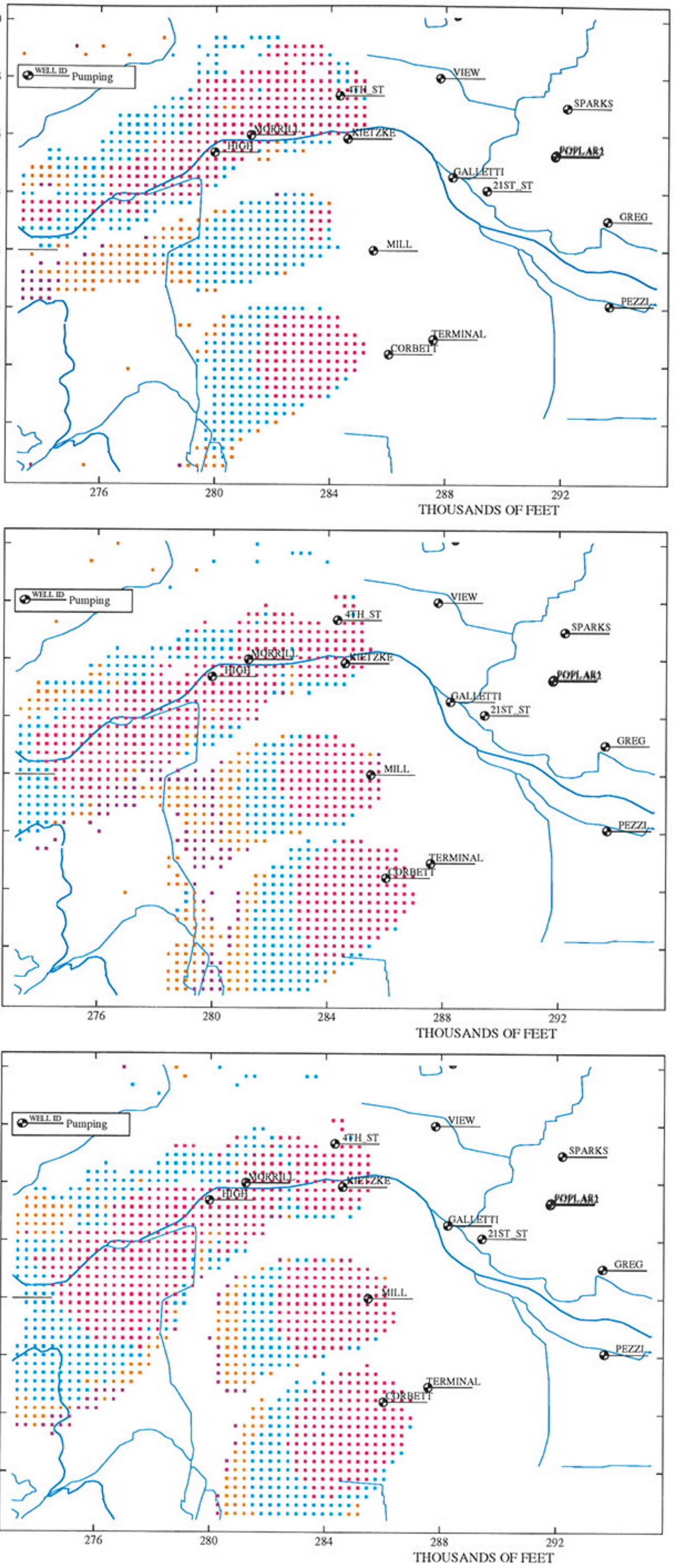
Travel Time

- 🟥 0 - 10 Years
- 🟦 10 - 20 Years
- 🟧 20 - 30 Years
- 🟪 30 - 40 Years

Bottom of Shallow Aquifer
(approx. 100 ft bgs)

Capture Zones for:
High St.
Morrill Ave.
Kietzke Lane
Mill St.
Corbett School

Deeper Aquifer
(approx. 200-250 ft bgs)



Note: Simulations assume a retardation factor of 1 and effective porosity equal to 0.15.

CDM

Figure 6-17
Simulated Travel Time to TMWA Wells with Wellhead Treatment
Central Truckee Meadows Remediation District

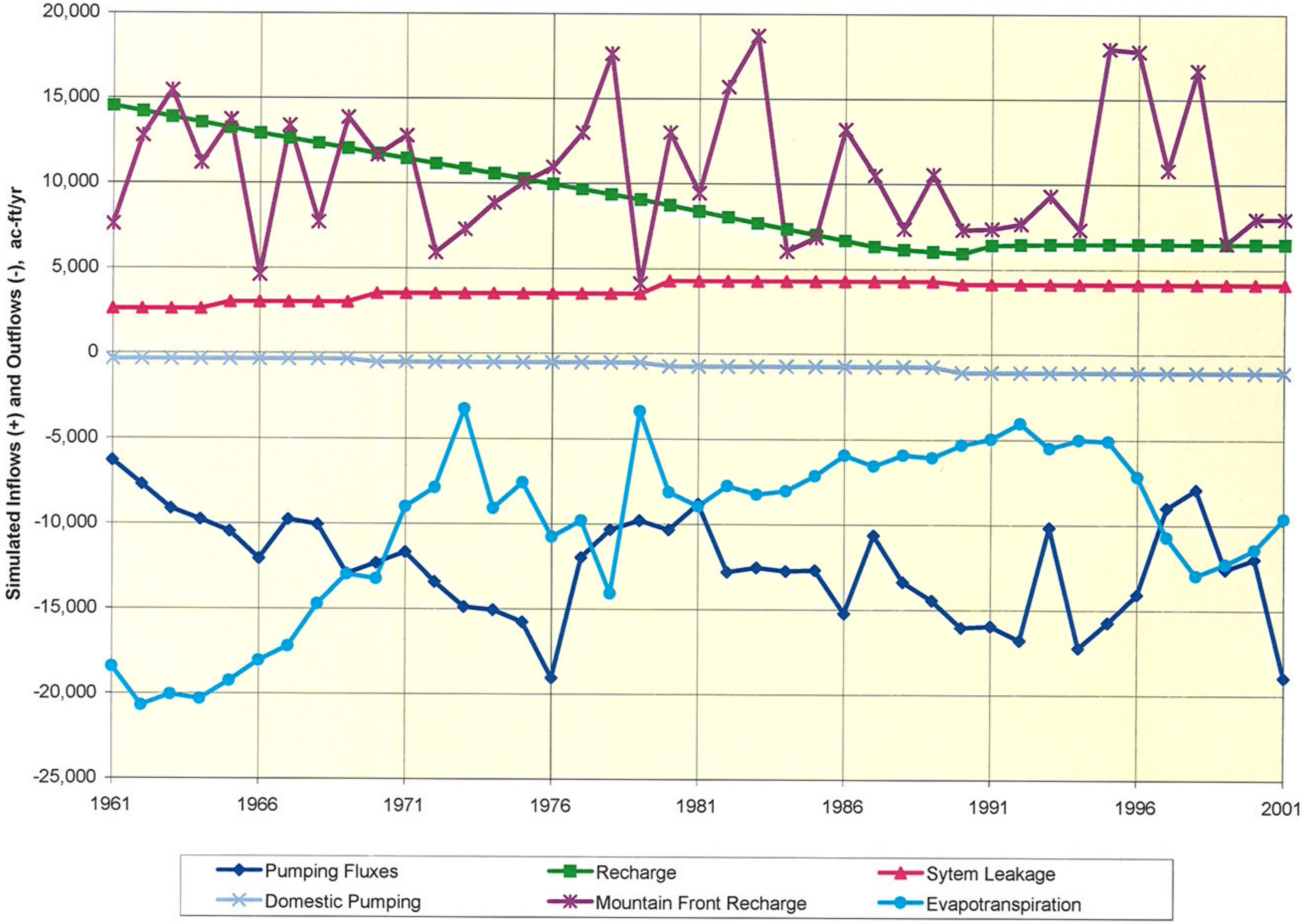


Figure 6-18
Simulated Groundwater Inflows and Outflows For Historical Transient Simulation
Central Truckee Meadows Remediation District

lt_trans19_check.xls: chart-pumping fluxes&rech
06/25/2002

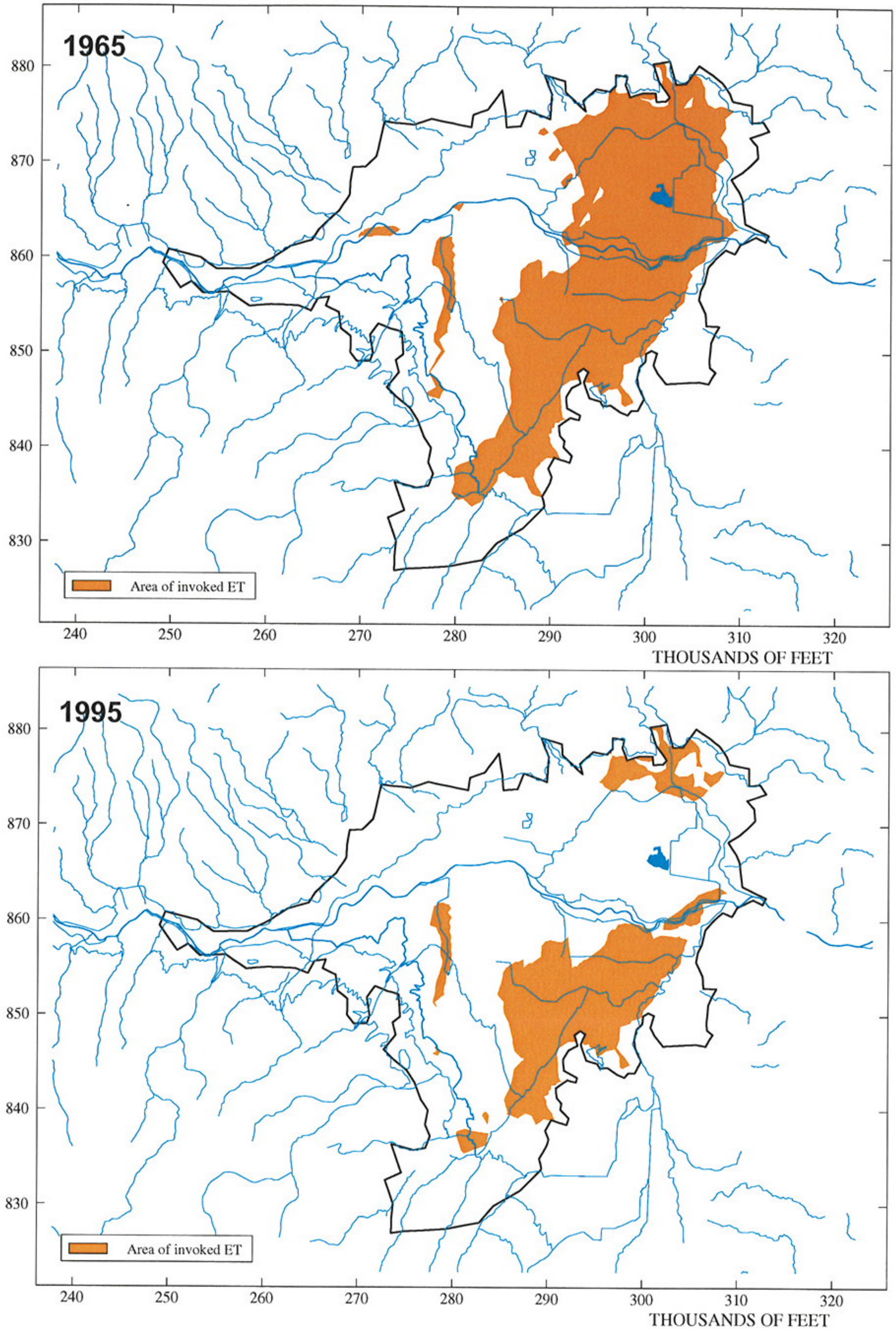
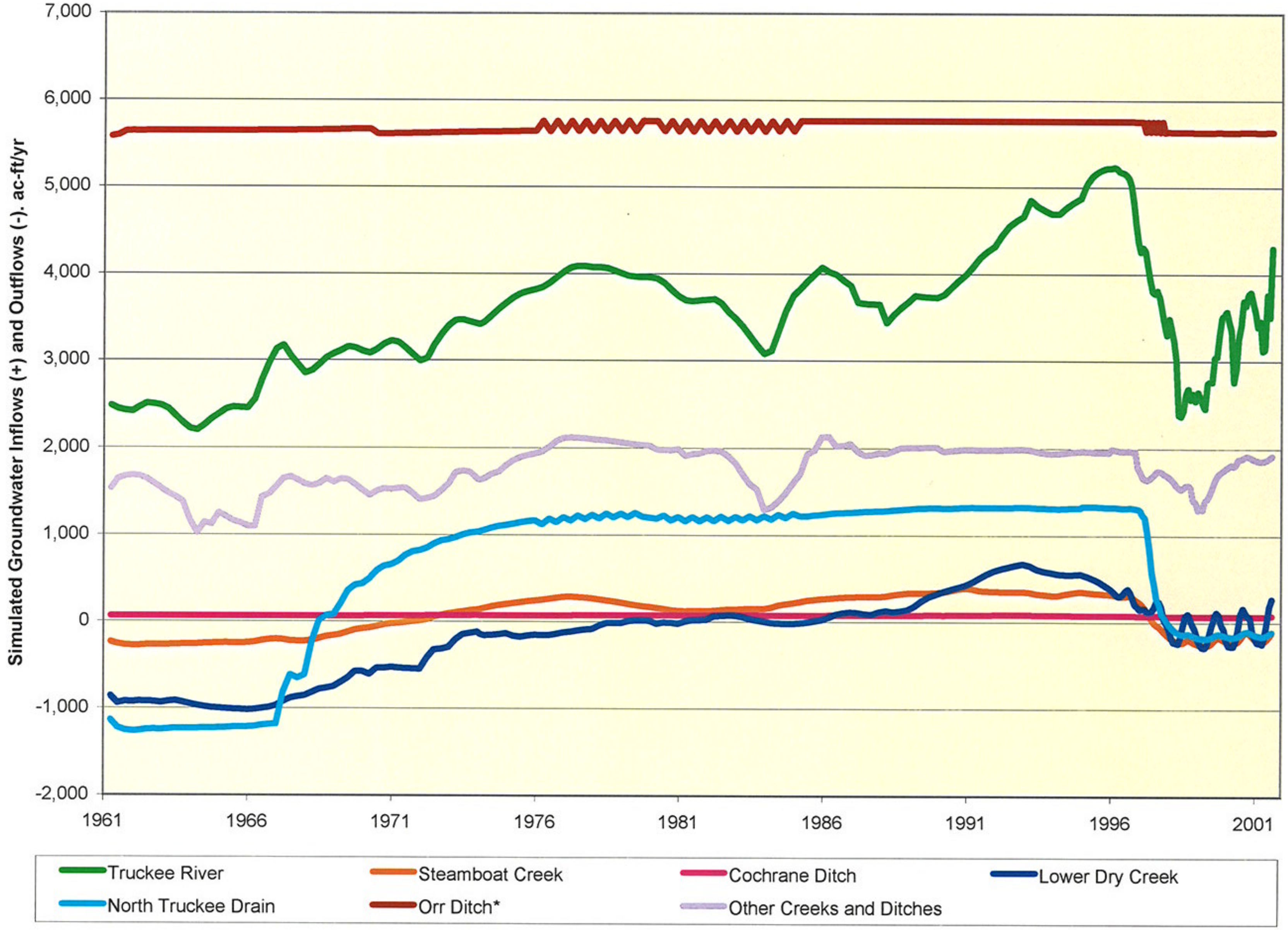


Figure 6-19
Areas of Simulated Evapotransipration, 1965 and 1995
Central Truckee Meadows Remediation District



* Orr Ditch inflow rate includes flux induced from the ditch itself and flux from MFR.

lt21_riverths.xls: Chart-Model TM
06/28/2002

Figure 6-20
Simulated Groundwater Inflows and Outflows To/From Surface Water
Central Truckee Meadows Remediation District

Section 7
Contaminant Transport Conceptual Model

This section presents the conceptual model of contaminant transport for the PCE contained within the alluvial aquifers of Central Truckee Meadows (CTM). The conceptual model was developed based on:

- A review of the data generated during the field investigations characterizing the nature and extent of PCE contamination, within the confines of Central Truckee Meadows;
- An understanding of the three-dimensional groundwater flow systems, in part based on the numerical groundwater flow model;
- An understanding of PCE contaminant fate and transport mechanisms; and
- An understanding of the historical and current potential influences on contaminant extent and migration (e.g., sanitary sewer data, historical land uses, TMWA pumping regimes, etc.).
- An understanding of the historical use of PCE in the American workplace.

To this end, the conceptual model of contaminant transport is used to understand both the current distribution of PCE in the alluvial sediments and the fate of the PCE mass given the various influences on its migration (e.g., public water supply pumping, groundwater recharge, ongoing source contributions, etc.). Each of these factors is discussed in the section below.

7.1 Historical PCE Use in the United States

According to the US Environmental Protection Agency (USEPA):

- PCE is mainly used for dry cleaning and textile processing; however it is also used as a chemical intermediate, and as a degreasing agent.
- PCE is also used for rubber coatings, solvent soaps, printing inks, adhesives and glues, sealants, polishes, lubricants, and silicones.

(Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Tetrachloroethylene (Draft). U.S. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1991.)

Use of PCE began to increase in the 1940s, and by the late1950s it had virtually replaced carbon tetrachloride and trichloroethylene in commercial dry cleaning. PCE is currently the solvent of choice in most of the world, except in regions, such as Japan, where petroleum-based solvents have remained important in the dry cleaning industry. In 1990, about 53% of the world demand for PCE was for dry cleaning, and about 75% of all dry cleaners used it to clean garments. By 1998, dry cleaners accounted for just 25% of all PCE use in the country (http://www.inchem.org-/documents/iarc/iarc/iarc774.htm).

Note that exposure to PCE was limited in the early days of its use because of its limited distribution and use. According to a cohort study in Missouri, in which follow-up was from 1948 to 1978, predominant human exposure in the US to PCE was considered to have occurred only since about 1960 (http://www.inchem.org/-documents/iarc/iarc/iarc777.htm).

7.2 Distribution of PCE and the Impact of PCE on Groundwater Production

The first indications that PCE contamination existed in the CTM alluvium occurred in 1987 during the sampling of the local public water supply wells operated by Sierra Pacific Power Company (SPPCo) (which are now operated by TMWA). PCE concentrations have been monitored nearly continuously on a monthly basis by SPPCO and TMWA since 1987. PCE has been detected regularly in the TMWA wells at concentrations greater than 5 µg/L. Time history plots of PCE in the five TMWA wells are provided in Figures 7-1 and 7-2.

These data indicate that for many of the public water supply wells, PCE concentrations have been increasing since 1987 at various rates - ranging from the steady increases at Mill Street and Kietzke Lane wells (approximately 1 µg/L PCE concentration increase per year since the late 1980's), to the limited changes that have occurred at the High and Morrill Street wells - 15 and 20 µg/L, respectively (concentrations have remained at fairly consistent over the last 15 years). In order to protect the public from PCE concentrations above drinking water standards, air strippers were installed on the five water supply wells.

Highlighted below are the most striking observations about these data and the impacts of PCE on the public water supply.

- All the wells, save 21st Street, that have concentrations of PCE above 5 µg/L are currently equipped with wellhead treatment in the form of air stripping to remove the PCE from the water before it is transmitted into the public drinking water supply.
- Wellhead treatment was operational at High and Morrill Street wells in June 1996, and at the Kietzke, Corbet and Mill wells in September 1998.
- After wellhead treatment was installed on these wells and the wells began pumping, concentrations were observed to decrease over time for as many as 3 years.

- After the initial decrease, which was expected given the typical impacts of dilution on production wells contaminated by limited groundwater borne contaminants, all these five wells continue to demonstrate concentrations of PCE between about 9 and 20 µg/L, even with the dilution.

- Given that the five TMWA wells with wellhead treatment produce on average about 1.3 billion gallons of water a year (since the summer of 1998), about 20 gallons of PCE are removed from the aquifer by the production wells each year. This is the equivalent of about 4 drums of pure PCE per decade.

Evaluation of additional data is necessary to gain a clearer understanding of the nature and extent of PCE contamination in the CTM, especially as it relates to the planning and implementation of the CTMRD. These additional data include the current observed distribution of PCE contamination within the CTM alluvium and TMWA capture zone delineations presented in Section 6.

Figures 7-3 and 7-4 present the distribution of PCE within the CTM for the shallow and deep alluvium, respectively. The two primary characteristics of the PCE distribution within the CTM alluvium are the low concentrations and its widespread distribution. These characteristics are discussed below.

To begin with, the PCE concentrations are generally low.

- With few exceptions the observed concentration of PCE detected in the groundwater, regardless of depth, ranges from non-detect to 40 µg/L. In fact, PCE above 40 µg/L was detected in only 57 samples collected from 1987 through 2001, which is less than 5% of all samples.

- Less than one half of all detects over 40 µg/L were greater than 100 µg/L.

- For all the groundwater samples with detectable concentrations of PCE (including wells where more than one sample had been collected) the average concentration of PCE is about 20 µg/L. Note that this includes over 1,300 individual groundwater samples.

The widespread distribution of PCE contamination, as indicated in Figures 7-3 and 7-4, is supported by the following observations.

- The area of shallow groundwater contamination, defined as the area encompassing wells where PCE has been measured above 5 µg/L, appears to be over 5,000 acres or about 8 square miles, not including the Sparks area (noting that significant gaps exist between locations with groundwater monitoring data).

- The area of deep contamination, characterized as located at a depth of greater than 100 feet below ground surface (bgs), extends over about 5 square miles. Note that in one of the locations where discrete-depth sampling occurred during drilling and installation of a deep monitoring well, PCE contamination was detected at 350 feet bgs.

- Another indication of how deep the PCE contamination has penetrated the CTM alluvium relates to the top of the screened intervals of the production wells with observed PCE concentrations. The High, Morrill, Kietzke and Corbett pumping wells have top of screens varying from 133 to 233 feet bgs. Mill, on the other hand, has a top of screen at 326 feet below ground surface.

- Noteworthy is the possibility that the PCE contamination may extend well beyond that area characterized by the existing monitoring well and sampling program. Based on past and current land use, shallow groundwater east of downtown and throughout the Sparks industrial and commercial corridor could contain PCE in a detectable range, if not above 5 µg/L. In this light, the distribution of PCE could extend over nearly 20 square miles affecting hundreds to thousands of land owners.

Putting together the observed horizontal and vertical distribution of PCE contamination, it is clear that the contamination is widespread, and does not necessarily follow the normal conceptual model of a single "plume of contamination" emanating from an identifiable hot spot.

When the observed PCE distribution information is combined with the observed contaminant concentration data from the TMWA wells, it would appear that no localized "plume or plumes" of PCE occurring at elevated concentrations are impacting the public water supply wells. Instead, it appears that the PCE contributing to the public water supply wells is spread over a large percentage of the horizontal aquifer extent and vertical water column from which TMWA's wells produce water. Downward movement of groundwater contaminated by PCE in the shallow alluvium into the deeper water supply production zone is induced by areal recharge, infiltration from rivers as well as by well pumping.

Note that the distribution of PCE within the CTM has not been fully characterized given the limited resources available to install, develop and sample monitoring wells. Although the nature and extent of PCE have been adequately characterized to develop the remediation Plan, the PCE extent in certain areas may warrant further characterization for purposes developing cost allocation for benefit. The areas where additional characterization may be warranted include:

- Locations between the Truckee River and 5th Street east of downtown

- Locations east of 395 within the Sparks commercial and industrial areas north of the Truckee River

- Locations north and east of the intersection at Mill and Kietzke to the Truckee River

- Locations between the Truckee River and Liberty east of Arlington
- Locations bounded by Mill, Kietzke, Virginia and Plumb

7.3 Potential PCE Source Areas

Given that the observed concentrations of PCE in the shallow groundwater are relatively low and wide spread, and that the PCE contamination penetrates the groundwater to depths of 350 feet or more, it appears that a large quantity of the groundwater tributary to the public water supply wells contains detectable levels of PCE. In fact, the average PCE concentration in the shallow aquifer is about 20 µg/L and the average PCE concentration in groundwater produced by the TMWA wells is about 15 µg/L. Therefore, it would appear that the majority of the produced groundwater originates from the zone 350 feet and above, with only limited dilution occurring.

For the PCE to reside in such a large area, both horizontally and vertically, it is likely that the PCE emanates from many widely distributed sources - sources that may include both small scale sources and the sanitary sewers that carry wastewater from all points in the CTM to the regional wastewater treatment plant. Each of these potential source types is described below.

7.3.1 Potential Small-Scale Sources

Numerous small-scale sources that may be impacting shallow groundwater contamination likely exist throughout CTM. Historical land use along the chief thoroughfares such as Kietzke Lane, Virginia, 4th Street, Keystone, etc. includes a myriad of light industrial uses such as dry cleaners, metal painting shops, printers, automobile and body repair shops, and chemical and paint manufacturers. Property ownership over the past 50 to 70 years have changed hands, such that some of the past potential contributors may long since be gone as evidenced by the land use analyses performed by the County and discussed in Section 2.3.1.9. Still other contributors may still exist today, as evidenced by the sanitary sewer sampling results presented in Section 2.3.1.10.

Releases from these types of light industrial operations could occur in a number of ways.

- Poor housekeeping could contribute occasional spills and accidental releases to the ground's surface, eventually leading to the development of soil and groundwater contamination.
- Leaking underground facilities (e.g., tanks, wet wells, dry wells, sewer line connections) could contribute contaminant mass to the soil and groundwater on a daily or weekly basis.

- Poor operational practices could lead to the habitual dumping of solvents into leaking sewers, wells, or unlined pits, which could lead to significant soil and groundwater contamination.

Any and all of these types of release could have occurred, and may continue to be occurring within the CTM. It is estimated that 75% of all active dry cleaners probably have some level of solvent contamination (Schmidt, et.al., 1999). Current regulations are more stringent than past regulations regarding the storage, handling, and disposal of solvents, however, small quantities of controlled material, which can cause significant environmental damage, are difficult to track and regulate.

As previously indicated, only three suspected source areas have been identified through the field activities conducted to date. Given the likelihood that other source areas exist within CTM, a deliberate, focused effort will be planned and implemented to install additional groundwater monitoring wells near locations with past land uses that may be consistent with the use of solvents, for these type of sources are probably the most significant contributors to the PCE contamination in CTM.

7.3.2 Sanitary Sewers

Localized hotspots do not appear to be the sole cause of the PCE contamination within CTM given the widespread, low level contaminant concentrations observed in the alluvial aquifer system. Therefore, a more wide spread "source type" may be a significant contributor to the PCE contaminant distribution observed in the aquifer system. Leaking sanitary or storm sewers used to carrying process water discharged either legally or illegally from light industrial operations may be the culprit.

Past business practices for some light industrial operations including the "dumping" of process wastewater, either in batch or continuously, into the sanitary sewer system. Although this practice was allowed through a portion of the 1970's, it is no longer allowed today. The Cities' and County's stormwater NPDES permit controls dry weather discharges of process water into storm sewers, whereas discharges to the sanitary sewers are controlled by the Cities of Reno and Sparks industrial pre-treatment program, which began in 1977.

Unfortunately storm and sanitary sewers leak. Leaks occur around joints, in locations where the pipe may have broken or corroded, and during the construction of new lines and connections. Given that storm and sanitary sewers are designed to be placed on course grained bedding material that is typically of a higher permeability than the surrounding natural formation, the storm and sanitary lines can also become conduits for contaminant migration, both because of the potential for leaking materials to migrate into and along the bedding material and because these pipes regularly carry water. Therefore, PCE that enters into a storm or sanitary sewer could potentially leak out into the pipe's bedding material and be flushed from the bedding material each time water leaks out of the pipe and contacts the contaminant mass.

The likelihood that PCE contamination existing within the sanitary sewers beneath the streets of Reno and Sparks is considerable considering that past and perhaps current (albeit illegal) practices for PCE disposal involves discharging of high concentrations of PCE into the sanitary sewers. For example, recent sampling of the sanitary lines found concentrations of PCE above 5 µg/L in numerous locations throughout CTM (see Figure 2-7). This figure illustrates that PCE at detectable concentrations were found recently in 26 separate locations across CTM. Follow-up sampling further characterized the PCE in the sanitary sewers, with the following results:

- Of the 26 locations, additional sampling isolated the source of the PCE to individual sewer reaches (i.e., a location between two manholes) at 15 sites. Sampling at the other sites produced either ambiguous information or did not verify previous sampling results.
- In nine separate locations (Figure 2-7), PCE concentrations above 100 µg/L were detected and in at least one location (Sub region 1) a PCE concentration was detected at 34,000 µg/L. (The solubility of PCE is about 150,000 µg/L).

The mere presence of PCE in the sanitary lines may be indicative of a long-standing, albeit illegal, business practice that may be endemic to the Reno metropolitan area. Long-term discharge of small volumes of PCE at 26 locations across the CTM could conceivably contribute substantially to the 8 to 20 square mile area of PCE contamination. Given that the sanitary lines criss-cross every street and block of CTM, it is possible that leakage from the sanitary sewers, over time, have contributed to the current distribution of PCE in the alluvial aquifer, especially in the nine subregions. In addition, if PCE exists in high enough concentrations when discharged, which can be roughly defined as in the 1,000 µg/L range, it may create a source of PCE within the bedding material of the sanitary sewer that can conceivably contribute PCE to the public water supply wells for decades to centuries.

Unfortunately the impact of PCE discharges into the City's sanitary sewers is not easily characterized given the temporal variability and spatial extent of the lines. Additional data collection to evaluate the nature of the impact of PCE discharges into the sanitary sewers within the nine sub regions identified in the Sewer Line Wastewater Report is warranted.

7.4 Distribution of Chloride and Nitrogen in the Shallow Alluvium

If the sanitary sewer system leaks, PCE may be carried from the near surface to the shallow groundwater system. Not only PCE would impact the shallow groundwater quality from such a leak, however. Chloride and nitrogen may also impact the native groundwater quality if sanitary sewer leaks were prevalent throughout CTM. Chloride and total nitrogen analyses were performed on groundwater samples as part of the characterization of natural attenuation. A presentation of these data is included in Figures 7-7 and 7-8, respectively.

Chloride data, which may be influenced by the chlorination of drinking water used as the source for most wastewater, would typically be in the 35 to 50 ug/L range. Although some of the observed chloride concentrations are in this range, there is no consistent trend of chloride concentrations indicative of leaking sanitary sewers.

Nitrogen may indicate a sanitary sewer leak, although in reduced conditions nitrogen would most likely be present as ammonia. These data do not suggest wide spread distribution of nitrogen.

Note that CTM-19S, which lies within sub region 9, contains elevated concentrations of both nitrogen and chloride. It is possible that a leaking sanitary sewer has impacted local groundwater quality in this area. Note that elevated concentrations of PCE were found immediately downgradient of this location. As indicated above, additional sampling of the sanitary sewers and the shallow groundwater beneath the sanitary sewers within the nine sub regions is warranted to better characterize the potential impact of PCE discharges that have occurred and may still be occurring.

7.5 PCE Transport Mechanisms

Understanding the processes that influence PCE migration through the subsurface will also help to characterize the overall nature and extent of the contamination within CTM. PCE migration or transport through the alluvial aquifer is influenced by four key processes: advection, dispersion, adsorption and biological and/or chemical degradation. These processes are discussed in the following section.

7.5.1 Advection

Advection, caused by the flow of groundwater from high hydraulic head to low hydraulic head (as indicated by the piezometric surface), is the most dominant process influencing the migration of PCE through the alluvial aquifer of CTM. As described in Section 6.2, the direction of groundwater flow changes with changes in TMWA pumping - which has had both a seasonal impact and long-term impact on groundwater flow direction. In general the direction of groundwater flow is from west to east through the CTM, however, TMWA pumping creates significant downward hydraulic gradients "pulling" shallow groundwater downward toward the production zones of the pumping wells. These downward hydraulic gradients vary both temporally and spatially, such that in any one location, hydraulic gradients could be either downward or upward, depending on the time of year and the production rate of nearby TMWA wells.

Prior to 1960, groundwater in the shallow alluvium most likely migrated more nearly horizontally, influenced by upward vertical gradients that had groundwater discharging in the marshlands of the eastern Truckee Meadows. After 1960, the US Army Corps of Engineers removed a bedrock outcrop at the mouth of Vista Canyon, effectively draining the marshlands of eastern Truckee Meadows, allow groundwater to discharge both to the Truckee River and to Vista Canyon.

After 1960, groundwater mainly discharges to either the groundwater production wells operated by TMWA, the Truckee River and its tributaries, and to the local gravel pits. Some groundwater is lost to the atmosphere through evapotranspiration, however this influence has been reduced in recent years by the increased water supply production and the paving of the CTM, especially in the eastern portion of Sparks.

TMWA groundwater production from 1961 to 1995 has increased by over a factor of nearly 7, increasing from about 22,600 ac-ft/yr (~20 mgd) (as a daily average) to over 142,000 ac-ft/yr (~127 mgd). TMWA production rates are shown on Figure 7-9. The increased pressure on the alluvial aquifer has greatly impacted downward vertical gradients and advection of the PCE through the shallow alluvium, especially in the vicinity of the highest producing wells during that time period – High, Mill, Morrill, and Kietzke, respectively.

As noted in Section 6, the alluvial aquifer in the CTM contains finely interbedded silts and fine sands with cobbles, gravels and some medium to coarse sand. Although no consistent, locally extensive low permeability zone restricting the vertical flow of groundwater has been found under the downtown Reno area, the interbedding of the silts and fine sands demonstrate a high degree of anisotropy, with horizontal permeability significantly larger than vertical permeability, by a factor of perhaps as much as 500 or 1000 to 1. This anisotropy acts to reduce the influence of the vertical gradients caused by the production pumping of the TMWA wells. Nonetheless, the vertical impacts do persist, and are ever increasing over the period from 1961 to 1995, a period of 34 years.

Groundwater production from the TMWA wells during this period was seasonal in nature. Therefore, magnitude of the vertical gradients likely varied seasonally as a result of pumping changes. The seasonal nature of vertical flow with in the aquifer flow may have contributed to the current distribution of PCE by spreading of PCE vertically along the general west to east horizontal flow direction.

In addition, as indicated by the well capture zones presented in Section 6.3, the majority of the groundwater tributary to the High, Morrill, and Kietzke wells flow beneath the Downtown Reno area. Given the increasing amount of public water supply production from groundwater over the past few decades, it is reasonable to surmise that the contribution of groundwater from beneath the Downtown area tributary to these wells – groundwater which contains PCE at an average concentration of perhaps around 20 µg/L – has been increasing over the same period of time. Noting the nearly "steady state" nature of the PCE contaminant concentrations in these three TMWA wells, it would appear that production pumping is continuing to draw substantial quantities of groundwater from the contaminated zone of groundwater beneath Downtown Reno.

It is clear that a substantial quantity of PCE contamination migrating from west to east beneath the Downtown Reno area is being captured by the three TMWA wells given that:

- Most of the groundwater flowing through CTM discharges into TMWA production wells; and
- The only wells that capture groundwater originating in the Downtown Reno area are the High, Morrill and Kietzke wells

Similarly, the Mill and Corbett wells capture significant amounts of groundwater from the water table located beneath the commercial properties lining South Virginia (from Mill to Moana), Plumb and Moana. As indicated during the sanitary sewer sampling effort (see Figures 7-5 and 7-6), PCE was detected above 100 ug/L in numerous locations along these major commercial thoroughfares. It is likely, therefore, that sources of PCE contamination located south of Mill along or near these major streets have, and continue to, contribute PCE to the Mill and Corbett wells.

Noteworthy is that based on advection alone (as indicated by the capture zone maps presented in Section 6.3) the suspected source area at the intersection of Mill and Kietzke would not impact any of the five TMWA wells currently operating with air stripping facilities. Based on the piezometric surfaces presented in Section 6.2, this source area appears to contribute PCE to groundwater that migrates east and northeast toward the Reno-Hilton lake, Truckee River, and the Galletti and 21st Street wells.

7.5.2 Density Impacts

Note that impacts of density, caused by elevated concentrations of PCE in the saturated zone, may influence the localized migration of PCE contamination downward into the alluvium. This type of density gradient, related to the presence of dense non-aqueous phase liquids (DNAPL), may occur in areas immediately adjacent to locations where PCE had been dumped onto or leaked into the ground. Aqueous phase concentrations above 1 percent of effective solubility (which is about 1,500 µg/L depending on the presence of other contaminants in the groundwater) can be correlated to the presence of DNAPL in or adjacent to the saturated zone.

Note that in only one sample (at well 133j), was the PCE above 1,000 µg/L, and the concentration in that well has since dropped to below 500 µg/L. Although DNAPL may exist with the CTMRD, the data collected thus far do not indicate the presence of DNAPLs at this time.

7.5.3 Dispersion

Advection alone does not dictate the areal and vertical extent of the PCE in the alluvial aquifer. Dispersion, caused by the heterogeneity of the porous media through which the groundwater flows, also may cause PCE to spread horizontally and vertically through the water column. Dispersion along with advection may be especially important to the vertical migration of PCE in the alluvial sediments, given that dispersion by itself may not cause significant vertical migration of groundwater contaminants into the water column. Dispersion through the sediments such as those found in CTM may cause the contamination to migrate dozens of feet downward into the saturated sediments in addition to the vertical migration caused solely by advection and downward vertical gradients. Dispersion may also be increased in situations where the groundwater flow alternates direction under the influence of seasonal pumping.

7.5.4 Retardation

Retardation is used as a characteristic parameter to represent the two associated processes of contaminant adsorption on to and desorption from the soil in the saturated zone. Retardation is used to adjust the groundwater velocity, creating an apparent groundwater velocity that takes into account to process of mass being removed from (through sorption) and added to (through desorption) migrating groundwater. Although the adsorption and desorption processes are not linear by nature, nor are they reversible and congruent, we have assumed that they are for this project.

Incorporating retardation into the simulations and analyses presented herein does not remove mass from the water column, it only acts to reduce the apparent velocity of the migrating PCE contamination.

Retardation has been correlated to the fraction of organic material within the soil matrix and the grain size distribution. Given that the aquifer system within CTM is nearly devoid of naturally occurring organic material (i.e., it is less than 0.01 percent), retardation was assumed to not influence the apparent groundwater velocity.

7.5.5 Degradation and Natural Attenuation

Natural attenuation in groundwater systems results from the integration of several subsurface attenuation mechanisms that may effectively reduce the contaminant toxicity, mobility, or volume. Natural attenuation mechanisms are classified as either nondestructive or destructive. Nondestructive mechanisms are processes that result in reduction of contaminant concentration without destruction of contaminant mass. These mechanisms include dispersion, dilution, sorption, and volatilization. Destructive mechanisms include intrinsic biodegradation and abiotic (chemical) degradation.

For chlorinated aliphatic hydrocarbons (CAHs) such as PCE, reductive dechlorination is the most effective biodegradation process in terms of mass reduction. Reductive dechlorination is the process by which anaerobic microbes (dehalogenators, halorespirers) substitute a hydrogen atom for a chlorine atom on the CAH molecule. Through this process, the more chlorinated CAHs can be dechlorinated to form less chlorinated compounds (e.g., PCE to TCE to cis-1,2-DCE to vinyl chloride and finally to ethene). In order to complete the reductive dechlorination reaction, an oxidation reaction is needed. Microbes will use natural organic matter and other carbon sources like BTEX as carbon and energy sources. These microbes will metabolize the carbon sources and as a by-product produce hydrogen. The presence of cis-1,2-DCE and vinyl chloride (biodegradation products of PCE and TCE) is an indication of the occurrence of reductive dechlorination.

Only five of the wells sampled as part of the field investigations (less than 1%) have had detections of cis-1,2-DCE and no wells have had detections of vinyl chloride. The lack of cis-1,2-DCE and vinyl chloride production within the groundwater at CTM is an indication that conditions are not favorable for reductive dechlorination.

The high levels of DO and sulfate measured in most of the groundwater wells are the likely cause for the non-favorable conditions. Anaerobic conditions prevail at DO concentrations less than approximately 0.5 mg/L. At DO concentrations above 0.5 mg/L, aerobic biodegradation of the carbon source (toluene) prevails. Aerobic biodegradation of toluene consists of aerobic microbes using oxygen to oxide toluene and produce carbon dioxide. PCE and TCE do not typically biodegrade aerobically. Even in wells with low DO, sulfate levels are typically above 50 mg/L. In field situations, it is often observed that dechlorination of cis-1,2-DCE and vinyl chloride does not occur in the presence of levels of sulfate in excess of 50 mg/L.

It is nonetheless important to note that the dechlorination of PCE may be occurring at numerous locations within CTM given the widespread distribution of PCE and gasoline service stations. Literally dozens to hundreds of past gasoline service stations have leaked fuel into the shallow groundwater, causing the local groundwater to become anaerobic, which is conducive to the dechlorination of PCE. Fuel constituents mixed with solvents such as PCE have been found to promote dechlorination reactions at the Sparks Solvent Fuel Site in Sparks and the Stead Solvent Site in Stead.

7.6 Summary

The first indications that PCE contamination existed in the CTM alluvium occurred in 1987 during the sampling of the local public water supply wells operated by Sierra Pacific Power Company (SPPCo) (which are now operated by TMWA).

PCE contamination persists today in numerous of TMWA's water supply wells most notably at the High, Mill, Morrill, Kietzke and Corbett wells where well head treatment using air stripping is in place to remove PCE from the public water supply.

PCE has also been detected in Greg, Reno High, Sparks, Popular #2, 4th Street, Peckham, and 21st Street wells.

Once well head treatment was installed at the High, Mill, Morrill, Kietzke and Corbett wells, the concentration of PCE in the produced water decreased, which was expected given the typical impacts of dilution on production wells contaminated by limited groundwater borne contaminants. However all these five wells continue to demonstrate concentrations of PCE between about 9 and 20 µg/L, even with the dilution.

The two primary characteristics of the PCE distribution within the CTM alluvium, based on monitoring well data are the low concentrations and its widespread distribution.

- For all the groundwater samples with detectable concentrations of PCE (including wells where more than one sample had been collected) the average concentration of PCE is about 20 µg/L. PCE above 40 µg/L was detected in only 57 samples collected from 1987 through 2001, which is less than 5% of all samples. Note that this includes over 1,300 individual groundwater samples. The area of shallow groundwater contamination, defined as the area where PCE has been detected at values of at least 5 ug/L, appears to be over 5,000 acres or about 8 square miles, not including the Sparks area (noting that significant gaps exist between locations with groundwater monitoring data).
- The area of deep contamination, characterized as located at a depth of greater than 100 feet below ground surface (bgs), extends over about 5 square miles. Note that in one of the locations where discrete-depth sampling occurred during drilling and installation of a deep monitoring well, PCE contamination was detected at 350 feet bgs.
- Another indication of how deep the PCE contamination has penetrated the CTM alluvium relates to the top of the screened intervals of the production wells with observed PCE concentrations. The High, Morrill, Kietzke and Corbett pumping wells have top of screens varying from 133 to 233 feet bgs. Mill, on the other hand, has a top of screen at 326 feet below ground surface.
- Noteworthy is the possibility that the PCE contamination may extend well beyond that area characterized by the existing monitoring well and sampling program. Based on past and current land use, shallow groundwater east of downtown and throughout the Sparks industrial and commercial corridor could contain PCE in a detectable range, if not above 5 µg/L. In this light, the distribution of PCE could extend over nearly 20 square miles affecting hundreds to thousands of land owners.

If the average PCE concentration in the shallow aquifer is about 20 µg/L and the average PCE concentration in groundwater produced by the TMWA wells is about 15 µg/L, then it would appear that the majority of the produced groundwater originates from the zone 350 feet and above, unless significant PCE contamination extends deeper into the aquifer system, in which case the amount of contaminated aquifer contributing groundwater to the production wells would increase.

Two "hotspots" were identified based on the most recent field investigation efforts. These hotspots, which are located along 4th at Ralston, and at the intersection of Mill and Kietzke, were identified by low upgradient PCE concentrations and elevated (i.e., greater than 200 µg/L) PCE concentrations in monitoring wells. It is unknown what type of operations existed in these areas to create the observed hotspots; however, there are clearly hotspots in these areas. Other hotspots within the CTM likely exist, but have yet to be identified through field investigations.

Numerous small-scale sources that may be impacting shallow groundwater contamination likely exist throughout CTM. Historical land use along the chief thoroughfares such as Kietzke Lane, Virginia, 4th Street, Keystone, etc. includes a myriad of light industrial uses such as dry cleaners, metal painting shops, printers, and chemical and paint manufacturers. Property ownership over the past 50 to 70 years have changed hands, such that some of the past potential contributors may long since be gone, whereas some contributors may still exist today.

Localized hotspots do not appear to be the sole cause of the PCE contamination within CTM given the wide-spread, low level contaminant concentrations observed in the alluvial aquifer system. The likelihood that PCE contamination exists within the sanitary sewers beneath the streets of Reno and Sparks is high. Recent sampling of the sanitary lines found concentrations of PCE above 5 µg/L in numerous locations throughout CTM. In nine separate locations, PCE concentrations above 100 µg/L were detected and in at least one location a PCE concentration was detected at 34,000 µg/L. The mere presence of PCE in the sanitary lines may be indicative of a long-standing, albeit illegal, business practice that may be endemic to the Reno metropolitan area.

The majority of the groundwater tributary to the High, Morrill, and Kietzke wells flow beneath the Downtown Reno area. Given the increasing amount of public water supply production from groundwater over the past few decades, it is reasonable to surmise that the contribution of groundwater from beneath the Downtown area tributary to these wells - groundwater which contains PCE at an average concentration of perhaps around 20 ug/L - has been increasing over the same period of time.

It is uncertain whether or not these three TMWA production wells are pumping at high enough rates to capture all of the shallow groundwater flowing beneath the Downtown Reno area since the production pumping fluctuates seasonally and limited water level data exists east of Wells and west of Galletti and 21st Street wells.

However, it is clear that a substantial quantity of PCE contamination migrating from west to east beneath the Downtown Reno area is being captured by the three TMWA.

Similarly, the Mill and Corbett wells capture significant amounts of groundwater from the water table located beneath the commercial properties lining South Virginia (from Mill to Moana), Plumb and Moana. As indicated during the sanitary sewer sampling effort, PCE was detected above 100 µg/L in numerous locations along these major commercial thoroughfares. It is likely, therefore, that sources of PCE contamination located south of Mill along or near these major streets have, and continue to, contribute PCE to the Mill and Corbett wells.

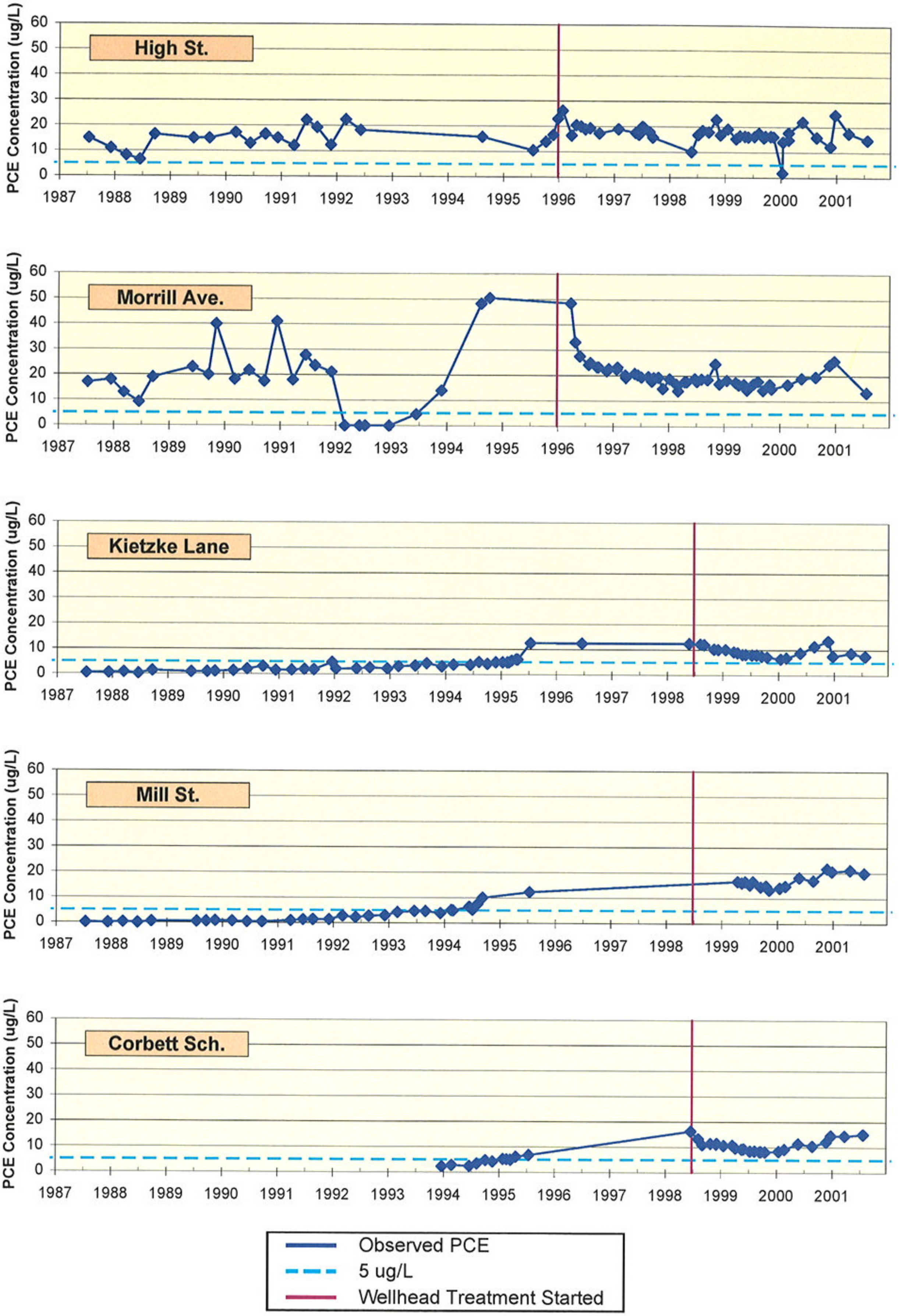


Figure 7-1
PCE Concentrations at TMWA Wells with Wellhead Treatment
Central Truckee Meadows Remediation District

TMWA well sampling update.xls: Charts_treatment
06/26/2002

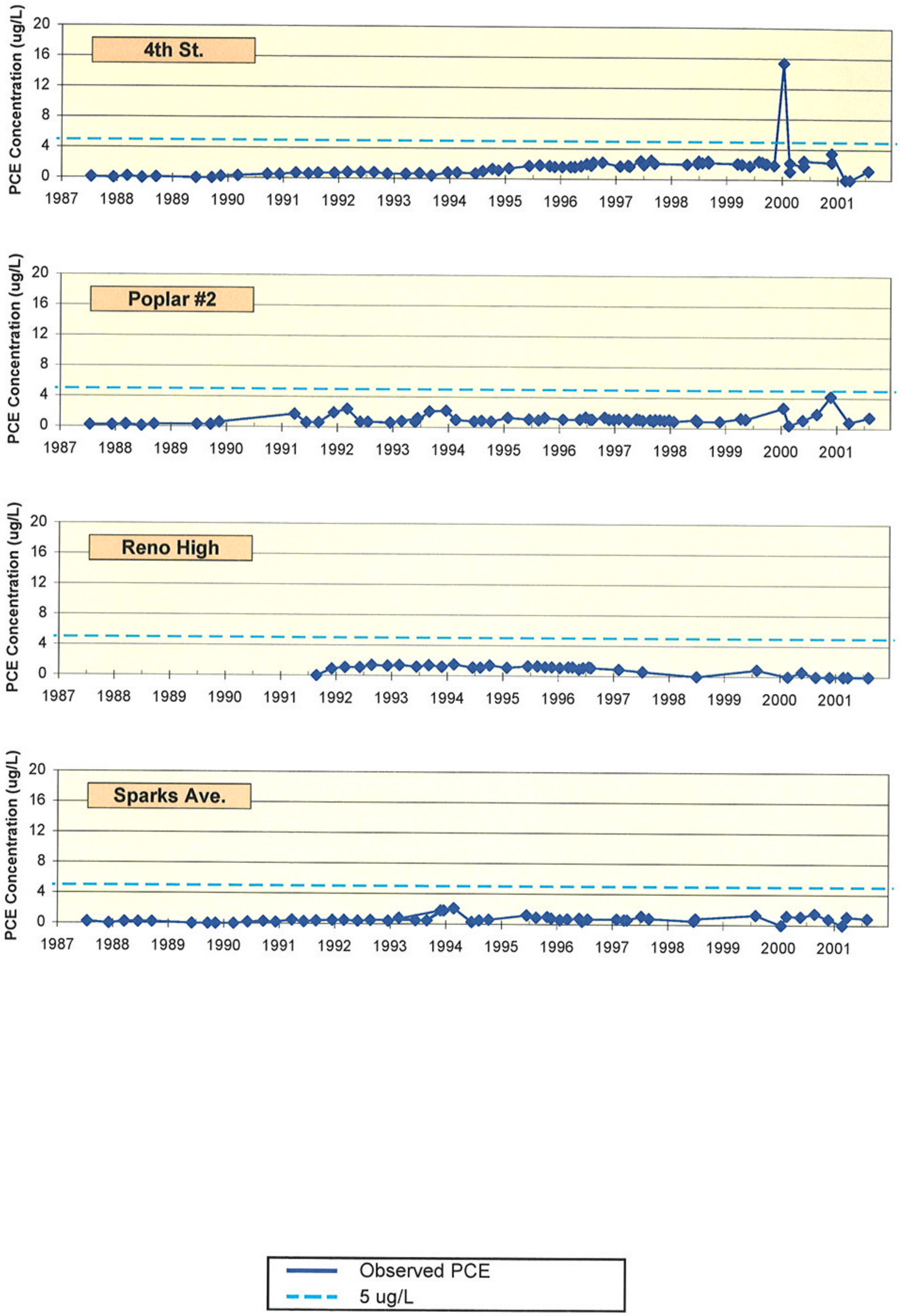


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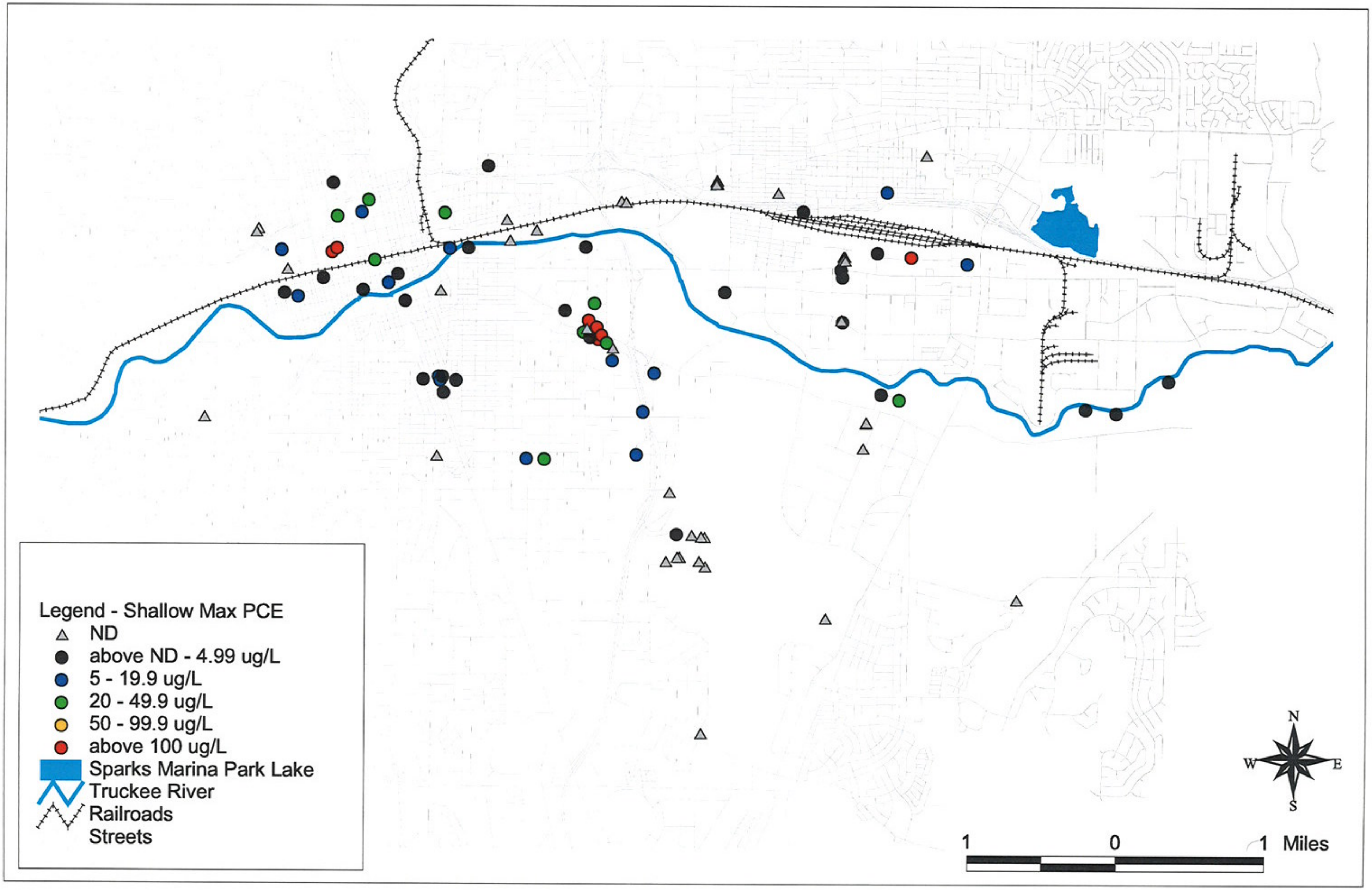
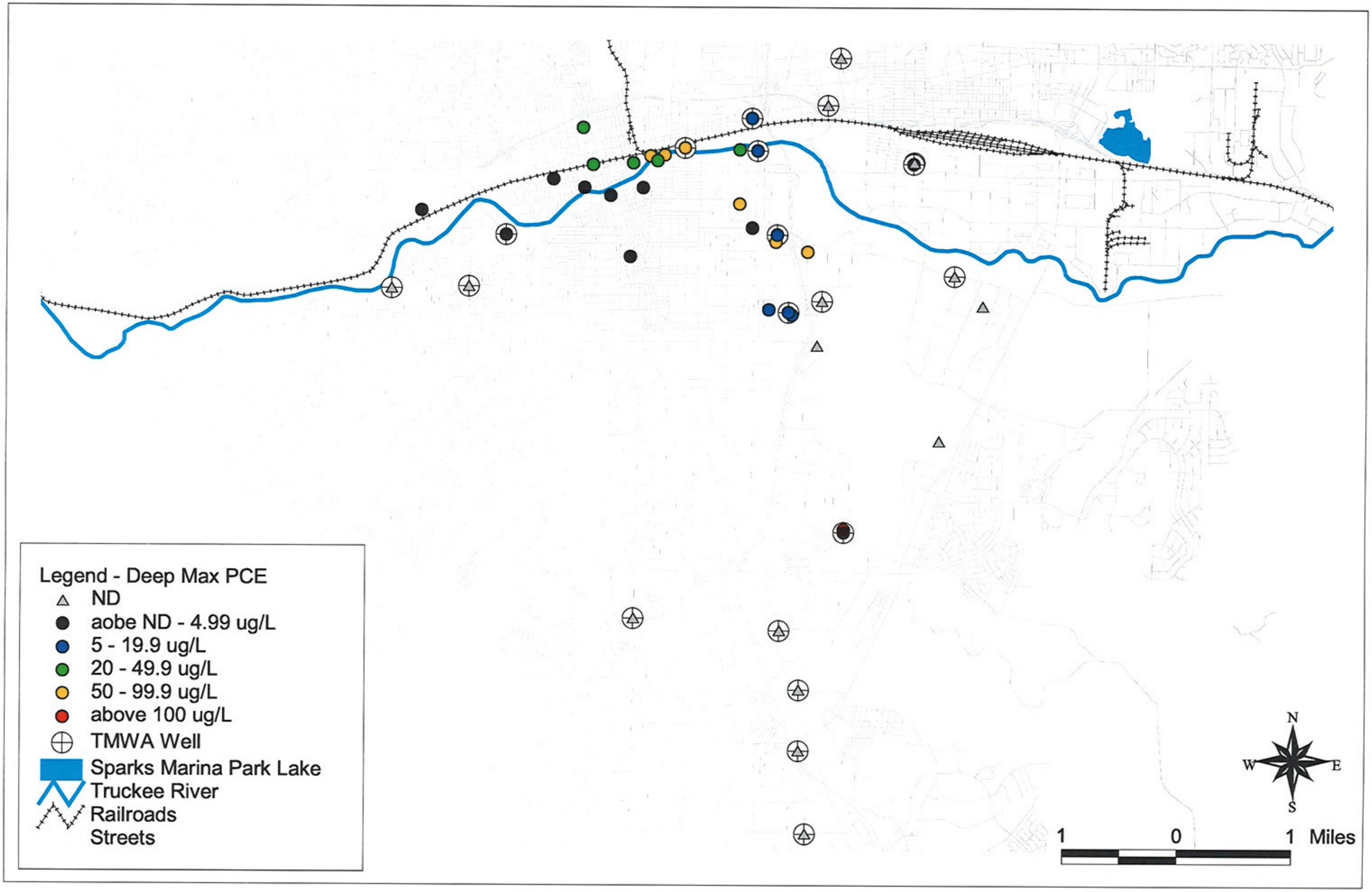
Figure 7-2
PCE Concentrations at TMWA Wells without Wellhead Treatment
Central Truckee Meadows Remediation District



Note: Maximum historical PCE concentrations used for this figure.

Figure 7-3
PCE Contaminanation Distribution - Shallow Aquifer
Centeral Truckee Meadows Remediation District



Note: Maximum historical PCE concentrations used for this figure.

CDM

Figure 7-4
PCE Contaminanation Distribution - Deep Aquifer
Centeral Truckee Meadows Remediation District

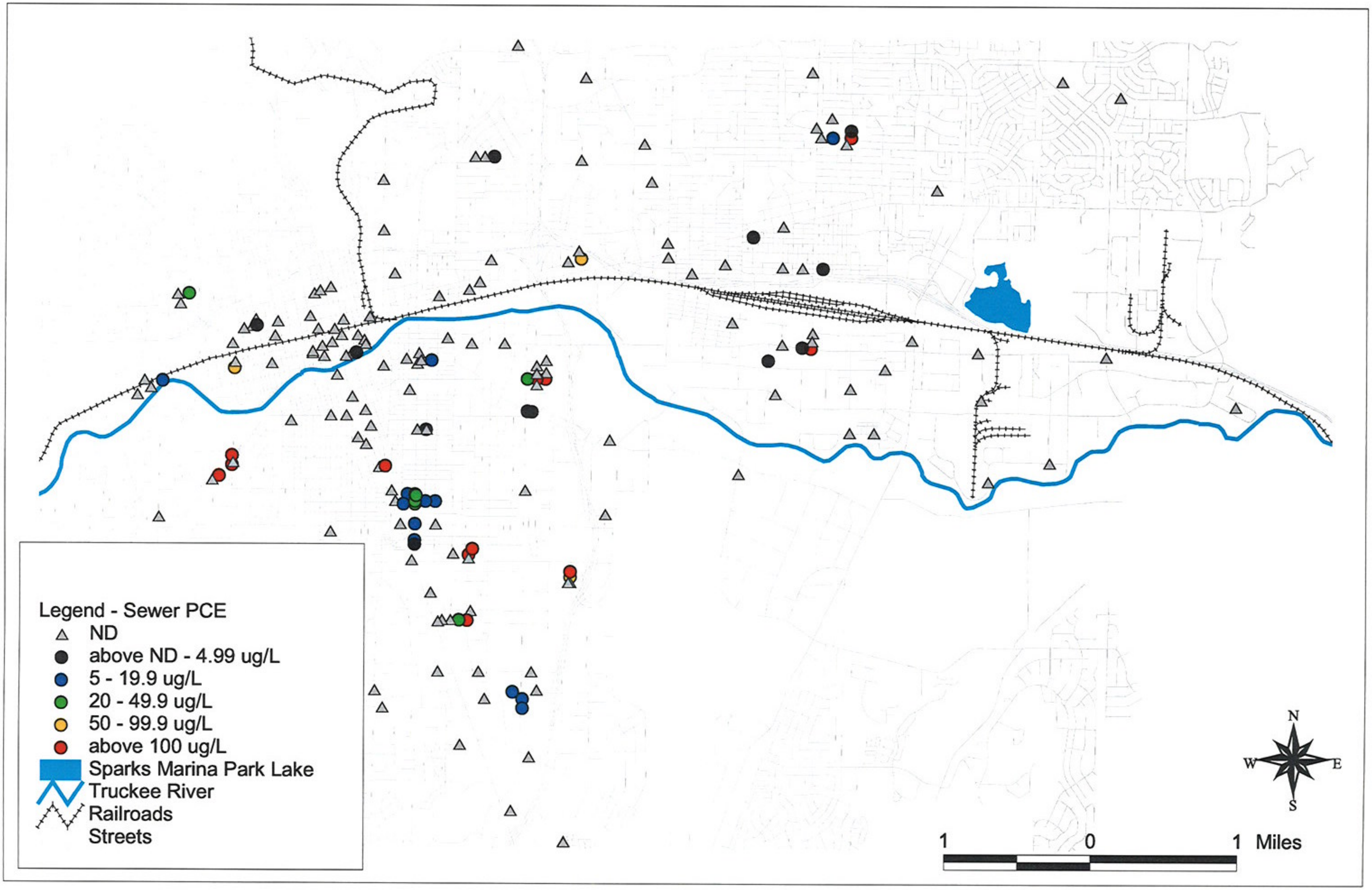
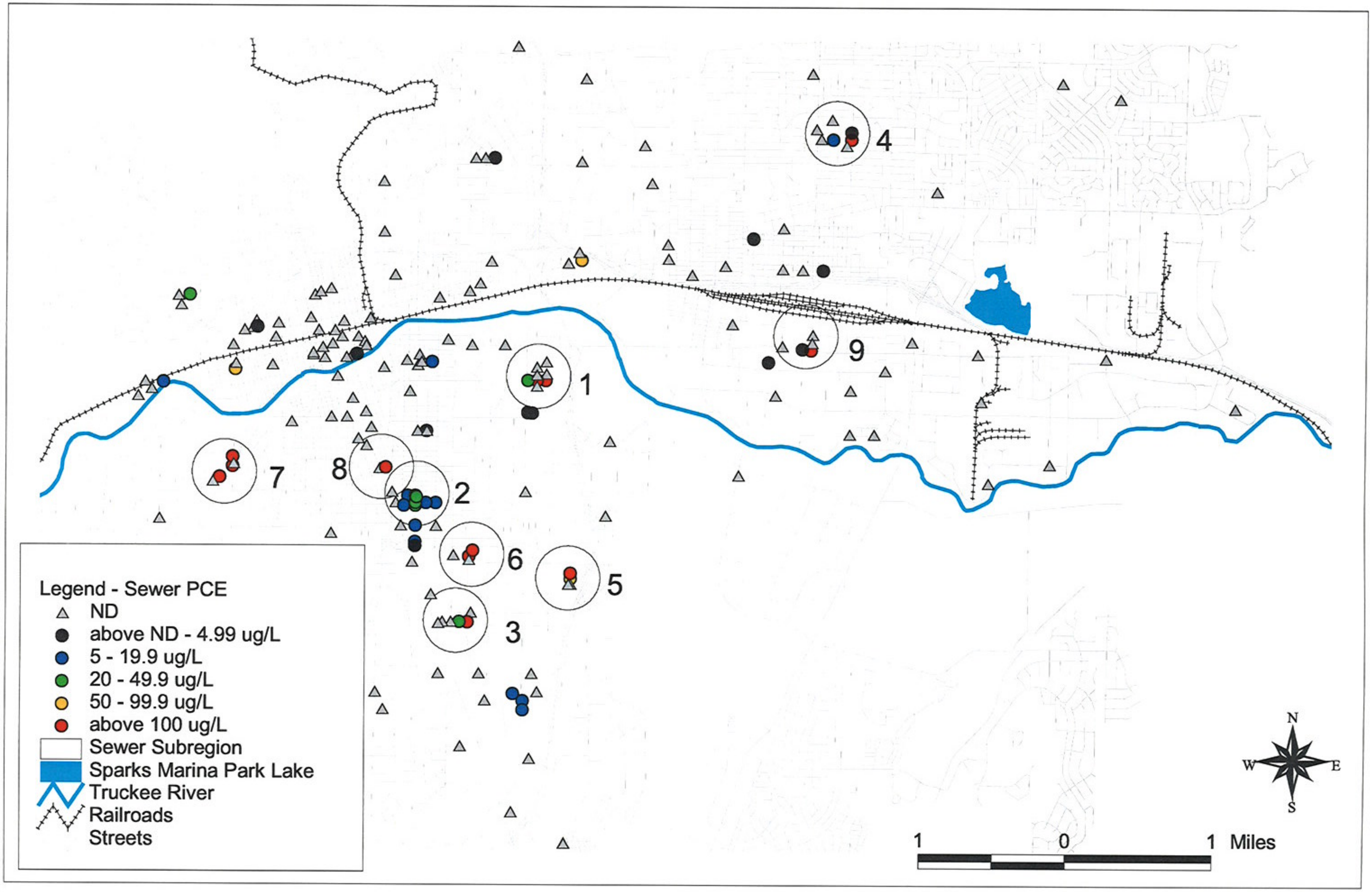


Figure 7-5
PCE Contaminanation Distribution from Sanitary Sewer Sampling
Centeral Truckee Meadows Remediation District



CDM

Figure 7-6
Sanitary Sewer Subregions
Centeral Truckee Meadows Remediation District

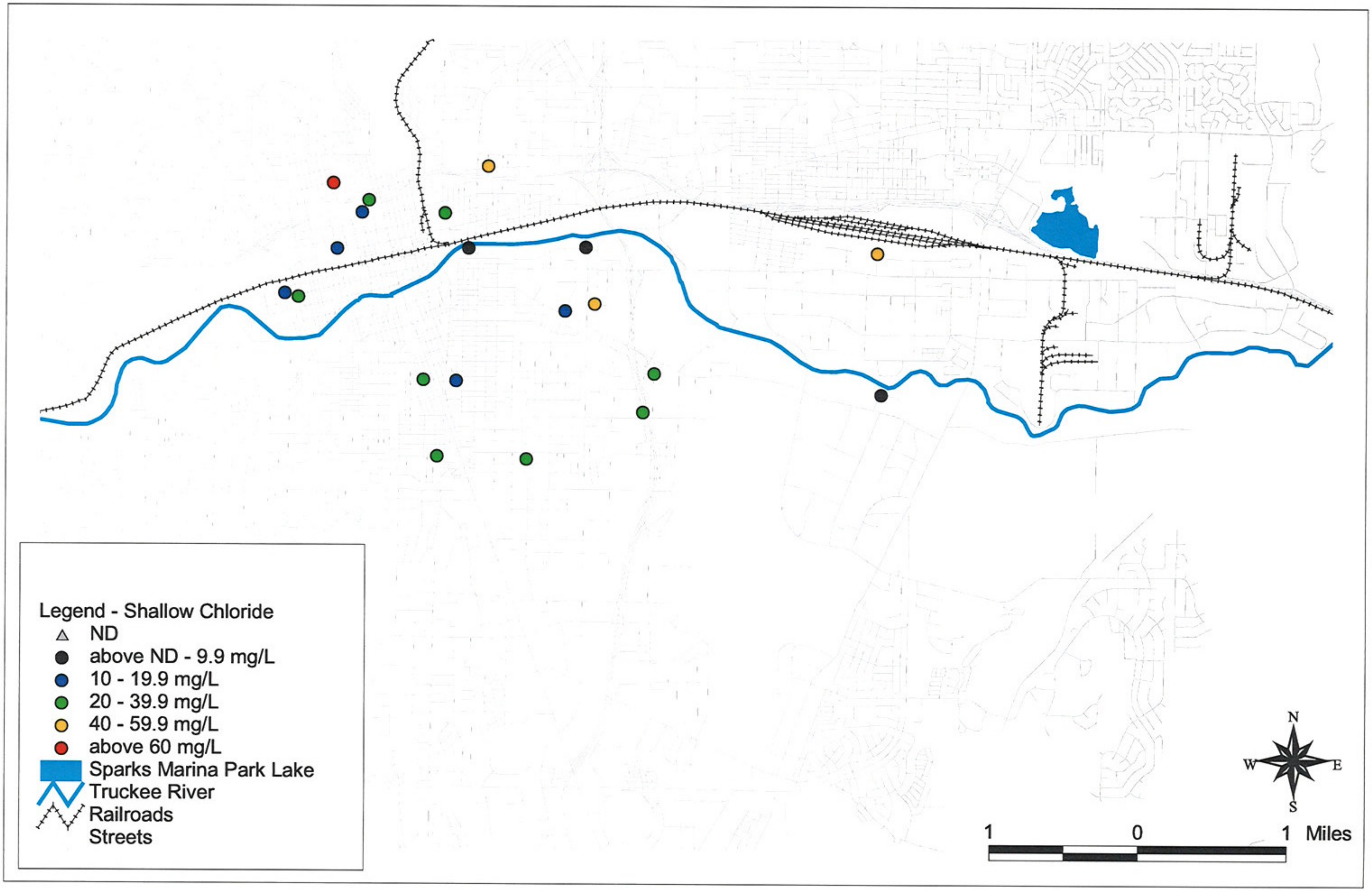


Figure 7-7
Chloride Distribution - Shallow Aquifer
Centeral Truckee Meadows Remediation District

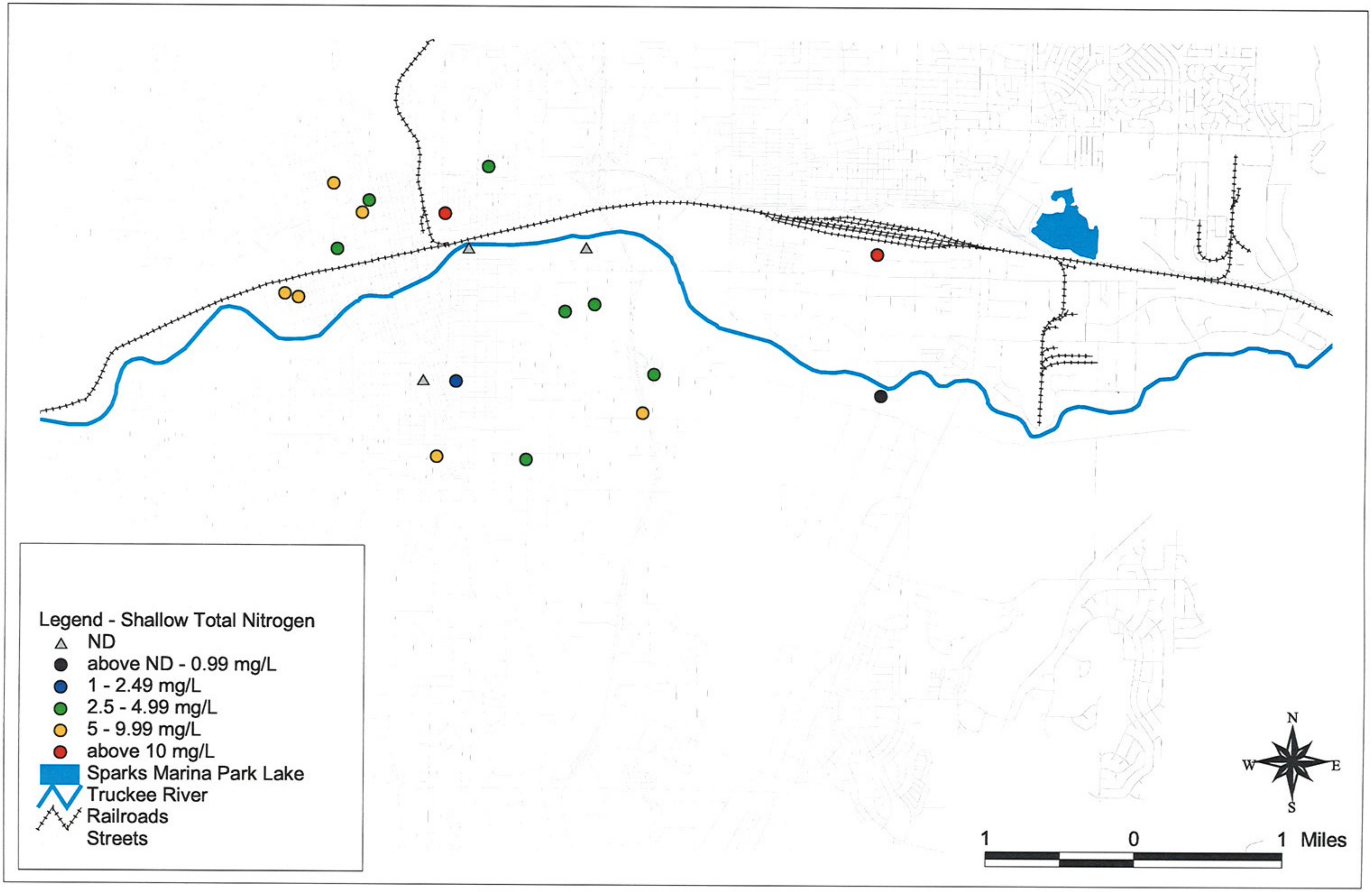
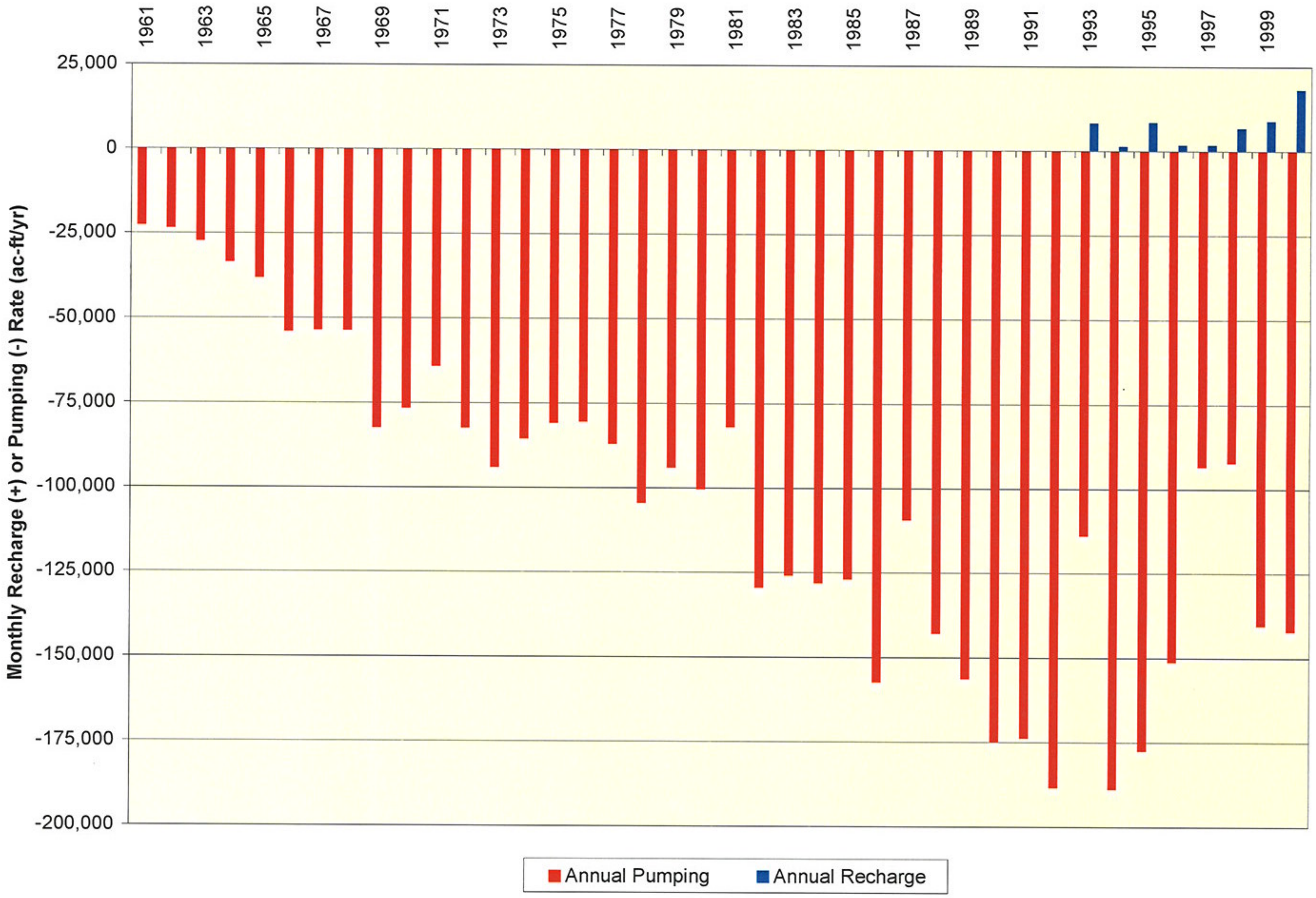


Figure 7-8
Total Nitrogen Distribution - Shallow Aquifer
Centeral Truckee Meadows Remediation District



pump_rch_th.xls: Chart-Annual TMWA
06/25/2002

Figure 7-9
Annual Recharge and Pumping at TMWA Wells
Central Truckee Meadows Remedation District

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Appendix A

Geophysical Logs

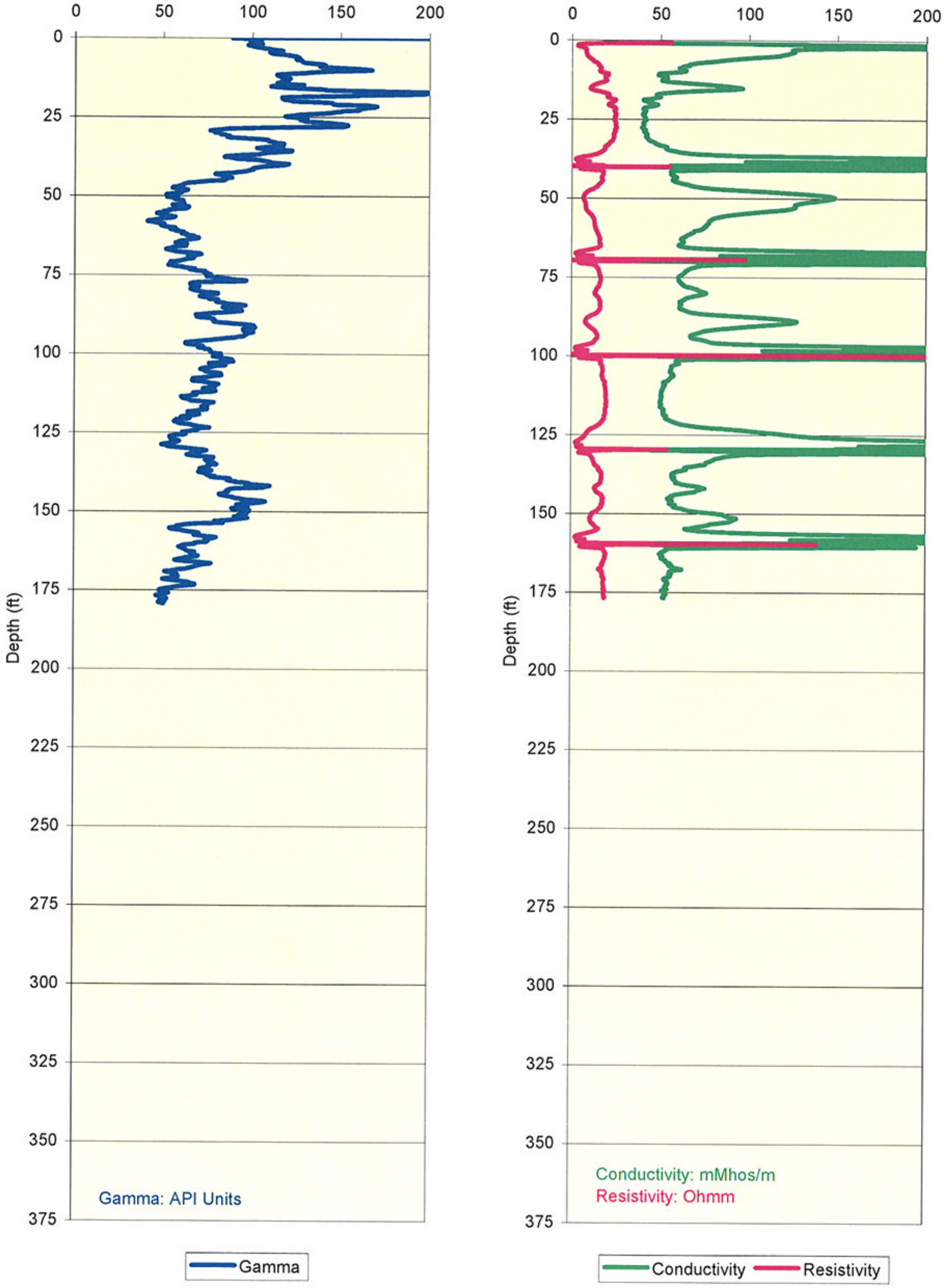

Figure A-1
Results of Geophysical Logging at Well CTM-4D
Central Truckee Meadows Remediation District

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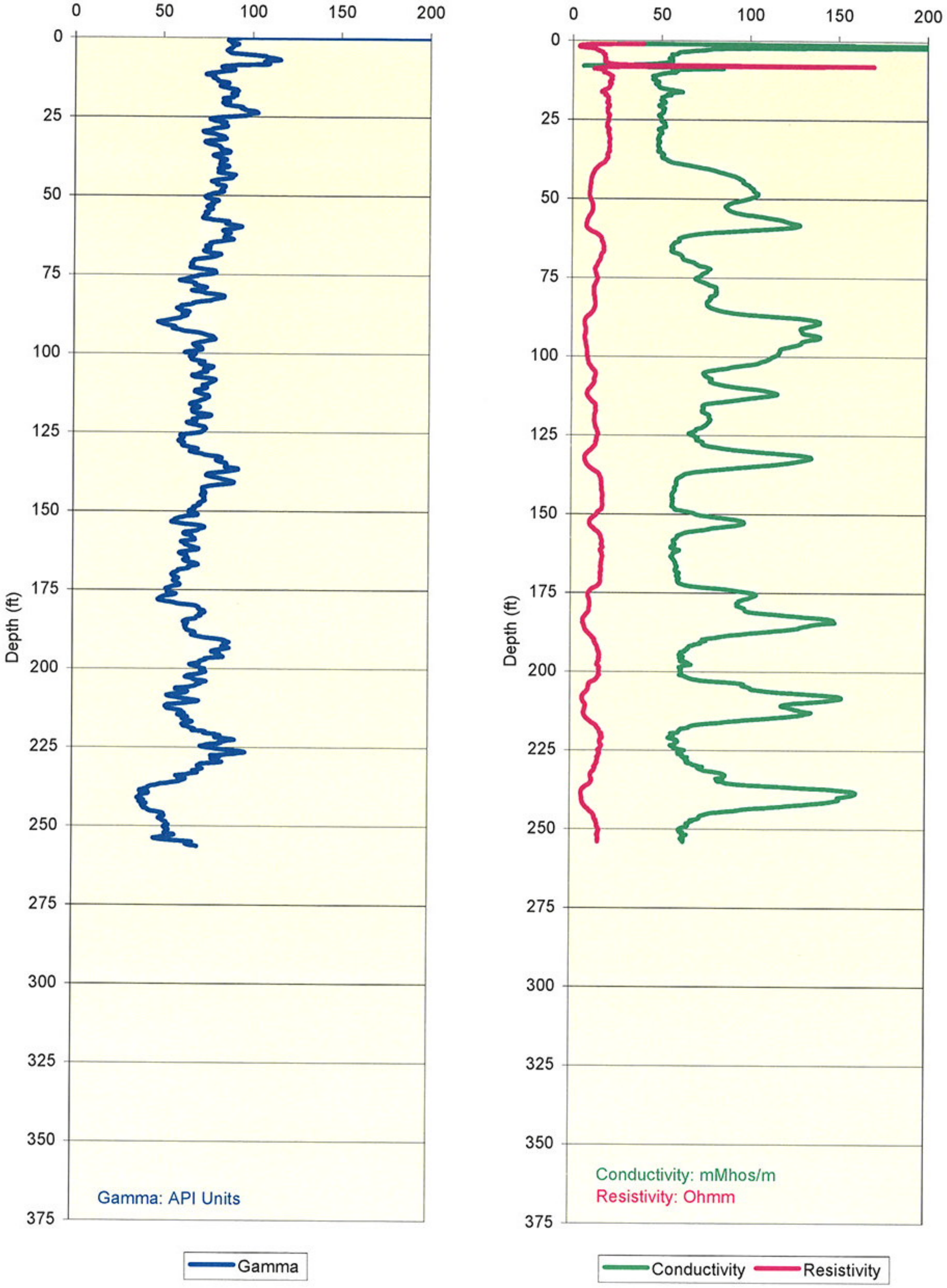
06/26/2002



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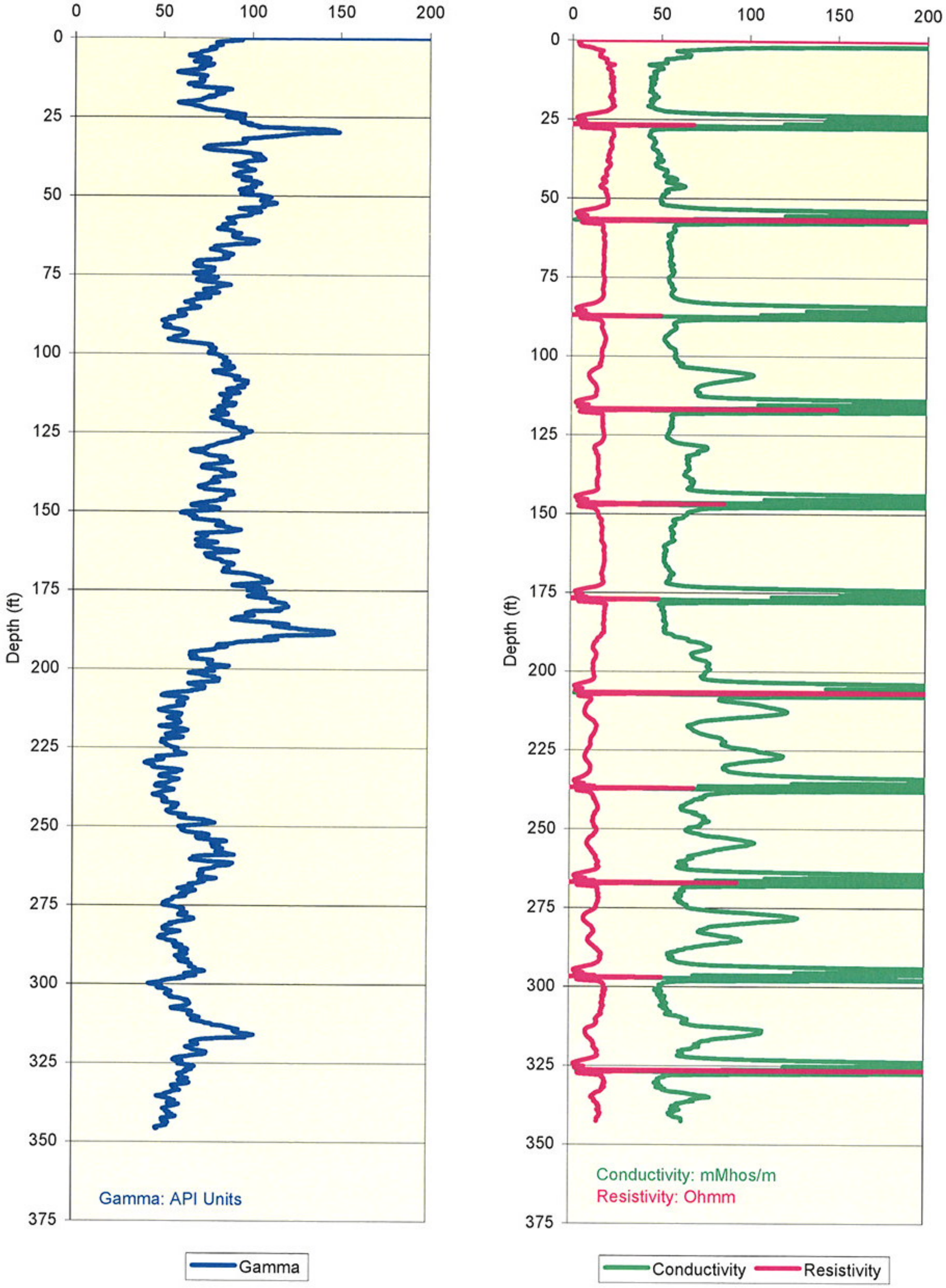

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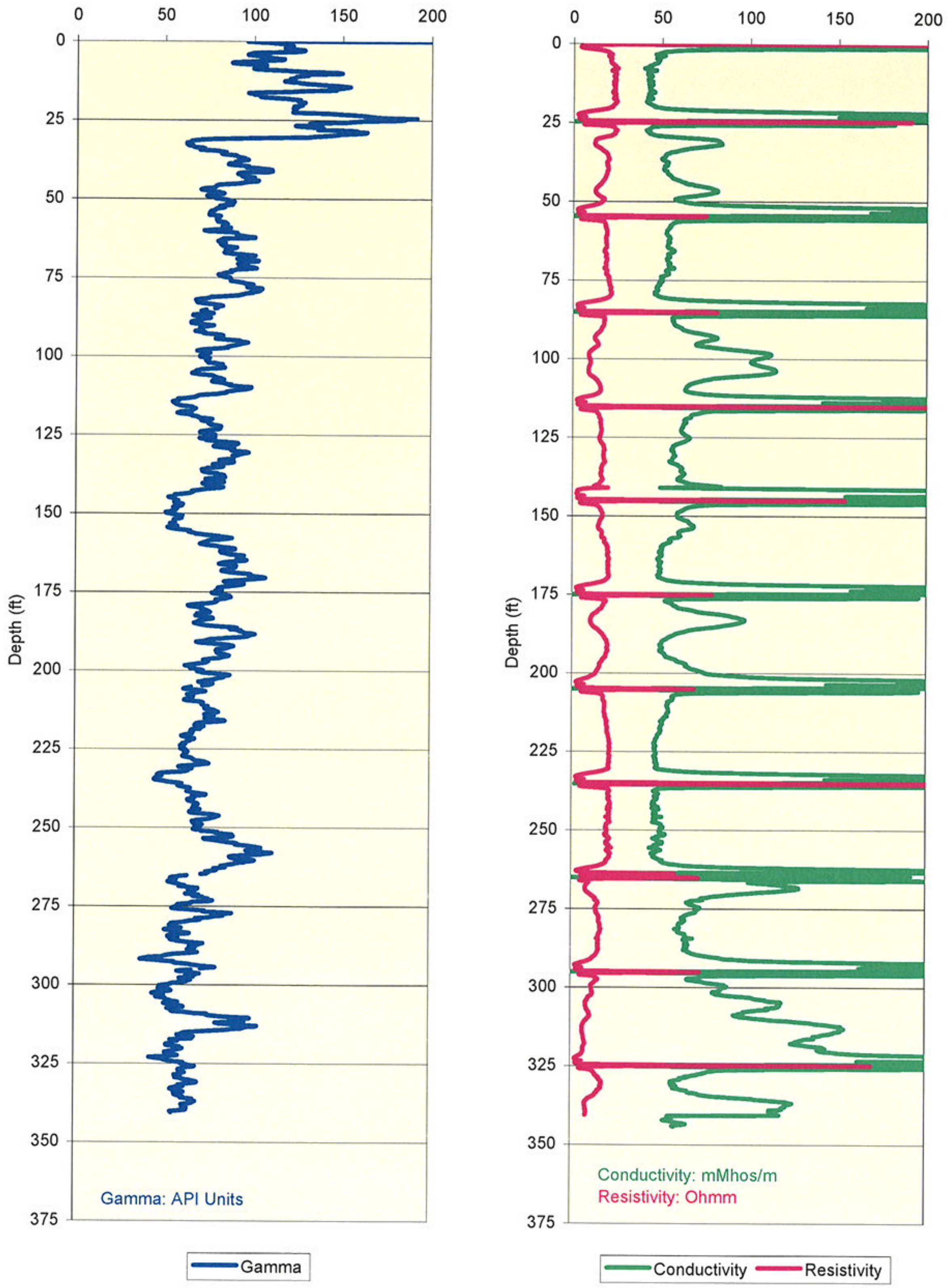

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Figure A-4
Results of Geophysical Logging at Well CTM-12D
Central Truckee Meadows Remediation District

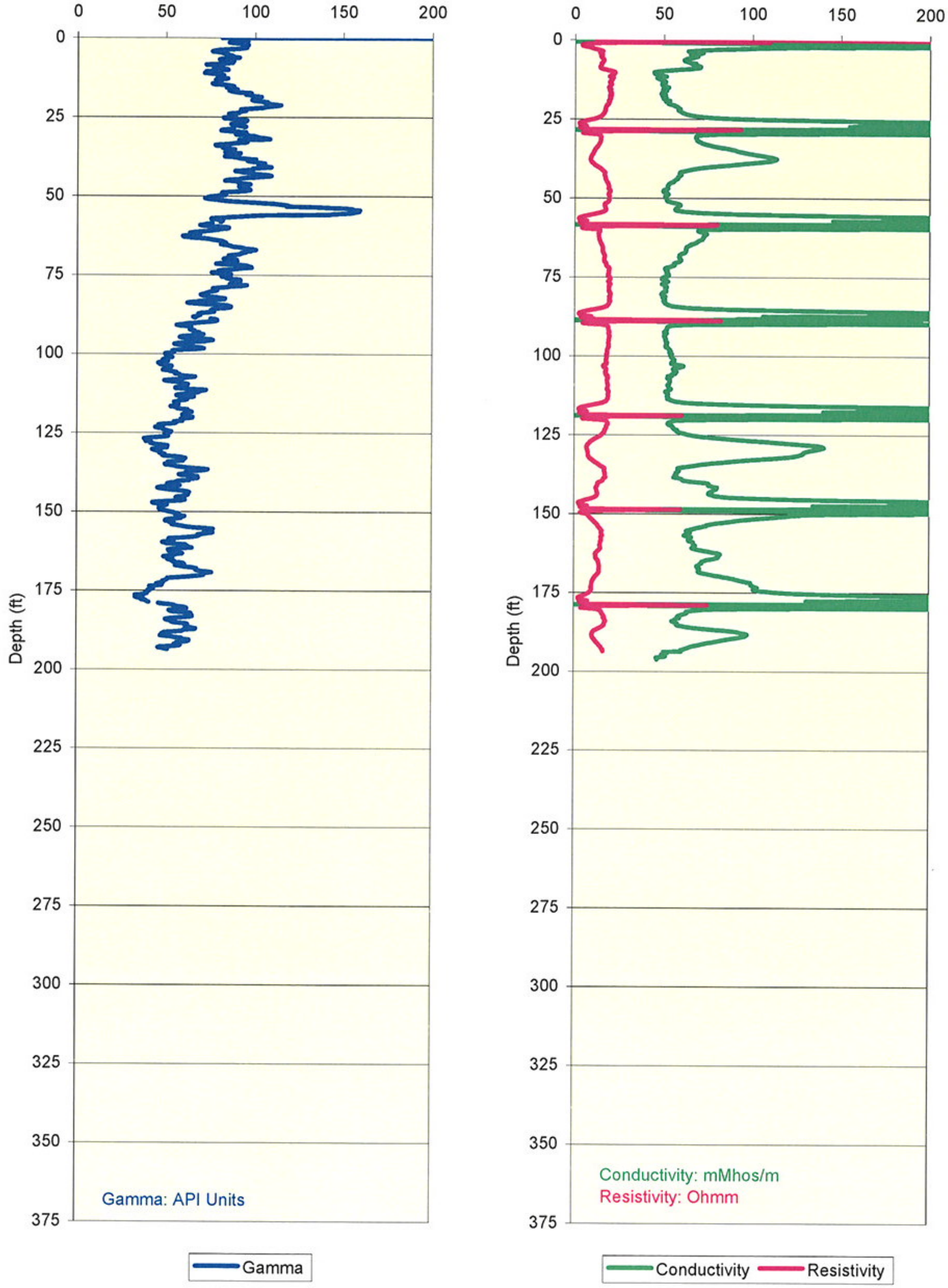

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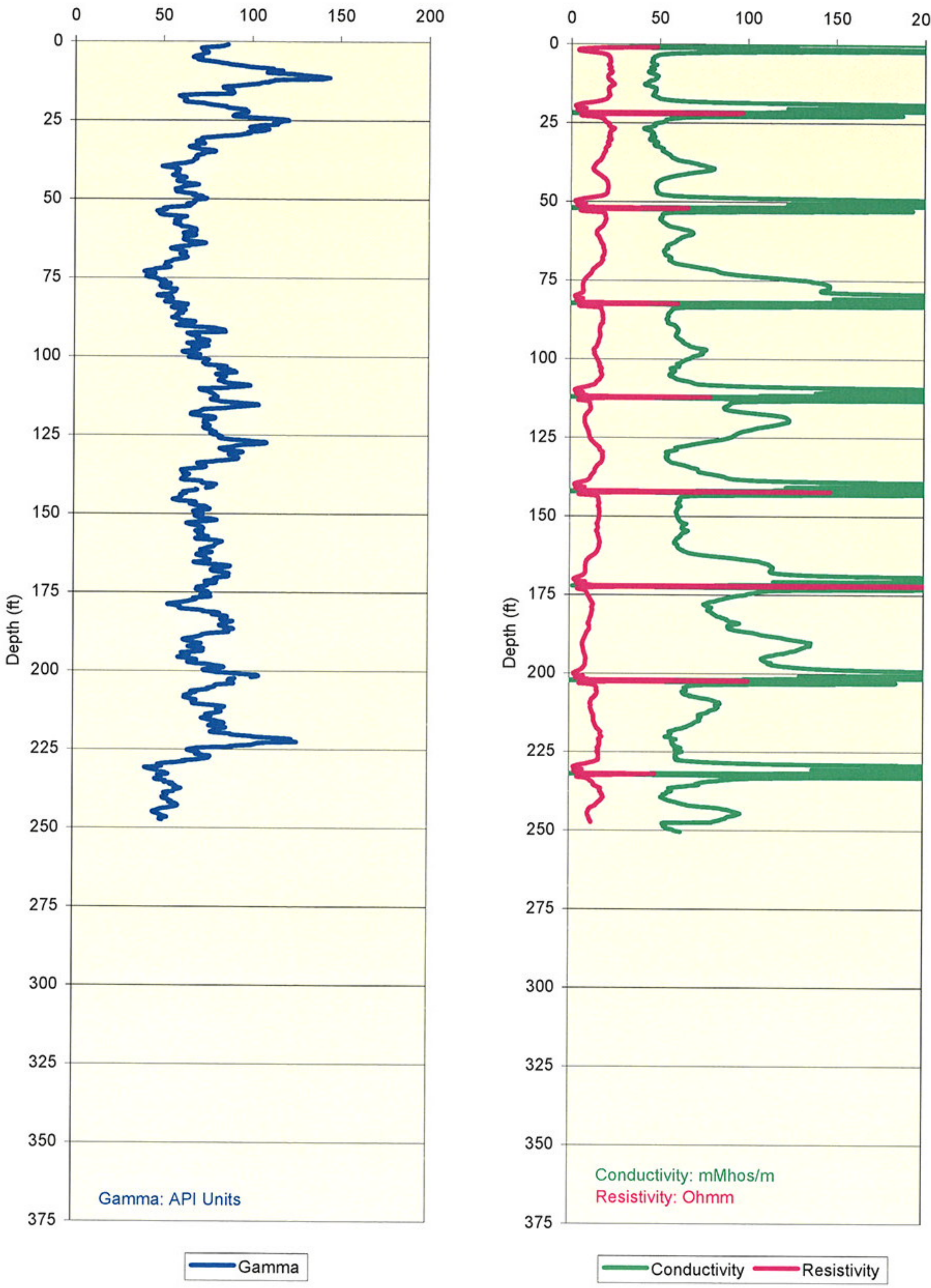
Figure A-5
Results of Geophysical Logging at Well CTM-17D
Central Truckee Meadows Remediation District



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Results of Geophysical Logging at Well CTM-22D
Central Truckee Meadows Remediation District

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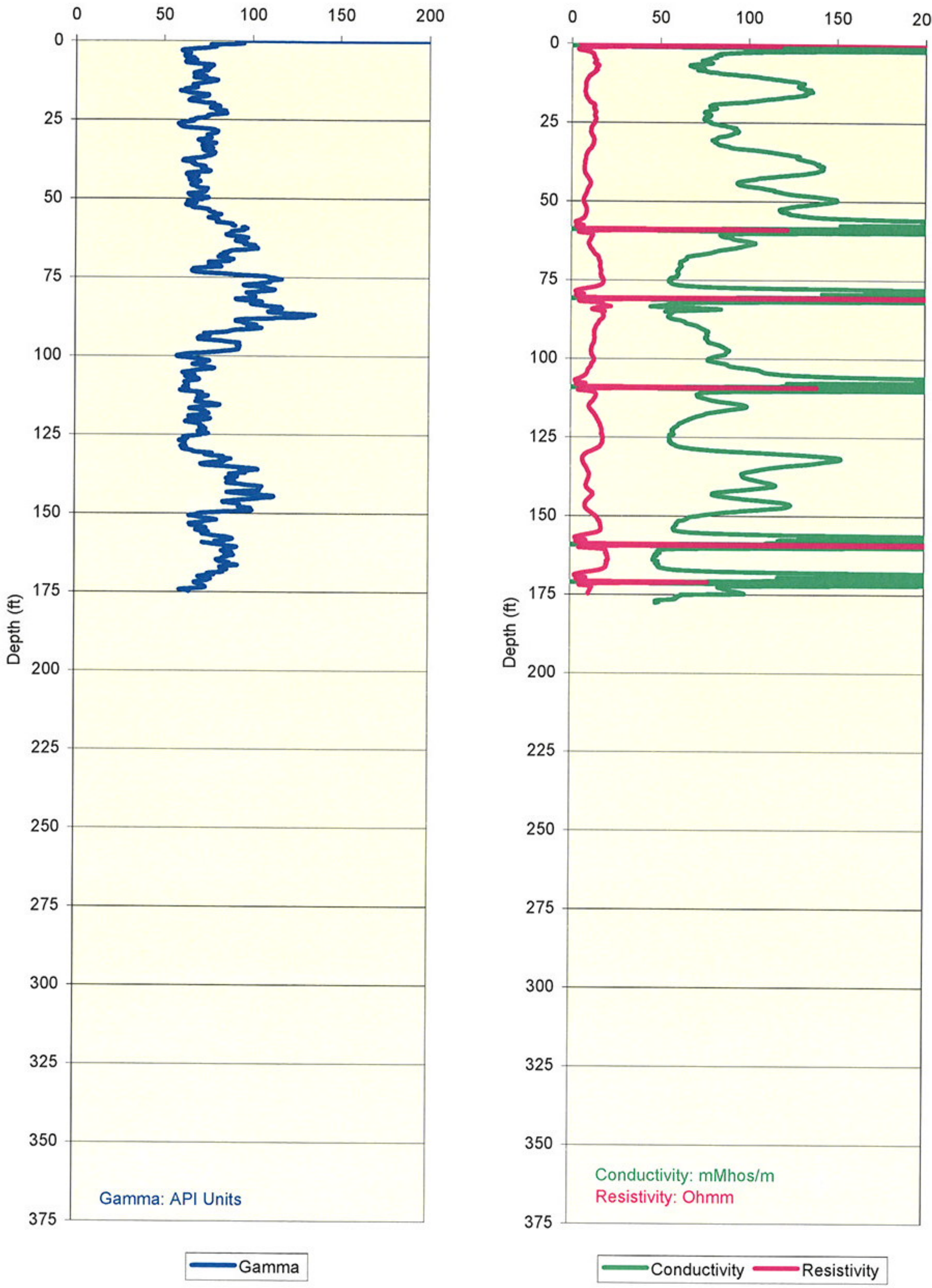

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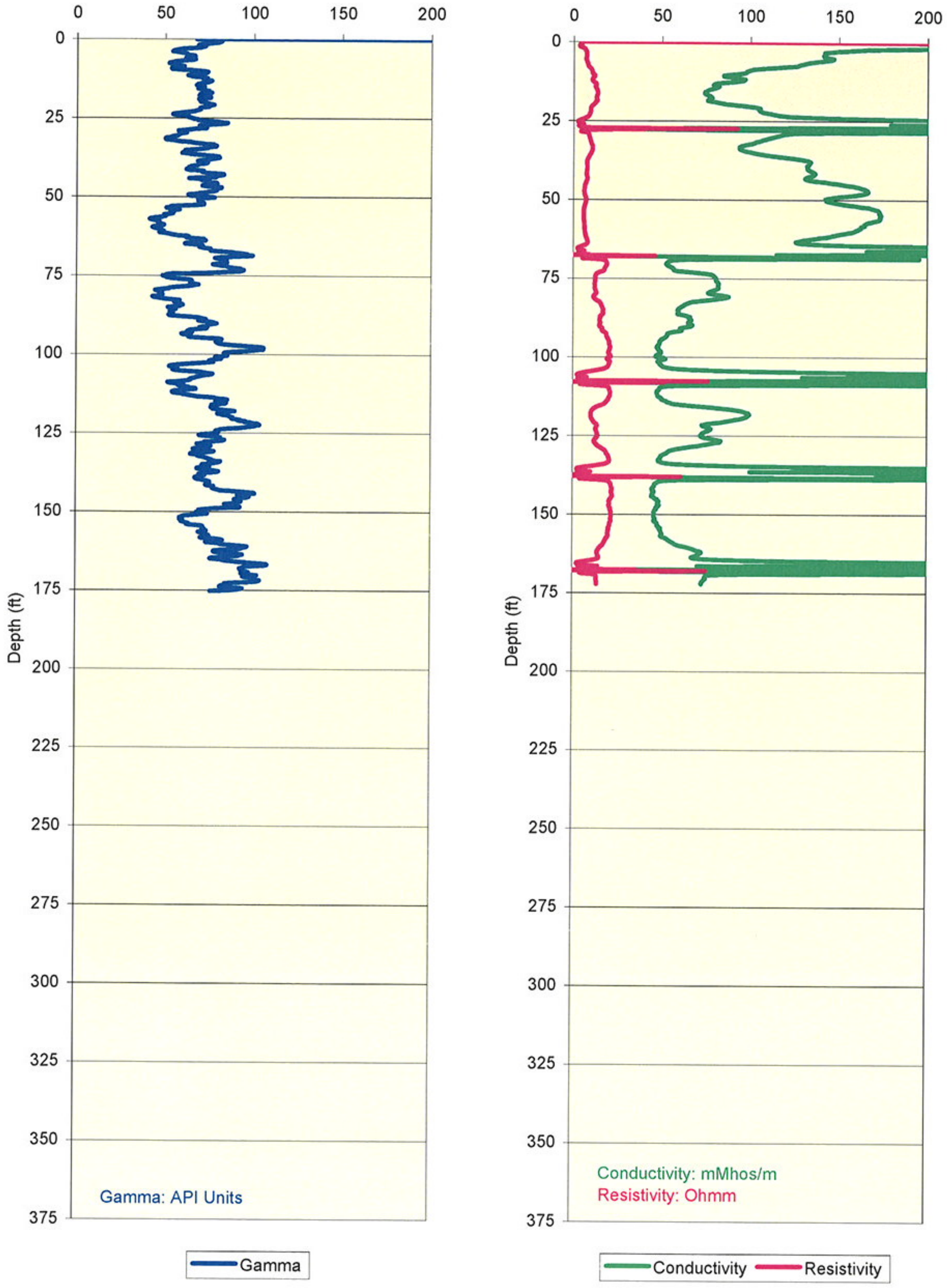
Figure A-7
Results of Geophysical Logging at Well CTM-23D
Central Truckee Meadows Remediation District



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Central Truckee Meadows Remediation District

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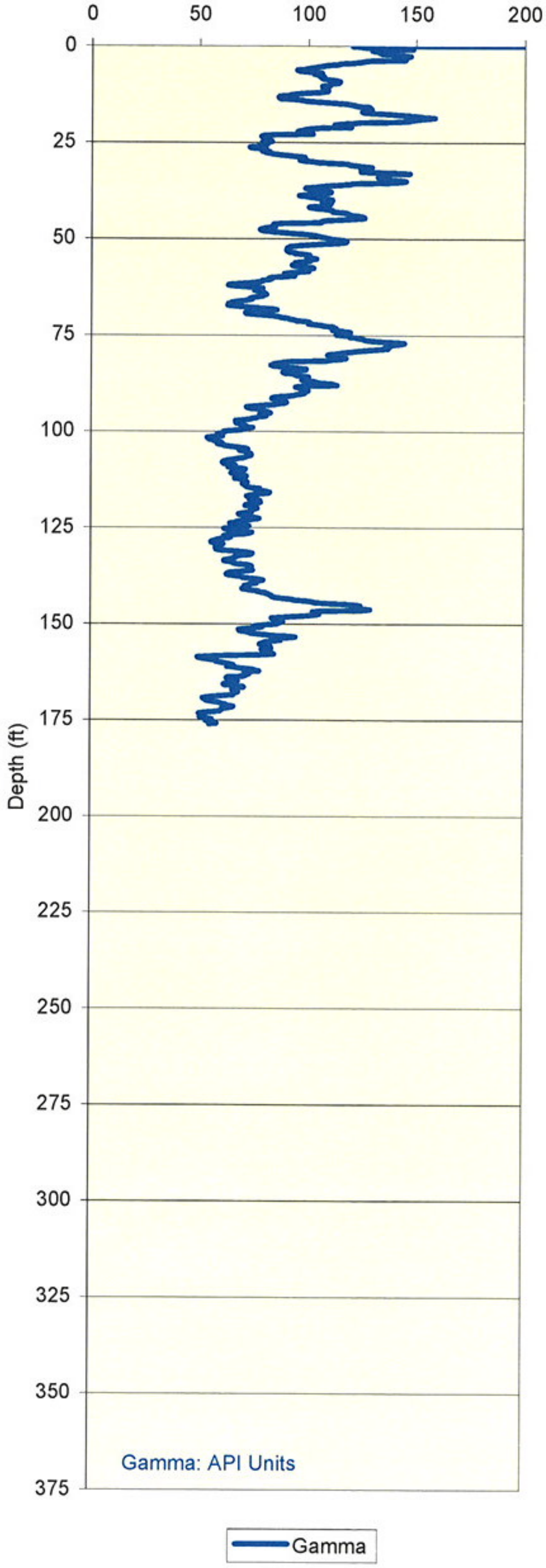

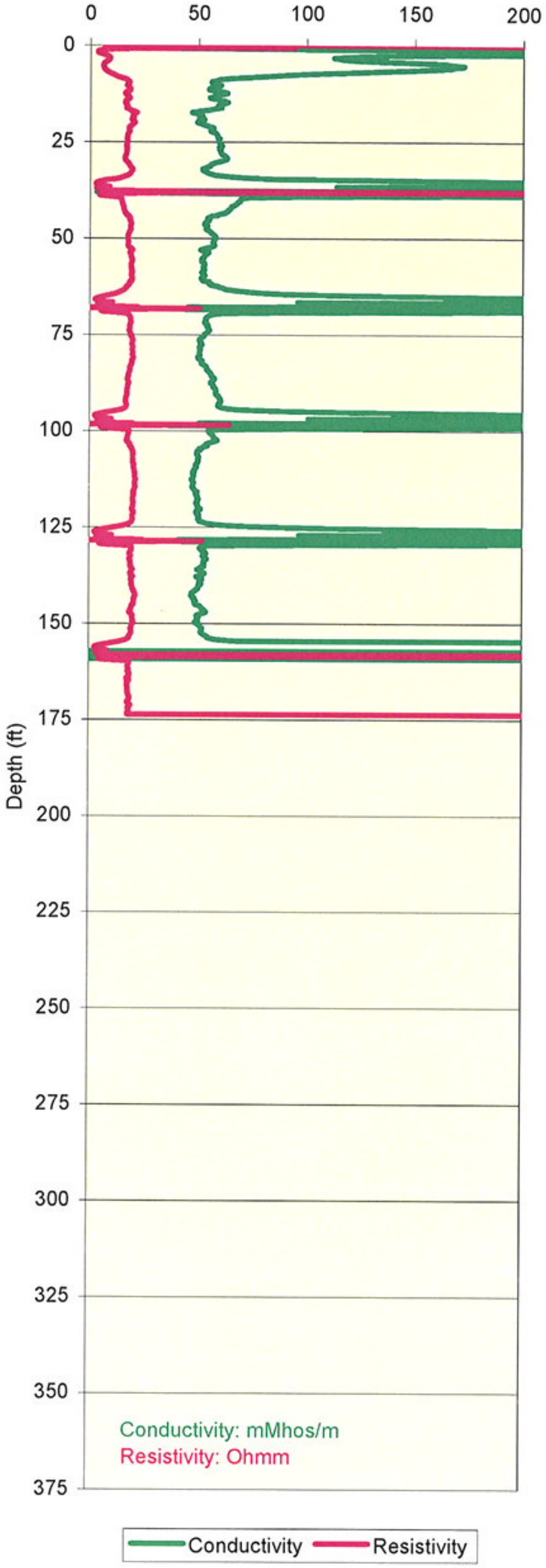

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Figure A-9
Results of Geophysical Logging at Well CTM-27D
Central Truckee Meadows Remediation District

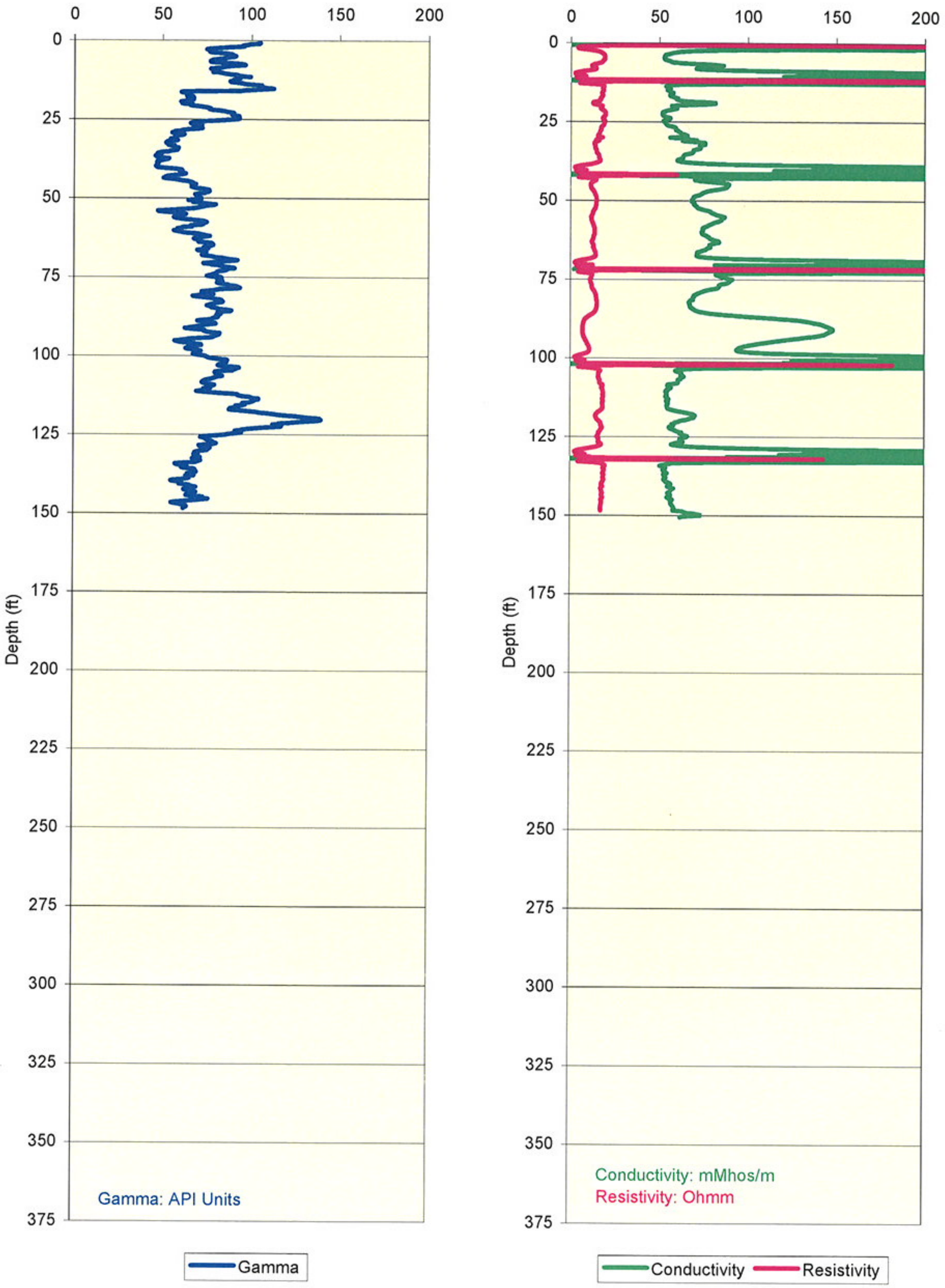

Figure A-10
Results of Geophysical Logging at Well CTM-30D
Central Truckee Meadows Remediation District

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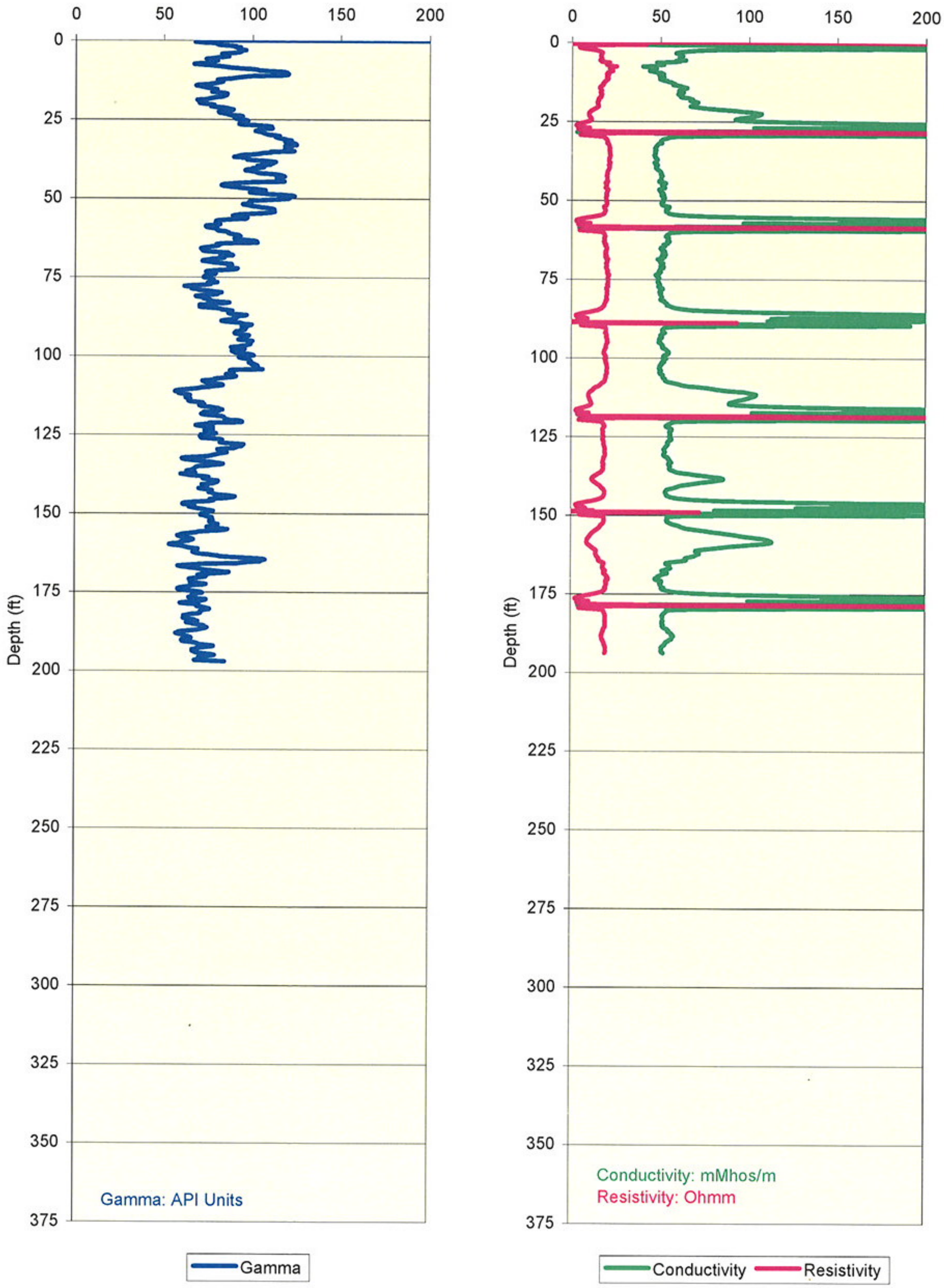

Figure A-11
Results of Geophysical Logging at Well CTM-33D
Central Truckee Meadows Remediation District

geophys.xls: Chart-33D
06/26/2002

Appendix E

Technical Memorandum – Remedial Technologies Identification and Screening

Central Truckee Meadows
Remediation District

Technical Memorandum
Remedial Technologies Identification and Screening

July 9, 2002

Technical Memorandum

Contents

Tables

Figure

Section 1
Introduction

The *Technical Memorandum -- Remedial Technologies Identification and Screening* (TM), was prepared by Camp Dresser & McKee (CDM) and Bouvette Consulting on behalf of the Washoe County Department of Water Resources (County). This TM is the fourth technical memorandum in a series of interim deliverables being produced in support of the Central Truckee Meadows Remediation District (CTMRD or "Remediation District") project. The initial three CTMRD technical memoranda are listed below:

- *Technical Memorandum – Field Investigations Program Data Summary,* dated July 9, 2002 (CDM, 2002a)
- *Technical Memorandum -- Human Health and Environmental Risk Analysis,* dated July 9, 2002 (CDM, 2002b)
- *Technical Memorandum -- Groundwater Modeling,* dated July 9, 2002 (CDM, 2002c)

Information and analyses documented in the technical memoranda are being used in the development of a Remediation Plan for the CTMRD. The purpose of the Remediation Plan is to address the presence of tetrachloroethene (PCE) in groundwater within the Central Truckee Meadows (CTM).

1.1 Background Information

PCE, an organic solvent used in a variety of commercial/industrial operations (e.g., commercial dry cleaning, paint manufacturing and distribution, auto repair) was initially found in groundwater within the limits of the city of Reno. Subsequent groundwater investigations have identified widespread occurrences of PCE and other volatile organic compounds (VOCs) in groundwater. Detailed discussions regarding site history, geology and hydrology, and planning and development of the field investigation program are compiled in the *Final Updated Work Plan* (CDM, 2001c) and in the three technical memoranda referenced above.

To address the presence of PCE in groundwater, the Nevada legislature established the Remediation District by enacting the State of Nevada Statue NRS 540A.250 through NRS 540A.285. The Remediation District was tasked to define the nature and extent of PCE in groundwater, to evaluate human health risks associated with the presence of PCE, and to develop and implement remedial actions addressing PCE impacts to the drinking water supply.

Remediation District Objectives and Goals

The objectives of the CTMRD have been defined, as follows:

- Protect the water quality within the CTM for municipal, domestic, or other beneficial uses.
- Protect from liability property owners that did not cause or contribute to subsurface PCE (or other non-fuel organic) contamination that may impact drinking water within the CTM.

The CTMRD goals, which translate the CTMRD objectives into more specific requirements for the selected remedial actions, have been defined as follows:

- Maintain the continued use of CTM groundwater for Public Water Supply.
- Manage PCE in groundwater and/or surface water in such a manner as to protect property owners and potable water users in the CTM.
- Select remedial action(s) that are reasonable and economically feasible.
- Allocate the costs associated with implementation of the Remediation Plan and its components equitably.

1.2 Purpose of the TM

The initial three technical memoranda characterized the physical, toxicological, and hydrogeochemical setting within the CTM as it relates to the distribution and nature of PCE, the key contaminant of concern. This TM provides documentation and analyses requisite to the selection of remedial technologies and remedial actions to be performed within the CTMRD.

Data generated as part of the field investigation program indicated widespread distribution of PCE contamination at low concentrations in the shallow aquifer and portions of the deep aquifer (i.e., depths greater than 100 feet). These data coupled with PCE levels that have been consistently detected in public water supply wells (i.e., Mill, Kietzke, High, Morill and Corbett) suggest that numerous, widely distributed sources are likely responsible for the observed contaminant distribution.

Although high, localized groundwater PCE concentrations have been identified, the data are not sufficient to adequately identify or characterize individual potential source areas for purposes of evaluating and selecting specific remedial actions or responses. Given that only a limited number of source areas have been suggested by the groundwater data to date, and the likelihood that many more sources exist within the CTMRD, an important function of the Remediation Plan will be to define institutional processes that will be used to identify, characterize, and remediate source areas. To this end, this TM has been designed to focus and streamline future efforts by identifying and discussing source characterization methods and remedial technologies that are applicable to the contamination conditions within the CTM. This TM will facilitate efforts by the CTMRD to:

- Collect data to identify and characterize sources.
- Evaluate remedial technologies.
- Select remedial actions for a given source type, location, size, and relative importance to protect the water quality within the CTM in a reasonable and economically feasible manner.

The specific objectives of this TM are highlighted below:

- Identify the general response actions that are applicable to source areas and their related plumes.
- Discuss the volume and extent of PCE contamination - both based on the available data and in terms of hypothetical source areas.
- Identify and screen technologies and process options.
- Evaluate remedial action technologies and process options.
- Develop a list of remedial technologies and process options that may be used to remediate source areas or their related plumes.

It is the list of retained remedial technologies and process options that will be used to focus and streamline future remedial action evaluations performed during implementation of the Remediation Plan.

1.3 Technical Memorandum Organization

This TM consists of five sections. Section 1, *Introduction*, provides background information, identifies the Remediation District objectives and goals, and defines the purpose of the TM (i.e., a description of how this TM fits into the overall framework of the ongoing development of the remediation program). Section 2, *Conceptual Site Model and Initial Screening of Technologies*, provides an updated description of the conceptual site model and defines what has been characterized as the primary "areas" of contamination within the CTM (i.e. source areas, plume areas, and water supply wellhead treatment). This section also presents the initial screening of technologies for all three areas of contamination. Based on this screening effort, short lists of remedial technologies specifically applicable to the three areas of contamination are defined. Section 3, *Source Area Characterization Method Evaluation*, identifies methods for characterization of the nature and extent of contamination for use in future source area evaluation efforts. Section 4, *Source Area Remedial Technology Evaluation*, describes the retained remedial technologies for PCE source areas and gives potential applications for these technologies. This TM concludes with Section 5, *References*.

Section 2
Conceptual Site Model and Initial Screening of Technologies

2.1 Conceptual Site Model

The Remediation Plan that will be developed to guide and direct future remedial actions performed within the CTMRD will be facilitated by evaluations documented in this TM.

Based on data generated as part of the field investigation program, the risk analyses, and the groundwater modeling, three distinct "areas" or "zones" of contamination have been identified. These areas of contamination, which have been differentiated based in part on the point of application of remedial actions, are listed below;

- Source areas;
- Groundwater plume areas (both shallow and deep); and
- Wellheads used for potable water supply.

Remedial actions, as well as field characterization activities, will need to address source "management" as it relates to prioritizing, characterizing, evaluating and remediating sources and their related plumes, and shallow and deep groundwater contamination. To this point, the presentation of remedial technologies and process options presented herein will address these three areas contamination, within the CTMRD.

Figure 2-1 presents a cross-sectional view of the conceptual model of contamination within the CTMRD. In this figure, the source area, the plume area and the public water supply wellheads are all identified. The conceptual source area, as indicated on this figure, includes both contamination above the groundwater in vadose zone soils and within the saturated zone (as shown in bright red). The plume area includes both shallow groundwater and deep groundwater. Within CTM, groundwater is considered to be shallow if it is less than 100 feet below ground surface. Deep groundwater is all groundwater below that depth. This depth was selected based in part on the distribution of PCE contamination, the lithology, and the practical aspects of implementing remedial actions at depths of greater than 100 feet, in that one set of alternative technologies that are applicable and cost effective above 100 feet, may not be cost effective below 100 feet. Public water supply wellheads are considered a critical point of application within the CTM because of the extensive use of groundwater as a water supply source.

All discussions presented in the following sections will differentiate potentially applicable characterization and remedial technologies and methods in terms of these three areas. Issues such as depth below ground surface, contaminant concentrations,

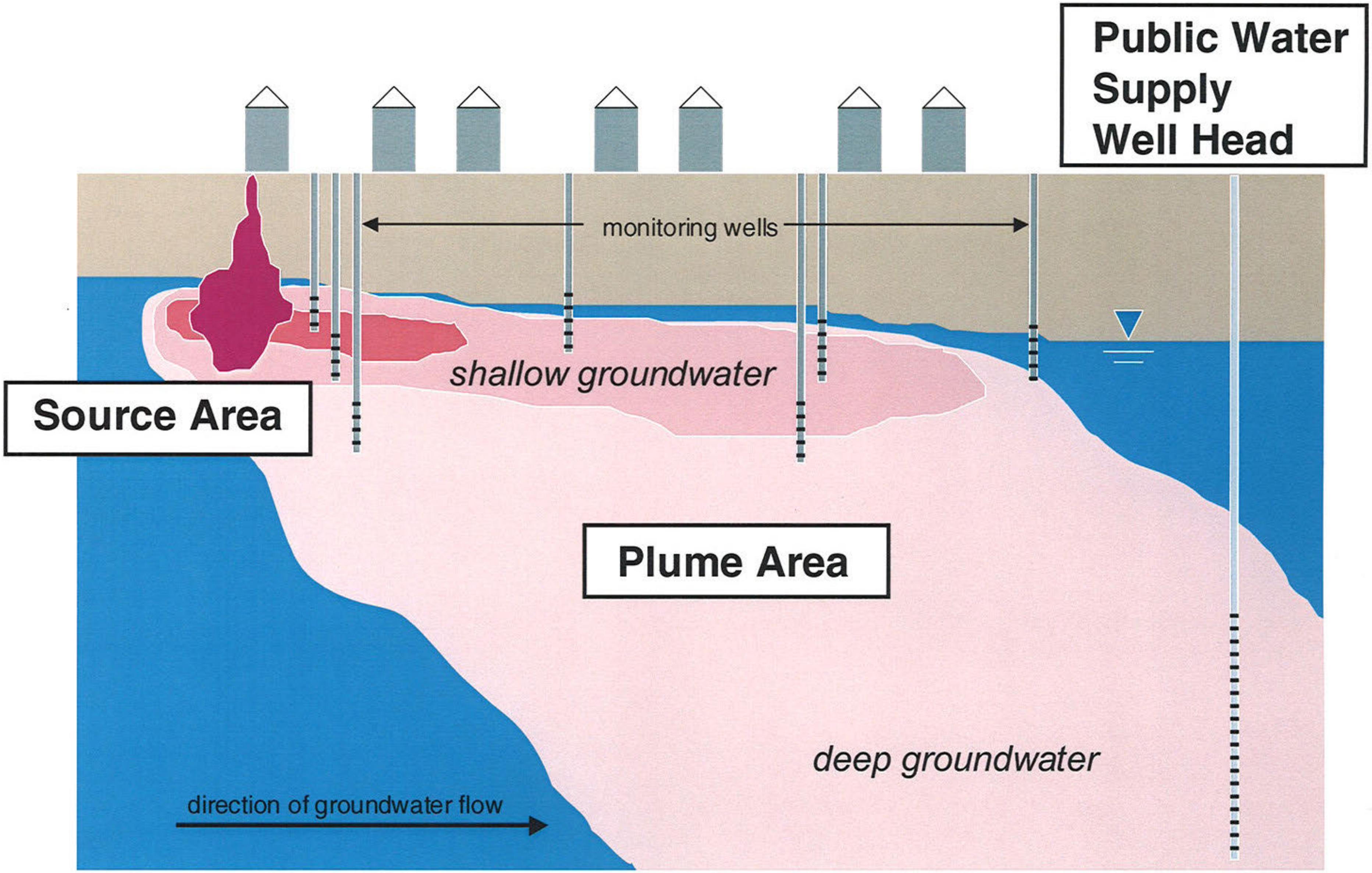

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Figure 2-1
Conceptual Model of Contamination within the
Central Truckee Meadows Remediation District

or contaminant volumes or mobility will influence applicability of a given technology to source areas or shallow or deep groundwater plume areas. Therefore, recommendations for characterization and remediation methods will be segregated into lists for source areas, plume areas, and wellhead treatment, as appropriate. Note that in some cases the recommendations for plume area remediation may be differentiated into subcategories for shallow and deep groundwater, as the situation warrants.

2.2 General Response Actions

This section presents the General Response Actions (GRAs) that are considered to be potentially applicable for remediation of PCE within the CTMRD. GRAs are measures that will satisfy the RDGs and RDOs for a particular area of contamination.

2.2.1 No Action

Under the No Action GRA, there would be no effort to physically restrict access to affected areas or to reduce any risk to human health and the environment. A long-term monitoring program may be performed to monitor the contaminant distribution in groundwater and to assess potential and actual risks.

2.2.2 Institutional Controls

Institutional controls are non-engineered methods by which federal, state, and local governments or private parties can restrict access to contaminated or affected environmental media. Most institutional controls are in the form of use or access restrictions. These may also include simple physical actions such as posting warning signs or more complex regulatory actions such as implementing well restrictions or zoning controls.

2.2.3 Containment

Containment response actions provide a means by which contaminant migration is minimized or eliminated. Containment response actions can be implemented both above and below ground. Examples of technologies under this GRA are hydraulic containment via pumping from wells, and physical barriers such as slurry walls.

2.2.4 Removal

Removal response actions consist of operations that partially or completely remove contaminants from the original site location. They include removal and transportation to another location for treatment or disposal, either onsite or offsite. The most relevant example for the CTMRD is soil excavation at source areas with off site disposal.

2.2.5 Treatment

Treatment response actions serve to reduce the toxicity, mobility, and/or volume of contaminants through physical or chemical alteration. There are four treatment technologies that fall under the treatment GRA: physical, chemical, biological, and thermal. Relevant examples include groundwater pump and treat, *in situ* chemical oxidation, *in situ* biological treatment and monitored natural attenuation.

2.3 Initial Screening of Technologies and Process Options

For each of the GRAs identified in Section 2.2, a number of potentially effective technologies exist that are applicable to each of the contamination areas or points of application within the CTM. Potentially effective technologies and associated process options have been identified and are initially screened on the basis of technical feasibility regarding CTMRD conditions and likely characteristics of PCE, the primary contaminant of interest.

In this section, the process options associated with the technically feasible technologies are evaluated relative to each other in terms of effectiveness, implementability, and cost. The emphasis of this evaluation is placed on the effectiveness of protecting human health and the environment, with less focus on implementability and cost. The three criteria used at this level of screening are described below.

2.3.1 Effectiveness

This criterion focuses on:

- The potential effectiveness of process options in handling the estimated contaminated areas or volumes of contaminated media and meeting the RDGs and RDOs;
- The effectiveness of the process options in protecting human health and the environment during the construction and implementation phase; and
- The reliability of the process options with respect to the anticipated contaminants and conditions for the areas of contamination.

2.3.2 Implementability

Implementability encompasses both the technical and institutional feasibility of implementing a process option. Technical feasibility is used as an initial screen to eliminate options that are clearly ineffective or unworkable. This criterion also considers institutional aspects of implementability, such as the ability to obtain necessary permits for offsite actions; the availability of treatment, storage and disposal services; and the availability of necessary equipment and skilled workers to implement the technology.

2.3.3 Relative Cost

Cost plays a limited role in the screening of process options. Relative capital and O&M costs are used rather than detailed estimates. In this evaluation, the cost analysis is based on engineering judgment, and each process option is evaluated as to whether costs were high, moderate, or low relative to other process options in the same technology type.

2.4 Initial Screening Results

The results of the screening process for technologies and process options that apply to the contamination areas or points of application are presented in Tables 2-1 and 2-2 for groundwater and soils, respectively. The process options within each technology type receiving the highest performance ratings for the evaluation criteria were retained for possible incorporation into one or more remedial action alternatives. These retained process options are listed for each of the three areas of contamination in Table 2-3. Provided below are summary discussions of each contamination area and the retained process options.

2.4.1 Plume Area

Given the process options identified in Table 2-3, the remedial alternatives potentially applicable to addressing contamination within the Plume Area include:

- No Action
- Monitored Natural Attenuation
- Institutional Controls (including Use Restrictions and Public Education)
- Groundwater Pump and Treat (includes groundwater extraction and optional treatment and disposal methods)

The following discussion addresses the application of groundwater pump and treat as a remedial alternative to address plume area contamination under the conditions existing within the CTM. The available groundwater data have been evaluated to estimate the volume of the contaminated water within the aquifer beneath the CTM. Contaminated groundwater is assumed to be any groundwater that contains detectable amounts of PCE. The estimated areal extent of contamination (shown in Figure 2-1) is approximately 13 square miles. The thickness of the zone of contaminated groundwater is more difficult to estimate given the large areal extent and the variability in the depth of PCE contamination. The thickness of the zone of contaminated groundwater varies from several feet near source areas to more than 350 feet in localized areas near production wells. For the purposes of this estimate, it

General Response Actions	Remedial Technology	Process Option	Description	Effectiveness	Implementability	Cost	Screening Comments and Areas Where Potentially Applicable
No Further Action	None	Not Applicable	Action is limited to groundwater monitoring only.	Low	High	Low	May be applicable for limited portions of plume areas or small source areas with limited access.
Natural Attenuation	Monitoring	Monitored Natural Attenuation	Structured monitoring program designed to verify contaminant attenuation through naturally occurring processes is protective of human health and the environment.	Low	High	Moderate	Potentially applicable for plume and source areas, especially when combined with active source reduction measures.
Institutional Controls	Use Restrictions	Use Restrictions	Limit exposure through placement of access or deed restrictions on properties within potentially impacted areas.	Low	Moderate	Moderate	Potentially applicable for plume and source areas. Although such measures do not directly address contaminant mass, they limit the potential for unacceptable human exposure to contaminants.
		Public Education	Increase public awareness through public hearings and media.	Low	High	Low	Potentially applicable. Although such measures do not directly address contaminant mass, they limit the potential for unacceptable human exposure to contaminants.
Hydraulic Containment	Vertical Barriers	Slurry Wall	Trench around contaminated areas and backfill excavation with a soil-bentonite or cement-bentonite mix	Moderate	Moderate	High	Potentially applicable. Potential for lateral and vertical migration of VOCs at inaccessible source areas.
		Grout Curtain	Pressure injection of grout along contamination boundaries in regular overlapping pattern of drilled holes	Moderate	Moderate	High	Not applicable. Continuity of curtain is difficult to achieve and potential for lateral and vertical migration of VOCs from source areas is likely.
		Sheet Piling	Lengths of steel sheets are connected and driven into the ground along contamination boundaries	Moderate	Moderate	High	Not applicable. Potential for lateral and vertical migration of VOCs from source areas. Also, not cost effective in most applications.
	Surface Water Infiltration Reduction	Source Area Capping	Clay, asphalt, concrete, or building structures placed over areas of high surface water infiltration to limit local groundwater recharge	Low	High	Low	Potentially applicable to reduce influx of contaminants into groundwater and limit contaminant mobility at some source areas. Effectiveness, however, is low/moderate due to limited recharge that currently occurs at the CTMRD.
		Storm Water Diversion/Control	Structures designed to prevent runon into infiltration areas and manage accumulation and discharges of precipitation	Low	High	Low	Potentially applicable to reduce influx of contaminants into groundwater and limit contaminant mobility at some source areas. Effectiveness, however, is low/moderate due to limited recharge that currently exists at the CTMRD.

▨ Process Option Eliminated from Further Consideration

Table 2-1

Screening of Groundwater Remediation Technologies and Process Options

General Response Actions	Remedial Technology	Process Option	Description	Effectiveness	Implementability	Cost	Screening Comments and Areas Where Potentially Applicable
Groundwater Collection/Extraction	Extraction	Groundwater Extraction Wells	Installation of a series of wells to extract contaminated groundwater	Moderate/High	High	Moderate	Potentially applicable for containment and/or mass removal from plume and source areas. Extraction would be most effective in more permeable water-bearing units, or if necessary, in conjuction with interceptor drains. Extraction in low permeable zones would be limited by small hydraulic capture zones.
		Dual Phase Extraction	Applying a high vacuum to a well located within the contaminated zone and screened across the water table, thereby inducing two phase flow: soil vapor and groundwater.	Moderate	High	Moderate	Potentially applicable at source areas with lower permeability soils. Simultaneously removes contaminants from vadose zone and groundwater.
		Interceptor Drains / Infiltration Galleries	Perforated pipe in trenches backfilled with porous media to collect contaminated water, or distribute amendments through piping network.	Moderate	Moderate	Moderate	Potentially applicable but limited to source areas with low permeability soils that preclude effective extraction by wells. More cost-effective when implemented in conjunction with concurrent soils excavation activities.
Treatment	*In Situ* Treatment	Enhancad Bioremediation	Enhance existing microbial conditions by injecting electron donating/accepting compounds, nutrients, and/or microorganisms into the subsurface	Low to High	Moderate	Moderate	Potentially applicable at source areas and small plume areas when used in conjunction with infiltration galleries, or applied to more permeable water-bearing units. Requires pilot testing to determine if proper conditions can be established.
		Chemical Oxidation	Inject chemical oxidizing agents to destroy contaminants in place	Low to Moderate	Moderate	Moderate	Potentially applicable to saturated soils at source areas applied to more permeable water-bearing units. Contaminated media need to be well-defined and the oxidant demand of aquifer materials needs to be determined in a lab.
		Air Sparging	System of wells to inject air into groundwater to remove volatiles by air stripping	Low to Moderate	Moderate	Moderate	Potentially applicable to saturated soils at source areas, however, use is limited to high permeability soils with limited heterogeneities. VOC-laden vapors must be collected via SVE for above ground treatment.
		Reactive Gate	Slurry wall that channels groundwater into a permeable cell ("gate") containing iron, or other medium, that reacts with or traps contaminants	Low to Moderate	Low to Moderate	High	Not applicable due to lack of competent bedrock to key gate into at reasonable depth.
		Phytoremediation	Use of specific plant types to enhance degradation of contaminants in groundweter	Low	High	Low	Not applicable. Root system of plants not likely to extend fully through the contaminated zone; groundwater uptake rates not sufficient to provide effective treatment.
	Ex Situ Treatment	Air Stripping	Air forced through liquid in a packed column or by diffused aeration to promote transfer of volatile contaminants into vapor	High	Moderate	Moderate	Applicable for plume and source areas and wellhead treatment. Treatment system "off-gas" would likely require treatment. Pretreatment for removal of total suspended solids and reduced metals may be required.
		Membrane Technologies	Use of high pressure to force water through a membrane leaving contaminants behind	Low	Low to Moderate	High	Not applicable. Not as reliable or cost effective as other technologies for VOC removal from groundwater; Reject stream requires disposal.
		UV-Enhanced Chemical Oxidation	Combination of ultraviolet light (UV) and strong oxidant to oxidize organics	High	Low to Moderate	High	Not applicable. Not es reliable or cost effective as other technologies for VOC removal from groundwater;
		Biological Treatment	Use of microorganisms to oxidize or reduce VOCs	Moderate	Moderate	High	Not applicable. Not as reliable, and characterized by high operation and maintenance relative to other process options.

▨ Process Option Eliminated from Further Consideration

Table 2-1 (cont.)
Screening of Groundwater Remediation Technologies and Process Options

General Response Actions	Remedial Technology	Process Option	Description	Effectiveness	Implementability	Cost	Screening Comments and Areas Where Potentially Applicable
	Ex Situ Treatment (Continued)	Activated Carbon Adsorption	Adsorption of organic contaminants onto activated carbon by passing contaminated media through reactive carbon columns.	Moderate to High	High	Moderate	Potentially applicable for vapor and liquid phase VOCs at plume and source areas and for wellhead treatment. Compare cost effectiveness to air stripping.
		▨ Synthetic Resin Adsorption Units	Selective adsorption of organic contaminants onto synthetic resins	Moderate	Moderate	Moderate	Not applicable. This technology has greater tolerance for high moisture content vapor streams as compared to activated carbon. However, the Implementability is considered moderate due to emerging status of process option and PCE is effectively removed by carbon.
		▨ Thermal Oxidation	Thermal destruction of VOC vapors through combustion processes	Low to Moderate	Moderate	High	Not applicable. Off-gas not antipicated to have combustable VOCs in range to make this alternative cost-competitive with other process options.
		Catalytic Oxidation	Thermal destruction of VOC vapors through combustion processes coupled with catalytic oxidizers	Low to Moderate	Moderate	Moderate to High	Potentially applicable, but only at source areas with very high contaninant concentrations in off gas. Treated vapors would likely require scrubbing processes to remove hydrogen chloride. Furthermore, off-gas not antipicated to have combustable VOCs in range to make this alternative cost-competitive with other process options.
		▨ Vapor Condensation Units	Condensation of VOC vapors through the use of a heat exchanger	Low	Moderate	Moderate	Not applicable. Most applicable to high contaminant concentrations (over the long-term) and low waste stream flow rates. Under these conditions, this option is not cost effective compared to other process options.
		▨ Oxidant Impregnated Materials	Oxidation of VOCs using high surface area materials such as alumina or zeolite coated with permanganate	Moderate to High	High	Moderate	Not applicable for vapor phase VOCs. This option is only applicable as a polishing treatment for low hydrophobicity compounds (e.g., VC) in effluent of vapor phase activated carbon units.
Disposal	Onsite Disposal	Injection Wells	Injection wells inject extracted and treated water into aquifer	Low	Low	High	Not applicable. Potential exists for impacting production wells and difficulty in obtaining reinjection permits.
		Surface Discharge	Extracted and treated water discharged on the surface (e.g., wetlands)	High	Low	Moderate	Potentially applicable, but appropriate disposal locations are limited and costs are highly variable depending on the treatment required for discharge.
		▨ Exfiltration Beds	Extracted and treated water discharged through perforated pipe in trenches backfilled with porous media	Low	Low	Moderate	Not applicable. Potential exists for impacting production wells and difficulty in obtaining reinjection permits.
		Atmospheric Emission	Discharge of vapor treatment "off-gas" to the atmosphere. Such off-gas may originate from various treatment options discussed above.	High	Moderate	Low	Applicable for vapor streams treated for VOCs. Implementation of this technology is moderate as regulatory permits would be required.
	Offsite Disposal	Storm Sewer Discharge	Extracted and treated water discharged to storm sewer	High	Moderate	Moderate	Potentially applicable, but would require National Pollutant Discharge Elimination Sytsem Permit (NPDES) permitting and monitoring.
		POTW	Extracted and treated water discharged to local POTW for treatment	High	Moderate	Moderate to High	Potentially applicable, but would require permits and monitoring for connection to POTW.

▨ Process Option Eliminated from Further Consideration

Table 2-1 (cont.)
Screening of Groundwater Remediation Technologies and Process Options

General Response Actions	Remedial Technology	Process Option	Description	Effectiveness	Implementability	Cost	Screening Comments and Areas Where Potentially Applicable
No Further Action	None	Not Applicable	Action is limited to groundwater and soil monitoring only.	Low	High	Low	May be applicable for small source areas with limited access.
Removal	Excavation	Surgical Excavation	Limited excavation of contaminated soils at or above the water table generally using backhoes or trackhoes.	Moderate to High	Moderate	Moderate	Applicable at source areas with limited vadose zone contamination that is well defined and accessible. Groundwater contaminants can also be removed if excavation extends below water table and excavtion is dewatered, however, groundwater treatment and disposal is then required.
Treatment	*In Situ* Treatment	Enhanced Bioremediation	Enhance existing microbial conditions by injecting electron donating/accepting compounds, nutrients, and/or microorganisms into the subsurface	Low to High	Moderate	Moderate	Potentially applicable for saturated soils at source areas when used in conjunction with infiltration galleries, or applied to more permeable water-bearing units. Requires pilot testing to determine if proper conditions can be established.
		Chemical Oxidation	Inject chemical oxidizing agents to destroy contaminants in place	Low to High	Moderate	Moderate	Not applicable to unsaturated soils at source areas, but may be applied to more permeable water-bearing units. Contaminated media need to be well-defined and the oxidant demand of aquifer materials needs to be determined in a lab.
		Soil Vapor Extraction	Extract soil vapors from a vertical well screened within the contaminated vadose zone. Treat the extracted vapors at the surface.	Moderate to High	Moderate	Moderate	Potentially applicable to unsaturated soils at source areas, particularly when soils are inaccessible or excavation is costly.
		▨ Phytoremediation	Use of specific plant types to enhance degradation of contaminants in groundwater	Low	High	Low	Not applicable. Root system of plants not likely to extend fully through the contaminated zone; land uses around most source areas likely preclude planting of vegetation required.
	Ex Situ Treatment	Ex Situ Soil Vapor Extraction	Excavated soils are stockpiled in covered piles with perforated piping inserted throughout. Vapors are extracted from the piping and treated.	Moderate to High	Moderate to Low	Moderate	Potentiall applicable for source areas with large tracks of vacant land where soil piles could be established and operated. Treatment system "off-gas" would likely require treatment.
		▨ Low Temperature Thermal Desorption	Soils are heated to 200 to 600 degrees F to volatize water and organic contaminants. A carrier gas or vacuum system transports vapors to treatment system.	Moderate to High	Low to Moderate	High	Not applicable. Not as reliable or cost effective as other technologies for VOC removal from soils.
		▨ Incineration	High temperatures - 1,600 to 2,200 degree F are used to volatiles and combust contaminants.	High	Low	High	Not applicable. Not as reliable or cost effective as off site disposal as hazardous waste.
		▨ Biological Treatment	Use of microorganisms to oxidize or reduce VOCs	Moderate	Low	Moderate	Not applicable. Not as reliable, and characterized by high operation and maintenance relative to other process options.
Disposal	Offsite Disposal	Non-Hazardous Waste Landfill	Excavated soils are transported to an off site landfill permitted for non-hazardous waste.	High	Moderate	Moderate	Potentially applicable for clean soils excavated at source areas, but would require sampling of soils to demonstrate soils are non-hazardous.
		Hazardous Waste Landfill	Excavated soils are transported to an off site landfill permitted for hazardous waste disposal.	High	Low	High	Potentially applicable for hazardous soils excavated at source areas, but transportaion distance may be long and costs high.

▨ Process Option Eliminated from Further Consideration

Table 2-2
Screening of Soil Remediation Technologies and Process Options

Table 2-3
Retained Process Options for Plume and Source Areas and Wellhead Treatment

Area	General Response Action	Process Option	Media Addressed
Source Areas	No Action	No Further Action	None
	Monitoring	MNA	Groundwater
	Institutional Controls	Use Restrictions	Groundwater
		Public Education	Groundwater
	Containment	Slurry Wall	Groundwater
		Capping	Groundwater
		Stormwater Diversion/Control	Groundwater
	Groundwater Collection/Extraction	Groundwater Extraction Wells	Groundwater
		Dual Phase Extraction	Groundwater and vadose soils
		Infiltration Galleries	Groundwater
	Groundwater Treatment	Enhanced Biodegradation	Groundwater
		Chemical Oxidation	Groundwater
		Air Sparging	Groundwater
		Air Stripping	Extracted Groundwater
		Activated Carbon	Extracted Groundwater and Vapors
		Catalytic Oxidation	Vapors
	Treated Water Disposal	Surface Discharge	Treated Groundwater
		Atmospheric Discharge	Treated Vapors
		Storm Sewer Discharge	Treated Groundwater
		Discharge to POTW	Treated Groundwater
		Soil Vapor Extraction	Vadose Zone Soils
		Excavation	Vadose Zone Soils
		Off Site Disposal	Excavated Soils
Plume Areas	No Action	No Further Action	None
	Monitoring	MNA	Groundwater
	Institutional Controls	Use Restrictions	Groundwater
		Public Education	All
	Groundwater Collection/Extraction	Groundwater Extraction Wells	Groundwater
	Treatment	Enhanced Biodegradation	Groundwater
		Air Stripping	Extracted Groundwater
		Activated Carbon	Extracted Groundwater
	Treated Water Disposal	Surface Discharge	Treated Groundwater
		Atmospheric Discharge	Treated Vapors
		Storm Sewer Discharge	Treated Groundwater
		Discharge to POTW	Treated Groundwater
Wellhead Treatment	No Action	No Further Action	None
	Institutional Controls	Use Restrictions	Groundwater
		Public Education	All
	Treatment	Air Stripping	Extracted Groundwater
		Activated Carbon	Extracted Groundwater

is assumed that the average thickness of contaminated groundwater is 100 feet and the average porosity of the aquifer is 0.3. The resulting volume of contaminated groundwater is approximately 249,600 acre-feet or 81 billion gallons.

Groundwater pump and treat can be implemented with the objective of contaminant mass removal or hydraulic containment, both of which can be implemented on a small-scale or on a large-scale.

- ***Small-Scale Remediation.*** Small-scale operations practically apply to remediation of source areas (higher concentration conditions within a fairly limited areal extent). Groundwater source area remediation discussions are provided below and in Sections 3 and 4.
- ***Large-Scale Remediation.*** Effective large-scale contaminant mass removal or hydraulic containment within the plume area would necessitate the installation of numerous groundwater extraction wells and would require extraction and treatment of significant volumes of groundwater. Such an operation would be cost prohibitive both in terms of initial capital costs (groundwater extraction well installation and treatment facility construction) and costs associated with ongoing operations and maintenance, including the cost of disposal of treated water.

Because of the limited effectiveness of groundwater pump and treat relative to mass removal or hydraulic containment over such a large areal extent and the associated high costs, this technology is not considered practical on a large scale. However, groundwater pump and treat, particularly when focused on remediation of source areas (higher concentration conditions within a fairly limited areal extent), is considered feasible and potentially effective.

2.4.2 Public Water Supply Wellhead

The process options retained for public water supply wellheads are:

- No Action
- Institutional Controls (including Use Restrictions and Public Education)
- Wellhead Treatment (via Air Stripping or Activated Carbon)

Five existing public water supply wells currently have operating wellhead treatment facilities (air stripping). Operations at these wells have demonstrated this process option to be an effective method for treating groundwater to established safe drinking water standards. Wellhead treatment of groundwater from public water supply wells will continue to be utilized as an element in the overall CTMRD remediation program.

2.4.3 Source Areas

The widespread and low-level nature of the PCE detections in groundwater within the CTM suggests multiple source areas. Data generated to date are not sufficient to define the nature and extent of any particular source. Source characterization is an essential step before being able to select the most effective process options for source area remediation. As will be defined in the Remediation Plan, future CTMRD activities will include additional source area characterization and evaluation of remediation options. To this end, the remainder of this TM (Section 3, *Source Area Characterization Method Evaluation*; and Section 4, *Source Area Remedial Technology Evaluation*) is intended to serve as guidance for identifying and evaluating characterization methods and remediation technologies for addressing PCE source areas.

Section 3
Source Area Characterization Method Evaluation

After a source of PCE contamination is identified within the CTM, further characterization may be necessary to determine the most effective method of source remediation, as well as the volume of contaminated media that requires remediation. A variety of soil and groundwater contamination characterization methods exist for PCE source area investigations. In the following subsections descriptions are provided for the characterization methods that are most commonly employed at dry cleaning sites and other PCE source areas (State Coalition for Remediation of Dry Cleaners, 2001). These methods have been evaluated based on the general subsurface environment present within the CTMRD, with PCE as the common contaminant. Method-specific advantages and disadvantages are discussed.

3.1 Active Soil Gas Survey

An active soil gas investigation is generally conducted using direct push technology (DPT) to collect soil gas samples. A DPT-based soil gas survey is a cost effective tool for delineating VOC contaminated source areas in the unsaturated zone and to a very limited extent in shallow ground water. DPT soil gas surveys are particularly useful if the exact location of the source area is unknown, since a grid of sampling locations can be set up over a large area of land.

Utilized with a mobile laboratory or portable gas chromatograph (GC), an active soil gas survey provides near real-time data that allow delineation of contaminant source areas in one mobilization. Shipping soil gas samples to fixed laboratory increases costs and delays receipt of data. Disadvantages and limitations are that this type of investigation is not applicable in areas with very shallow water tables (the probe will clog up with water) or in low permeability soils. However, given the setting at the CTMRD, active soil gas surveys are likely to be a valuable tool in investigating source areas, limited only by the depth to which a DPT sampling rod can be advanced.

3.2 Passive Soil Gas Survey

A passive soil gas investigation is similar to active soil gas surveys and is more applicable to low permeability soils. In general terms, a sampling device comprised of a small container of absorbent is buried in shallow soil and retrieved some time later for analysis of VOCs in an off-site lab. Samples are typically collected after a long time period of placement (up to two weeks), thus the data may be more representative than active soil gas survey data. Disadvantages and limitations are that passive soil gas surveys do not provide real-time data and require two mobilizations (one to install and one to remove the sampling device). If samples are analyzed off-site, a waiting period is required to receive analytical data. Another disadvantage is that results are provided in units of mass of VOCs adsorbed per trap, rather than concentrations of VOCs in soil gas. A possible advantage is that passive soil gas surveys can be more cost effective than active surveys when the number of sample locations is large. Also, the level of technical expertise required is lower compared to active surveys with on site lab analysis. In general, conditions at the CTMRD do not pose a limitation to the use of passive soil gas surveys.

3.3 Groundwater Investigation Using Standard Monitoring Wells

Investigations using standard monitoring wells can provide high quality lithologic and soil and groundwater data in any geologic setting. Soil borings are advanced and permanent or semi-permanent monitoring wells are installed, developed, and sampled. Samples can be obtained from permanent monitoring points over time to evaluate changes in groundwater quality. This technology is widely accepted and wells can be constructed in vertically distinct portions of an aquifer, or below confining units, with little risk of cross-contamination.

Disadvantages and limitations include a requirement for access by large trucks with high drill masts; necessity to abandon monitoring wells after closure; time and cost constraints of fixed laboratory use; relatively high cost of well installation and sampling; multiple mobilizations to install, develop, and sample monitoring wells; and the generation of large quantities of investigation-derived waste (IDW). This method can lead to an iterative process of well installation for contamination delineation, and may be expensive if not coupled with other characterization methods.

Monitoring wells are the most widely accepted tool for collection of representative time-variable groundwater samples. It is anticipated that groundwater characterization of CTMRD source areas will rely heavily on this method, particularly for defining the down gradient extent of contamination.

3.4 Direct-Push Groundwater Sampling

This technology provides a valuable tool for determining contaminant mass distribution and choosing compliance monitoring well locations. DPT groundwater investigations may reduce the number of monitoring wells installed and insure that wells are screened over discrete zones of concern. When used with a mobile laboratory or a portable GC, DPT groundwater sampling provides near real-time data that allow for adjustment of scope of work in the field thus avoiding the formerly iterative nature of contamination assessments. Soil gas, continuous soil cores, groundwater samples and geophysical data can all be collected with DPT. A high resolution of sampling points can provide a detailed lateral and vertical delineation of contaminants providing data especially useful for *in situ* remedial applications. A wide variety of equipment is available, including smaller rigs that can sample inside structures, beneath floor slabs. Minimal IDW is generated and small-diameter "mini-wells" can be installed using DPT.

Disadvantages of DPT investigations are that they are limited to more permeable unconsolidated sediments and usually to depths of less than 40 feet. More compacted material may result in refusal at shallower depths. The gravelly nature of some of the soils within the CTMRD may limit the use of this method at some locations. The risk of cross contamination needs to be considered when sampling from vertically distinct portions of an aquifer or below confining units. Also, DPT grab sample investigations provide "one time only" data only, and the short sensing zone of the sampler can miss discrete contaminant layers. For CTMRD source areas, DPT mini-wells may provide a cost effective method for delineating shallow groundwater contamination and then monitoring performance of remedial systems.

3.5 Test Pits and Excavation

Test pits and trenches can be excavated by hand or power equipment to permit detailed explanation of the nature and contamination of *in situ* materials. Test pits typically have a cross section of 4 to 10 feet square, while trenches are usually 3 to 6 feet wide, extending to any length required to reveal conditions along a specific line. This method may be of particular relevance at the CTMRD when investigating source areas associated with sewer line releases. Test trenches can be excavated along suspect lengths of sewer line to search for contaminated soils. Depending on the extent of contamination, excavation may be extended as the vadose zone remedy.

Many health and safety issues apply if the excavation is to be entered for sampling and many of these issues can be addressed by stabilizing the sides of the test pit or trench by sloping walls or using sheeting. Investigation by excavation provides relatively accurate data relative to subsurface conditions; however, provisions must be made for treating and/or disposing of any excavated contaminated soils.

3.6 Geophysical Characterization Techniques

Geophysical characterization techniques can be used in source area investigations to identify the source of contaminants (e.g. buried drums), evaluate subsurface features, and help to define contaminant distributions. The latter has received much attention, although a dependable geophysical technique for identifying DNAPL presence has yet to be developed. A few of the more common techniques are described below.

3.6.1 Ground Penetrating Radar

Ground penetrating radar (GPR) can be used to locate septic tanks, underground storage tanks (USTs), and buried utility lines. When integrated with lithological data, this method can be used to better define site stratigraphy. Although GPR cannot provide definitive information on subsurface conditions, it can be used at a rate of several line-miles per day making it a cost effective method when large areas are too be surveyed.

Disadvantages/Limitations: Limited depth of investigation - generally less than 30 feet below ground surface. The radio wave signal that is used in this method is attenuated by materials with higher electrical conductivity such as clays and pore spaces saturated with brackish, saline, or high total dissolved solids (TDS) ground water.

3.6.2 Soil Conductivity Survey

This method provides a means of measuring the electrical conductivity of subsurface soil, rock and groundwater. Electrical conductivity is a function of the type of soil or rock, its porosity, its permeability and the fluid composition and saturation. In most cases, the conductivity of the pore fluids will be responsible for the measurement. The survey may be performed used with direct push technology and lithology borings to delineate site stratigraphy. This will facilitate collection of groundwater samples at optimum locations and provide data that are critical for the design and installation of remedial systems.

Disadvantages/Limitations: Equipment and personnel for conducting a soil conductivity survey may not be widely available.

3.6.3 Metal Detectors

This method can be used to locate metallic objects in the subsurface such as USTs, pipelines, utility lines, buried drums, etc. Compared with other methods it is inexpensive and widely available.

Disadvantages: Application is limited to metallic objects.

3.6.4 Electrical Resistivity Survey

Electrical resistance (ER) provides information about the subsurface distribution of the ground resistivity. It can be used to delineate stratigraphy, locate buried objects and to a very limited extent may be used to infer groundwater quality and the potential presence of DNAPL. Both horizontal and vertical changes in resistivity can be mapped; however, lateral changes are more easily mapped by electromagnetic surveys. Typical productivity is several thousand line-feet per day (less than electromagnetics). This means that a relatively large area down gradient of a CTMRD source area could be surveyed for evidence of groundwater contamination with placement of a limited number of monitoring wells to confirm survey results.

Disadvantages: Interpretation of ER survey results is subjective and requires an experienced contractor. Utilities may interfere with survey methods. The general location of utilities should be determined prior to performing an electrical resistivity survey.

3.6.5 Membrane Interface Probe (MIP)

This method utilizes photoionization/flame ionization detectors (PID/FID) to detect organic compounds in soil and/or groundwater and can also be used to measure formation temperature, and conductivity. The MIP is continuously pushed, and utilizes a heated sensor with a permeable membrane to allow contaminants to diffuse into the probe which are then analyzed with an on-board GC. It can be utilized with direct push technology to estimate contaminant mass distribution.

Disadvantages/Limitations: Detection limits are in parts per million (ppm), which limits the tool to use in highly contaminated source areas.

3.6.6 Borehole Geophysical Logs

Borehole geophysical techniques provide information on rock and unconsolidated sediment properties and fluid movement. Borehole geophysical logs can be used to determine lithology, porosity, well casing depths, and to help delineate stratigraphy.

Disadvantages/Limitations: This approach is typically expensive and not widely available. Its use requires certain minimal borehole size. In some cases an open borehole. Use of this approach is expected to be limited at the CTMRD.

3.7 Analytical Techniques

This section provides a summary of analytical techniques that may be used for in-field level screening.

3.7.1 Mobile Laboratory

This approach provides on site analysis of groundwater and/or soil samples utilizing laboratory grade equipment [i.e., GC and gas chromatography/mass spectroscopy (GC/MS) units]. When used in conjunction with direct push technology, this approach provides near real-time data that allow for changing the scope of the assessment in the field.

Disadvantages/Limitations: Depending on the size of the characterization, this approach may not be cost competitive with off site analysis of samples.

3.7.2 Immunoassay Kits and Colorimetric Tubes

These kits are easy to use, relatively inexpensive and can be used as a screening tool that provides a quick verification that contamination is present.

Disadvantages/Limitations: The kits typically have relatively high detection limits. Additionally, kits are compound-specific.

3.8 DNAPL Detection

3.8.1 Ultraviolet Fluorescence

This method is not applicable for CTMRD source areas, since PCE is not fluorescent under a black light.

3.8.2 Hydrophobic Dye (Sudan IV)

This method is a quick direct indicator of DNAPL; however, it may not be definitive. Additionally, the dye is a toxic material.

3.8.3 Partitioning Interwell Tracer Test (PITT)

This is a method to determine the presence and distribution (volume and saturation) of NAPL in the subsurface by injecting tracers with different partitioning coefficients. Some tracers are retarded as a result of partitioning into and from the NAPL. Measuring the tracer concentrations in samples collected from a recovery well over time provides an indication of the concentration of NAPL. This approach may be very expensive and not especially applicable to the scale of work at dry cleaner sites. This method requires at least one injection and one recovery well.

3.9 Sonic Drilling

Sonic drilling was used successfully during the field investigation program performed for the CTMRD. This drilling method can penetrate both unconsolidated and indurated formations. The process generates continuous cores that are valuable in characterizing site stratigraphy. This drilling method generates a minimal amount of wastes - which is a consideration in contaminant source areas where investigation-derived wastes may be hazardous. No fluids are circulated in advancement of the drill string, therefore there is no flushing or invasion of the formation, nor is there any cross contamination that is generally associated with mud rotary drilling. Zones can be isolated with a packer to collect groundwater samples during drilling operations.

This method is typically expensive (though not necessarily so if cost savings on investigation-derived waste disposal are considered). The drill rig has a large "footprint" and may not be applicable to congested urban sites such as dry cleaning facilities. Also, rig availability may be limited.

3.10 Video Camera

This method can be used to provide a visual survey of the integrity of sewer lines. Breaches and leaks in sewer lines can act as point sources for discharge of dry cleaning contact water that can contain free-phase solvent. Video cameras have been used to examine some sewer lines in Reno and potential PCE source areas have been identified in this manner. Borehole video cameras can also be used in boreholes to identify dissolution zones.

Section 4
Source Area Remedial Technology Evaluation

This section describes and evaluates remedial technologies that may be used to remediate source areas that are identified within the CTMRD following the procedures that will be established within the Remediation Plan. The remedial technology evaluations were performed considering the specific conditions that exist within the CTMRD. This section provides discussion regarding conditions that are favorable for implementation of each technology.

4.1 No Further Action

Under this approach, no remedial action would be undertaken at the source area; however, a long-term monitoring program could be implemented. The main objective of this program would be to monitor the extent of groundwater contamination over time. An additional component of the monitoring program could be the development of a contingency plan that would be implemented if groundwater monitoring data indicate the groundwater quality at production wells is threatened by source area contaminant concentrations that cannot be addressed by wellhead treatment.

Potential Applications: No further action may be taken at some plume areas if the contamination is limited, if the location is such that the contamination does not pose a risk to production wells and/or if the contaminated groundwater is not accessible.

4.2 Institutional Controls

The institutional controls that could be implemented include:

- Fencing around treatment equipment, where appropriate
- Deed restrictions
- Land use restrictions
- Development restrictions
- Groundwater use restrictions

Potential Applications: The source area and vicinity could be certificated for no groundwater use such that no new production of groundwater for potable and non-potable uses would be allowed. Some deed restrictions and zoning ordinances could be put in place to ensure that exposure pathways are not completed.

Public Education

Public education is considered an institutional control that can be used to assist protecting of human health. This requires educating the public about the potential risks associated with exposure to contaminated groundwater. Water quality information can be disseminated through fact sheets, public meetings, and local news media announcements.

Public education by itself does not reduce the sources of contaminants; therefore, the effectiveness is considered low. However, in conjunction with remedial technologies, public education via fact sheets and public meetings is easily coordinated and highly implementable. The cost for such actions is typically low to moderate compared to other response actions.

4.3 Monitored Natural Attenuation

Monitored Natural Attenuation (MNA) is an *in situ* remediation technology that involves naturally occurring processes (e.g., biodegradation, dispersion, matrix diffusion, sorption, volatilization, and chemical degradation). These processes serve to reduce the concentration, and in some instances, mass of contaminants in groundwater and soils. MNA is recognized by the U.S. Environmental Protection Agency as a viable method of remediation that can be evaluated and compared to other remediation strategies. MNA occurs at all sites to some degree, but the types of contaminants, and the chemical, physical, and biological characteristics of the soil and groundwater determine its effectiveness at a particular location. This method of remediation may be used as the sole remediation technology when it: (1) is combined with some degree of source control; (2) is shown to be fully protective of human health and the environment; and (3) meets remedial objectives within a reasonable time frame. Once in place, an established monitoring program is required to evaluate its effectiveness. MNA may also be used in combination with other process options as a concurrent technology, or in a phased manner following the completion of other technologies.

Potential Applications: The effectiveness of MNA as a stand-alone technology is variable, depending on the location where it is applied and the degree of contamination. While MNA is applicable for the plume area, MNA effectiveness as a stand-alone technology would be low at most CTMRD source areas, because it likely would not meet a remedial objective that requires the reduction of groundwater concentrations to levels protective of human health and the environment in a timely fashion, as compared with other technologies. This is primarily due to the fact that most of the groundwater in the CTMRD is aerobic, preventing the anaerobic biodegradation of PCE. However, even though MNA by itself may not be effective, MNA (via abiotic processes) may be an appropriate risk control measure after an alternate remedial technology has resulted in a reduction of contaminant mass. MNA is highly implementable and requires moderate costs over the lifetime of a project.

4.4 Soil Vapor Extraction

Soil vapor extraction (SVE) removes VOC mass from vadose zone soils by application of a vacuum to a well screened within the contaminated soil interval resulting in *in situ* volatilization and removal of VOCs in extracted soil gas. Soil conditions must be conducive to SVE in that they are sufficiently permeable to air flow. Extracted vapors are treated at the surface prior to atmospheric discharge.

Treatment options for extracted vapors that are most appropriate for PCE include:

- **Granular Activated Carbon.** This technology is typically the most cost effective and is most appropriate when vapor concentrations are low. Carbon adsorption is typically used for vapor waste streams when contaminant concentrations are less than 1,000 parts per million by volume (ppmv).
- **Catalytic Oxidation.** This technology is only appropriate when vapor concentrations are very high. Since PCE is a chlorinated compound, hydrochloric acid is produced when it is thermally treated. This means all material on the oxidizer must be acid resistant and the off gas must be scrubbed, which will add operation and maintenance (O&M) costs and efforts.
- **Synthetic Resin Adsorption with On Site Condensation.** This technology is also only appropriate when contaminant concentrations are very high. Adsorption is accomplished using a customized synthetic adsorbent such as a zeolite that is regenerated on site with condensation of the reclaimed PCE.

Potential Applications: SVE is a potentially very effective technology for use at CTMRD source areas since PCE is volatile, the vadose soils are very permeable, and the vadose zone is generally thick. SVE has an important advantage over soil excavation in that it can remediate soils that are beneath structures that interfere with excavation. The most likely application of SVE may be at source areas associated with sewer line releases of PCE. In these cases, SVE may be used in conjunction with soil excavation too address inaccessible contaminated soils.

4.5 Air Sparging

Air sparging involves the installation of wells in contaminated groundwater areas and injecting air into the saturated zone. The induced airflow enhances the volatilization of the VOC contaminants from groundwater into the vadose zone. Once in the vadose zone, the VOCs can be removed via SVE. The application of this technology is highly dependent on the hydraulic conductivity, the radius of influence of the air injection and vapor extraction wells, and the airflow rate sustained through the contaminated zones. Preferential flow paths established for airflow have the potential for limiting the contaminant contact area and limiting the effectiveness of the sparging process. It should be noted that the injection of air may alter the groundwater reducing environment, thereby limiting any further reductive dechlorination of chlorinated contaminants. However, such introduction of air may lead to an oxidizing environment, thereby creating conditions in which reductive biodegradation of PCE will not occur.

Potential Applications: Similar to other *in situ* technologies, the effectiveness of air sparging is considered to be highly variable, depending on the soil characteristics of the targeted treatment zone. Air sparging is most applicable for groundwater remediation at source areas where the contaminants are volatile, the soils are relatively permeable and the aquifer depth is relatively shallow. Conditions within the CTMRD generally meet all of these criteria. However, soil heterogeneities can pose a significant obstacle to effective air sparging since treatment of the source areas may not be uniform.

4.6 Dual Phase Extraction

Dual phase extraction (DPE) involves applying a high vacuum to a well located within the contaminated zone and screened across the water table, thereby inducing two phase flow: soil vapor and groundwater. The soil vapor flow results in remediation of vadose zone soils via the same processes used in SVE. The groundwater flow to the dual phase extraction well results in removal of dissolved contaminant mass and helps to control or reverse the spread of dissolved contaminants from the source area. Groundwater extraction also results in a cone of depression exposing additional vadose zone soil from which VOCs can now be removed by soil vapor flow.

Potential Applications: DPE may be applicable to CTMRD source areas where contaminated soils are of low permeability. This is only likely if localized areas of low permeability native soils exist or if low permeability fill materials have been contaminated. In all other cases, SVE should be effective for vadose zone soils and a groundwater treatment or extraction technology can be used to address groundwater.

4.7 Groundwater Recirculation

A groundwater recirculation well establishes a vertical circulation cell that captures contaminated groundwater and transports it to the well for in-well air stripping. The recirculation cell is established by injecting air into a drop tube within the well. As the injected air bubbles to the surface of water within the well, airlift pumping occurs, bringing groundwater into the lower screened interval and pushing it out the upper screened interval. The in-well bubbling also serves to air strip VOCs from the influent groundwater and the treated water exits from the upper screen. An advantage to this approach is that all groundwater treatment is performed *in situ,* avoiding issues regarding re-injection, surface water discharge or POTW discharge.

Potential Applications: The generally permeable nature of the CTMRD soils and the volatility of PCE are both favorable characteristics for the use of this technology. Pilot testing is highly recommended to establish site-specific treatment zone dimensions and pumping rates. Only experienced vendors should be considered and costs may be higher when compared to other technologies. This process option should only be considered when other process options have been screened from use at a given source area.

4.8 Groundwater Extraction/Hydraulic Containment

The principal means of recovering contaminated groundwater is through altering of the groundwater gradient to enhance and/or control contaminant movement. This is typically accomplished by artificially influencing an existing gradient via groundwater extraction wells and/or by placing groundwater interceptor drains downgradient of the contaminated area.

4.8.1 Groundwater Extraction Wells

Groundwater extraction wells are commonly used as a method to influence groundwater flow and to recover contaminants. Extraction wells are used to contain the migration of a contaminant plume and/or reduce contaminant mass in groundwater. Such wells would be located within and/or downgradient of the potential source area. In general, extraction wells are versatile under a variety of environmental conditions and have design and operating flexibility. Extraction wells may be used alone, or in combination, to sufficiently contain the spread of a groundwater contaminant plume. Multiple wells should be positioned in such a way that their radii of influences overlap, thereby achieving a significant reduction in downgradient plume migration.

Groundwater extraction wells are considered to be moderately to highly effective because they can reduce contaminant migration; reduce the potential for vertical contaminant migration into strata below the upper-most groundwater; and upon prolonged duration, may be expected to reduce groundwater contaminant concentrations. Extraction wells are highly implementable, and have relatively moderate capital and maintenance costs, although long-term operation may be expected.

Potential Applications: Groundwater extraction at CTMRD source areas would generally be effective given the generally high permeability of the soils. Groundwater extraction will typically be used as a means to contain migration of contaminants from a source area and to a lesser extent to remove contaminant mass. Since remediation of source areas is preferable to containment, treatment process options should be implemented whenever possible before relying on containment options.

4.8.2 Interceptor Drains/Infiltration Galleries

Groundwater can also be removed by installing of subsurface drains to intercept groundwater as it migrates beneath a given area. Such drains would consist of perforated pipe in trenches backfilled with porous media. Subsurface drains or interceptor trenches may be used as an effective containment remedy. Similar to interceptor drains, although for a different application, infiltration galleries would be constructed such that the piping network is designed to optimize the distribution of amendments to the subsurface for use with in situ remedial process options (e.g., bioremediation, chemical oxidation).

Potential Applications: Since the CTMRD shallow saturated soils are generally permeable, use of infiltration galleries or interceptor drains should not be necessary to extract contaminated groundwater. Extraction wells will typically be the most cost effective option for groundwater extraction.

4.9 *Ex Situ* Treatment of Groundwater

The most applicable *ex situ* treatment options for extracted groundwater containing PCE at the CTMRD are described below.

4.9.1 Air Stripping

Air stripping towers and low-profile strippers have been used effectively for removing numerous dissolved VOCs from groundwater waste streams. Contaminated water enters the stripping tower at the top and is evenly distributed across the internal packing media through distributor nozzles or weirs. Clean air is introduced into the bottom of the tower below the packing using a forced air blower, and flows upward through the packing. As the falling contaminated water flows countercurrent to the rising air stream, VOCs are stripped from the water and enter the air stream. Volatilized organics are discharged to the atmosphere or an off-gas treatment system. The internal packing media acts to increase the total surface area available for mass transfer of the organic contaminants from the liquid to the vapor stream. Treated water falls from the packing into the stripper basin and exits the tower.

The extent of compound removal by air stripping is governed by many factors, including contaminant concentrations in groundwater, temperature of the air and water, the air-to-water ratio, and contaminant physical properties (e.g., Henry's Law constant). Air stripping tower performance may also be influenced by the presence or absence of various inorganic compounds and suspended solids in the groundwater. Groundwater with elevated hardness may result in calcium and magnesium salt deposits in the tower packing media. Elevated iron (concentrations over 5 mg/L) or manganese concentrations, when oxidized in the air stripper, would result in metal hydroxide precipitation, which can severely foul the packing media and reduce its effectiveness to remove VOCs. In addition, elevated total suspended solids (TSS) concentrations in the groundwater can also result in solids deposition on the tower packing and reduce liquid-to-air mass transfer.

PCE exhibits a relatively high Henry's Law constant and, therefore, would be effectively treated with air stripping. For this reason, air stripping is considered highly effective. The implementability of this technology is moderate. The cost of air stripping is moderate relative to other *ex situ* treatment options.

Potential Applications: The most likely applications for air stripping at CTMRD source areas are for treatment of extracted groundwater from DPE wells or vertical extraction wells. Groundwater within the CTMRD may contain moderately high concentrations of iron and suspended solids that may require pretreatment. Pretreatment equipment could include multi-media filters to remove TSS, followed by greensand filters (if necessary) to remove iron. An alternative approach to pretreatment equipment may be the use of proprietary chemical complexing agents that prevent iron from precipitating in the air stripping unit. The need for pretreatment should be explored during the remedial design phase and the appropriate combination of pretreatment steps identified.

4.9.2 Activated Carbon Adsorption

One process option for organics removal from both liquid and gaseous phases is activated carbon adsorption. Activated carbon adsorption is most often carried out in a pressurized vessel that contains a bed of granular activated carbon. Contaminated liquid or vapor enters a pressurized vessel and is evenly distributed over the granular activated carbon. As the contaminated stream flows through the activated carbon media, organic compounds are adsorbed onto the micro-porous surfaces of the activated carbon by an electrical attraction. When the porous surfaces of the carbon become saturated with adsorbed organic material, the carbon must be replaced with new or thermally regenerated carbon media. Activated carbon adsorption is a surface attraction phenomenon influenced by several factors including physical properties of the carbon and contaminant compounds, and system characteristics such as dissolved solids concentration, temperature, and pH. Depending on the composition of the waste stream, pre-treatment steps such as multi-media filtration or clarification might be necessary to enhance the removal efficiency and life of activated carbon filters. Operating times before carbon exhaustion are primarily a function of the flow rate and the concentration of organic compounds in the influent stream.

Potential Applications: PCE exhibits a relatively high adsorption capacity, and therefore would be effectively treated with activated carbon. As with air stripping, the most likely applications for activated carbon at CTMRD source areas are for treatment of extracted groundwater from DPE wells or vertical extraction wells. Groundwater within the CTMRD may contain several reduced metals (e.g., reduced iron and manganese), which, if not removed or complexed, may oxidize and plug the carbon media. For these reasons, activated carbon is considered to be moderately to highly effective. This technology is highly implementable. The costs of carbon adsorption are typically moderate to high and depend on the frequency of carbon bed exhaustion, which require carbon replacement or regeneration and disposal of spent carbon and concentrated wastes.

4.10 Groundwater Disposal

Groundwater discharge options that are considered for the CTMRD source areas include treated water discharge to a storm sewer, and discharge of untreated groundwater to a local Public Owned Treatment Works (POTW) via a sanitary sewer collection system.

4.10.1 Storm Sewer Discharge

This option discharges treated groundwater to a storm sewer present within or adjacent to the source area. Appropriate National Pollutant Discharge Elimination System (NPDE) permits and a sampling program to meet compliance with discharge permit requirements would be required for surface discharge. Effluent limits for surface discharge are typically MCLs for VOCs. Secondary treatment may be required to improve the quality of discharge water. Such steps may require polishing to reduce TDS.

Storm sewer discharge is considered to be a highly effective disposal alternative. This option is moderately implementable as it would require regulatory permitting. The cost of storm sewer discharge is moderate relative to other alternatives.

4.10.2 POTW Discharge

Extracted groundwater may be discharged to a local POTW provided that a piping network to such a facility exists or can be established, and the necessary permits may be obtained from the facility and regulatory agencies. This option, if allowed, would be highly effective with moderate to high costs depending on the level of pretreatment required.

Potential Applications: One of the treated groundwater discharge options described above must be used when groundwater is extracted from a source area. Storm sewer discharge and POTW discharge will likely be used most often, depending on access to a storm sewer, permitting requirements and available capacity at the POTW.

4.11 Excavation and Off-Site Disposal

This option involves excavation of contaminated soils with disposal at either a non-hazardous landfill, a hazardous waste landfill or an industrial waste landfill, depending on the nature (or lack of) contamination. Excavation requires the following key tasks at each location:

- Permitting and Planning
- Contaminated Soil Excavation
- Waste Handling and Temporary Storage
- Transportation and Disposal

If the targeted soils extend beneath the water table, typically the soil will be placed on a lined and bermed impoundment where drained water is captured, treated, and discharged. The excavated area may be backfilled with fresh soil and capped with a clay and soil cap to prevent continued infiltration through the backfill.

Depending on the size of the excavation, the equipment used may include backhoes, bulldozers, track hoes and/or clam shells. Transportation is typically by dump truck.

Potential Applications: Limited excavation of contaminated soils with off site disposal is expected to play an important role in CTMRD source area remedies. This approach is primarily applicable when the extent of contaminated vadose zone soils is small, well defined and accessible to excavators. If leaking sewer lines are identified and are to be replaced, excavation can be used during removal of the old line too remove the majority of contaminated material. SVE can then be used to address any residual contamination.

Regarding soil disposal, in the Reno area non-hazardous soils could be disposed of at the Washoe County Lockwood Landfill, however, this facility will not accept soils with detectable VOCs. Soils classified as hazardous could be disposed of at the US Ecology site in Beatty, NV. Since this facility is 330 miles from Reno, transportation costs may be significant with this option.

4.12 Enhanced Bioremediation

Enhanced bioremediation is a groundwater technology that involves injection of an electron acceptor, electron donor, microorganisms, and/or nutrients to stimulate or enhance the biodegradation of VOCs. For PCE, the enhanced bioremediation technology would typically involve induction of reduced groundwater environments. As such, biodegradable organic carbon (electron donor) would be injected in sufficient quantities to sufficiently lower the groundwater-reducing environment and stimulate the rapid, reductive dechlorination of VOCs. It is important to note that PCE is not biodegraded under oxidizing groundwater environments. Thus, injection of air into the subsurface or use of oxygen releasing compounds are not applicable to source areas with PCE. Inherent challenges that may affect the feasibility of this process option include the ability to adequately deliver amendments to the subsurface; the presence of competing electron acceptors/donors; the presence, of a microbial consortia capable of degrading PCE; and the possibility of forming additional toxic intermediates, such as vinyl chloride.

The effectiveness of enhanced bioremediation is considered to be highly variable, depending on the soil characteristics of the targeted treatment zone. For example, the effectiveness would be low if amendments could not be uniformly delivered or if high concentrations of sulfate, nitrate and/or oxygen are present. In contrast, the effectiveness of this process option may be high if applied to permeable water-bearing zones with low concentrations of electron acceptors/doners. The implementability of enhanced bioremediation is moderate as it would require subsurface injection permits, and the costs are typically moderate.

Potential Applications: Enhanced biodegradation may be applicable at some CTMRD source areas when the volume of groundwater to be treated is small and well defined. Soils must be permeable enough to allow accurate delivery of amendments to the targeted areas. In some cases, Hydrogen Releasing Compound (HRC) or other amendment may be used to treat localized areas of contamination. Performance monitoring is needed to ensure that the desired conditions have been established within the targeted zone and that complete biodegradation occurs.

4.13 Chemical Oxidation

In situ chemical oxidation involves the delivery of chemical oxidants to convert subsurface contaminants to innocuous end products (e.g., water, chloride ions, and carbon dioxide). The most common field application of chemical oxidation is based on Fenton's Reagent addition, whereby hydrogen peroxide is injected with an iron catalyst creating hydroxyl free radicals. These hydroxyl free radicals result in relatively non-specific chemical reactions that destroy organic compounds in the subsurface, including contaminants such as PCE. Proprietary catalysts may also be used in the injection process to increase the efficiency of reactions; such reactions are referred to as Fenton's-Like Reactions. Permanganate is also a common chemical oxidant used in the application of chemical oxidation. Inherent challenges that may affect the feasibility of this process option include the ability to adequately deliver amendments to the subsurface; the presence of high organic soils or reduced metals that consume excessive amounts of chemical oxidant; and the potential mobilization of naturally occurring metals in the subsurface.

Similar to enhanced biodegradation, the effectiveness of *in situ* chemical oxidation is considered to be highly variable, depending on the soil characteristics of the targeted treatment zone. For example, the effectiveness would be low in the native soils if there is a poor distribution of amendments. In contrast, the effectiveness of this process option may be high if applied to more permeable water-bearing zones. The implementability of chemical oxidation is moderate as it would require subsurface injection permits, and the costs are moderate.

Potential Applications: Similar to in site biodegradation, chemical oxidation may be applicable at some CTMRD source areas when the volume of groundwater to be treated is small and well defined. Deliver of the oxidant is the key to success and multiple injections may be required before no further rebounding of contaminant concentrations is observed following injection. UIC permitting may be a deciding factor in using this option.

4.14 Source Area Capping

The infiltration of surface water into contaminated areas of source areas may contribute to contaminants leaching into groundwater as the contaminants are desorbed from soil and transported down into groundwater. It may be possible to cap certain portions of source areas by the placement of concrete, asphalt, building structures, or clay capping material over areas with soil contamination.

Capping of source areas by itself is considered to be low to moderately effective because it reduces groundwater concentrations; however, the added benefit of capping may be low due to the limited recharge that currently occurs in the Reno area. Furthermore, capping does not reduce the presence of contaminant mass in the potential source areas. However, this option may be used in conjunction with other technologies to reduce groundwater contamination. This process option is considered highly implementable and costs for implementing source area capping are typically low to moderate with respect to other response actions.

Potential Applications: Capping will only generally be used at CTMRD source areas as part of a remedial approach that includes other active components. Paving should be considered when it fits in with the intended land use of the source area and when runoff from the pavement can be effectively handled.

4.15 Storm Water Diversion/Control

Storm water run-on near source areas may pond under conditions of high rainfall and percolate vertically through the soil, creating additional recharge which serves to increase the mobility of contaminants. Storm water diversion or control structures could serve to reduce the volume of water infiltration through source areas and reduce the vertical and lateral migration of VOCs.

Storm water diversion/control by itself is considered to be low to moderately effective in that it reduces groundwater concentrations; however, the added benefit of storm water diversion/control is low due to the limited recharge that typically occurs in the Reno area. Furthermore, this process option does not reduce the presence of contaminant mass in the source areas. This process option is considered highly implementable and the cost for implementing storm water diversion/control is typically low to moderate with respect to other response actions.

Potential Applications: Stormwater diversion will only generally be used at CTMRD source areas as part of a remedial approach that includes other active components. It should be considered in the context of the intended land use of the source area and must be designed to compliment stormwater management in the surrounding properties.

Section 5
References

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Appendix F
Listing of Groundwater Wells

Provided in this appendix is a listing of groundwater wells included in the Central Truckee Meadows Remediation District groundwater monitoring program. Three categories of wells are listed: Truckee Meadows Water Authority (TMWA) water supply wells, CTM groundwater monitoring wells installed as part of the field investigation program, and "other" wells (existing wells sampled during the Planning Phase of the CTMRD project). Included in the table are the number of samples collected from each well, total depth of the well (if available), screened interval (if available), and coordinate information (northing and easting).

Well Designation	*Number of Samples Collected from Well*	*Total Well Depth (ft bgs)*	*Screen Interval (ft bgs)*	*Coordinate Information*	
				Northing	*Easting*
		TMWA Wells			
TERMINAL (59)	20	685	330 - 665	14858939.00	2287576.90
HIGH (60a)	52		133 - 511	14865400.00	2279967.40
GREG (61)	35	274	110 - 260	14863032.00	2293611.25
POPLAR1 (62)	1	665	453 - 645	14865330.60	2291813.90
HUNTER LAKE (63)	7	480	210 - 470	14859593.00	2271273.25
RENO HIGH (64)	30	618	179 - 420	14861978.70	2272983.80
4TH ST (64a)	61	490	176 - 480	14867370.50	2284310.00
KIETZE (64c)	50	508	233 - 495	14865874.80	2284585.10
VIEW (64d)	27	530	150 - 518	14867986.20	2287803.30
SPARKS (64e)	46	282	152 - 272	14866957.00	2292199.30
POPLAR2 (64f)	49	300	146 - 286	14865276.40	2291785.40
MILL (64g)	41	660	326 - 640	14862009.60	2285487.40
PEZZI (64h)	22	563	214 - 266	14860096.60	2293676.90
CORBETT (64i)	26		180 - 280	14858426.30	2286028.90
SWOPE (64j)	8		170 - 350	14859506.40	2267705.20
PECKMAN (64k)	25		149 - 809	14848274.00	2288615.25
21ST ST (64l)	31		119 - 248	14864084.80	2289426.10
LAKESIDE (SPA)	26		180 - 400	14844302.00	2278921.50
S. VIRGINIA (SPB)	28		108 - 272	14841007.80	2286577.10
DELUCCHI (SPC)	29		114 - 308	14843741.70	2285671.20
HOLCOMB (SPD)	23		120 - 334	14834364.00	2286888.75
HUFFAKER (SPE)	16		135 - 300	14838196.00	2286573.50
EI RANCHO (SPG)	10		142 - 360	14870155.80	2288384.70
MORILL (SPH)	66		178 - 578	14866001.10	2281234.20
POPLAR6 (SPI)	15				
SPJ	9				
SPK	22				

Well Designation	***Number of Samples Collected from Well***	***Total Well Depth (ft bgs)***	***Screen Interval (ft bgs)***	***Coordinate Information***	
				Northing	***Easting***
		CTM Wells			
CTM-10D	31	347	326.5 - 346.5	14863421.71	2283739.87
CTM-11S	4	46	25 - 45	14861656.58	2285428.81
CTM-12D	22	347	326.5 - 346.5	14861668.37	2285425.99
CTM-13S	8	56	35.5 - 55.5	14863685.78	2284776.02
CTM-14S	7	25	4.5 - 24.5	14860981.49	2278705.21
CTM-15S	6	71	50 - 70	14860945.70	2279869.67
CTM-16S	6	41	20 - 40	14858163.93	2282372.25
CTM-17D	16	200	179 - 199	14858290.08	2286176.00
CTM-18S	5	35	14.5 - 34.5	14859840.95	2286510.08
CTM-19S	7	31	10.5 - 30.5	14865510.43	2294834.46
CTM-1S	6	51	30.5 - 50.5	14865566.99	2273656.93
CTM-20S	6	25	4 - 20	14860468.37	2294992.58
CTM-21S	7	37	16 - 36	14865699.61	2284464.80
CTM-22D	18	252	231.5 - 251.5	14865920.86	2283755.32
CTM-23D	12	181	160 - 180	14848391.28	2288630.75
CTM-25D	15	178	157 - 177	14852490.87	2293011.65
CTM-27D	15	179	158 - 178	14860974.09	2278708.40
CTM-28S	7	44	23.5 - 43.5	14865635.85	2275613.71
CTM-29S	7	36	15 - 35	14864046.06	2273769.32
CTM-2S	10	50	29.5 - 49.5	14863908.97	2274253.27
CTM-30D	14	152	131.5 - 151.5	14865293.83	2278837.53
CTM-31S	6	52	31.5 - 51.5	14867356.48	2276745.37
CTM-33D	13	199	178.5 - 198.5	14858545.72	2285129.75
CTM-37D	8	86	65 - 85	14862315.52	2284349.60
CTM-37S	7	46	25.5 - 45.5	14868572.91	2280975.56
CTM-38D	10	96	75 - 95	14861212.40	2286918.48
CTM-39S	5	39	18 - 38	14861205.84	2286915.38
CTM-3S	9	51	30.5 - 50.5	14866922.83	2276495.89
CTM-40S	6	149	118 - 148	14867956.67	2275472.64
CTM-41S	6	53	32 - 52	14858263.26	2279192.23
CTM-4D	16	180	159.5 - 179.5	14866914.11	2276498.23
CTM-5S	5	60	39.5 - 59.5	14866774.53	2275631.18
CTM-6S	7	44	23 - 43	14866906.40	2279451.31
CTM-7S	5	41	20.5 - 40.5	14865661.38	2280295.79
CTM-8D	14	261	240.5 - 260.5	14865655.66	2280296.09
CTM-9S	12	61	40 - 60	14863430.96	2283743.44

Well Designation	*Number of Samples Collected from Well*	*Total Well Depth (ft bgs)*	*Screen Interval (ft bgs)*	*Coordinate Information*	
				Northing	*Easting*
Other Wells					
100	1	204	193 - 203	14864551.02	2275139.06
101	2	51	38 - 48	14864569.03	2275139.06
102	3	200	187 - 197	14864148.56	2276579.76
103	3	29	17 - 27	14864150.61	2276571.69
104	4	49	37 - 47	14865211.63	2276966.59
105	4	196	182 - 192	14865214.08	2276976.16
106	5	26	14 - 24	14865630.78	2279633.92
107	4	186	176 - 186	14865617.80	2279635.43
108	2		36 - 46	14864138.93	2279304.91
109	3		187 - 197	14864150.18	2279301.33
111	12	49	9 - 48	14867658.33	2295166.27
111a	31		9 - 48	14865338.20	2296043.63
112	31	59	18 - 58	14865110.99	2298029.12
112a	41			14865160.35	2300066.75
113	30			14865170.71	2298881.81
114	1	40	10 - 40	14867625.16	2291304.14
115	1	40	10 - 40		
115a	1			14867643.14	2291216.29
115b	1			14867551.51	2291129.52
115c	1			14867613.56	2291078.76
115d	1				
118	1	31	18 - 30	14868049.39	2289111.11
118a	1	38	18 - 38	14868058.93	2289130.37
118b	1	37	18 - 38	14868040.32	2289113.15
118c	1	39	19 - 39	14868019.17	2289117.87
118d	1	39	19 - 39	14868014.54	2289096.22
118e	1	33	15 - 35	14867931.55	2289157.19
118f	1	38	19 - 39	14867933.90	2289106.48
119	1	30	4.5 - 29.6	14865364.34	2293670.61
119a	1	26	4.5 - 26.15	14865366.86	2293624.58
119b	1	29	4.5 - 29.41	14865270.91	2293626.33
119c	1	27	4.5 - 26.73	14865225.82	2293700.56
120a	1			14864786.73	2291542.21
120b	1			14864665.33	2291744.28
120c	1			14864611.76	2291796.60
122a	2	13	3 - 13	14861069.81	2279267.79
122b	2	10	3 - 7	14860949.19	2279305.63
122c	2	13	3 - 13	14861080.87	2279391.25
123a	1	84	60 - 85	14866345.02	2272843.83
123c	1	85	60 - 85	14866210.54	2272761.19
123d	1	85	60 - 85	14866229.79	2272791.99
126a	1		7 - 17	14859432.95	2294442.84
126b	1		7 - 17	14859463.38	2294456.56
133 30.7	2	53	23 - 53	14862690.56	2284615.91
133a 11.7	1	53	23 - 53	14862723.05	2284622.02
133b 5.5	1	54	23 - 53.5	14862815.93	2284590.50
133c 20	1	54	23 - 53.5	14862772.31	2284665.83
133d ND	1	53	23 - 53	14862641.87	2284623.86
133e 16.7	1	54	23 - 53.5	14862697.26	2284579.60
133f 112 138	5	50	25 - 50	14862404.92	2284932.11
133g 36.2 36.5	2	54	28 - 53.5	14862663.03	2284394.91
133h 240 448.9	3	54	28 - 53.5	14862663.55	2284736.97

Well Designation	***Number of Samples Collected from Well***	***Total Well Depth (ft bgs)***	***Screen Interval (ft bgs)***	***Coordinate Information***	
				Northing	***Easting***
133i ND 2.1	2	54	28 - 53.5	14862490.20	2284621.09
133j 120 1108	7	54	28 - 53.5	14863073.30	2284572.85
133k 35.9 235.41	5	54	28 - 53.5	14862839.12	2284866.87
133l 22.4 [illegible]	4	47	22 - 47	14862555.62	2285036.39
133m 33.3	3	47	22 - 47	14862271.28	2285222.44
133n ND	1	54	28 - 53.5	14862793.61	2284517.51
133o ND	1	42	17 - 42	14862101.38	2285442.64
137	4			14865849.65	2279117.33
138	6			14865386.28	2278080.55
139	3			14864911.03	2275748.62
140	3			14865330.94	2276985.87
141	2			14865375.02	2277698.95
142	3			14865483.58	2278427.07
143	2			14865865.09	2279883.65
144	2			14866063.29	2280168.69
145	2			14866087.24	2280890.80
146	2			14865706.20	2279129.50
147	2			14865736.67	2279518.04
148	2			14865982.94	2279741.24
150	1			14865214.08	2279857.66
152	1			14865194.19	2279883.90
153	1			14865287.58	2279935.46
155	1			14865389.47	2279985.22
156	1			14865297.75	2279888.34
157	1			14865201.03	2279846.06
159	1			14865235.23	2279830.94
160	1			14865239.51	2279859.51
162	1			14865269.25	2279832.50
163	1			14865261.82	2279865.87
165	1			14865285.71	2279861.14
166	1			14865298.91	2279799.99
18a	2	40	25 - 40	14865509.99	2275461.76
18b	3			14865537.65	2275572.58
18c	2			14865555.21	2275441.20
19	1	15	5 - 15	14858546.01	2294349.07
22	1	15	4 - 14	14855371.77	2288738.47
22a	1	19	6 - 16	14855395.09	2288609.25
23	1	16	4 - 14	14855454.04	2288261.55
~~25a~~	~~1~~	~~13~~	~~5 - 15~~	~~14854652.76~~	~~2287838.84~~
25b	1	18	6 - 16	14854683.89	2287829.94
25c	1	19	6 - 16	14854662.53	2287756.69
25d	1	15	3 - 13	14854324.00	2288749.88
25e	1	16	6 - 16	14855482.95	2287738.35
25f	1	21	7 - 17	14854501.34	2287355.25
25g	1	16	3 - 13	14854517.34	2288542.64
3	2	22	12 - 22	14856974.59	2287473.98
30	1			14867903.03	2288728.20
33	1		63.6 - 73.6	14866297.71	2282717.51
33a	1			14866021.95	2282512.12
33b	1			14865993.31	2282817.85
33c	1			14866045.61	2283013.20
34	1		51.9 - 61.9	14865926.55	2281759.03
3a	2			14856996.40	2287395.20

Well Designation	***Number of Samples Collected from Well***	***Total Well Depth (ft bgs)***	***Screen Interval (ft bgs)***	***Coordinate Information***	
				Northing	***Easting***
3b	1		100 - 200	14856875.49	2287348.83
3c	1			14856881.53	2287448.61
3d	2			14856946.77	2287436.59
4	1	21	6 - 21	14864637.45	2293593.25
40	1	62	5 - 62	14867313.22	2285712.57
44a	1	85	40 - 85	14867283.71	2285889.15
44c	1			14867427.62	2286004.20
5	1	65	45 - 65	14864897.29	2293542.84
56a	1			14861075.05	2295962.10
56b	1	225	186 - 224	14858714.26	2294990.63
60	1	490	178 - 578		
65	2	38	13 - 33	14864895.12	2273875.66
66	1	15	10 - 15	14863102.27	2293571.18
67	4	15	10 - 15	14860272.59	2295628.80
68	1	15	10 - 15	14852492.98	2293029.17
69	1	20	15 - 20	14853157.35	2299828.53
71	1	30	22 - 29	14859622.61	2270946.36
73	4	38	34 - 39	14858313.15	2286287.43
74	5	38	29 - 39	14858148.74	2283024.96
75	3	27	19 - 29	14860514.38	2279423.86
76	1	32	22 - 32	14868976.25	2296572.94
76A	2			14848395.27	2288621.74
77	3	230	177 - 230	14863079.90	2269061.06
79f	1		13 - 18	14859945.24	2302245.43
79h	1		17 - 22	14859825.21	2303337.82
79k	1		19 - 24	14860958.38	2305194.54
82	3	370	156 - 360	14863788.65	2277799.59
84	1	220	180 - 220		
86	1	232	130 - 232		
97	3	34	8 - 33	14863777.32	2278058.49
98	3	30	10 - 30	14864413.89	2277471.64
99	2	55	13 - 53	14864714.79	2277783.98
99a	3			14864811.82	2278141.78
99b	3			14864639.53	2277408.72
99c	4			14865209.95	2278031.44
99d	2			14865100.79	2277671.62
99e	2			14864033.97	2278000.20
99f	3			14864927.06	2278012.42
99g	3			14864893.32	2277911.71
99h	2			14864837.92	2277647.41
99i	3			14864999.17	2278085.99
W12	1			14862713.95	2270576.07
W13	1		5 - 24.5	14866663.27	2281660.26
W19	1			14864596.00	2276645.32
W21	1			14868440.71	2279443.30
W22	1			14866629.14	2278503.38

214 total wells	1539 samples
27 TMWA wells	775 TMWA samples
36 CTM wells	358 CTM samples
151 other wells	406 other samples

Appendix G
Groundwater Monitoring Program

Provided in this appendix is a general description of the groundwater monitoring program that will be performed as part of the ongoing Central Truckee Meadows Remediation District activities. The groundwater monitoring program will be developed in greater detail as part of the Final Remediation Plan. Included in this description are a statement of the groundwater monitoring program objective, groundwater monitoring system (listing of wells and the frequency of sampling), listing of monitoring parameters, data reporting, and program modifications.

Objective

The objective of this monitoring program is to collect data for ongoing characterization of the nature and extend of the PCE contamination within the Central Truckee Meadows. The data generated as part of this program will be valuable in terms of tracking and assessing changes in the nature of the PCE contamination conditions after implementation of the various remedial activities of the Remediation Plan.

Groundwater Monitoring System

The groundwater monitoring system will consist of the wells listed in Table G-1. The table categorizes the wells as TMWA wells, CTM wells, and Other Wells. Included in the table is a listing of the proposed frequency of sampling of the wells, maximum PCE concentration detected, range of detected PCE concentrations, and well construction details (screened interval and total depth).

Monitoring Parameters

Table G-2 consists of a listing of the field parameters and water quality parameters that will be measured at each well. The table identifies the analytical method number and the units of measurement for each parameter. Field parameters will consist of water level measurements, temperature, specific conductance, pH, turbidity, dissolved oxygen, and redox potential. Water quality parameters selected for the program – inorganic and organic parameters – are critical for assessing the progress of monitored natural attenuation of the PCE.

At a minimum, synoptic water level measurements will be performed semi-annually. If a particular well is sampled more frequently, water level measurements will also be collected.

Table G-1
Groundwater Monitoring Program

Well ID	*Sample Program*	*Maximum PCE (ppb)*	*Range PCE (ppb)*	*Screen Interval (ft)*	*TD (ft)*
TMWA Wells					
Poplar Street #2 (#64F)	Quarterly-TMWA	2.7	0.1-2.7	146-286	
Pezzi (#64H)	Annually -TMWA	<1	<0.1-<1	214-266	
Peckham (#64K)	Quarterly-TMWA	0.3	<0.1-0.3	149-809	
Morrill St. (#60)	Quarterly-TMWA	16.1	16.1	168-480	490
Mill Street (#64G)	Quarterly-TMWA	16.6	<0.1-16.6	326-640	
Kietzke Lane (#64C)	Quarterly -TMWA	12.5	0.3-12.5	223-498	
High St. (#60A)	Quarterly-TMWA	22.8	<0.2-22.8	133-511	
Greg Street (#61)	Annually -TMWA	0.4	<0.1-0.4	110-260	274
Fourth Street (#64A)	Quarterly-TMWA	15.4	<0.1-15.4	176-480	
Corbett Street (#64I)	Quarterly-TMWA	8.4	<0.2-8.4	180-280	
CTM Wells					
CTM-9S	Quarterly	4.8	<1-4.8	40-60	62
CTM-8D	Quarterly	97	<1-97	240.5-260.5	261
CTM-7S	Quarterly	4.5	<1-4.5	20.5-40.5	41
CTM-6S	Quarterly	36	20-36	23-43	44
CTM-5S	Quarterly	28	7.4-28	39.5-59.5	62
CTM-4D	Quarterly	44	<1-44	159.5-179.5	180
CTM-41S	Quarterly	<1	<1	32-52	53
CTM-40S	Quarterly	1.5	<1-1.5	118-148	155
CTM-3S	Quarterly	8.3	1.5-8.3	30.5-50.5	49
CTM-39S	Quarterly	45	Nov-45	18-38	40
CTM-38D	Quarterly	55	Nov-55	75-95	98
CTM-37S	Quarterly	3.8	<2.5-3.8	25.5-45.5	46
CTM-37D	Quarterly	3.1	<1-3.1	65-85	88
CTM-33D	Quarterly	8.4	8.4	178.5-198.5	200
CTM-31S	Quarterly	22	15-22	31.5-51.5	52
CTM-30D	Quarterly	28	<1-28	132-152	154
CTM-2S	Quarterly	10	7.4-10	29.6-49.6	52.5
CTM-29S	Quarterly	3.7	<1-3.7	15-35	36
CTM-28S	Quarterly	130	39-130	23.5-43.5	46
CTM-27D	Quarterly	1.4	<1-1.4	158-178	180
CTM-25D	Quarterly	<1	<1	157-177	180
CTM-23D	Quarterly	440	<1-440	160-180	180
CTM-22D	Quarterly	30	<1-30	231.5-251.5	253
CTM-21S	Quarterly	2	<1-2	16-36	42
CTM-20S	Quarterly	2.2	<1-2.2	4-24	24
CTM-1S	Quarterly	5.6	<2.5-5.6	30.5-50.5	52
CTM-19S	Quarterly	1.2	<1-1.2	10.5-30.5	32
CTM-18S	Quarterly	5.1	1.9-5.1	14.5-34.5	35
CTM-17D	Quarterly	18	<1-18	179-199	201
CTM-16S	Quarterly	14	9.9-14	20-40	40
CTM-15S	Quarterly	2.7	<1-2.7	50-70	73
CTM-14S	Quarterly	2.4	<1-2.4	4.5-24.5	26.5
CTM-13S	Quarterly	34	14-34	35.5-55.5	55
CTM-12D	Quarterly	55	1.2-55	326-346	346
CTM-11S	Quarterly	9.8	3.8-9.8	25-45	48
CTM-10D	Quarterly	50	<1-50	326.5-346.5	350
Other Wells					
1	Annually	<1	<1	181-201	200
3	Annually	<1	<1	12-22	22
4	Annually	3.3	2.6-3.3	6.25-21.25	21.25
5	Annually	2.3	<1-2.3	45-65	65

Table G-1
Groundwater Monitoring Program

Well ID	Sample Program	Maximum PCE (ppb)	Range PCE (ppb)	Screen Interval (ft)	TD (ft)
19	Annually	<1	<1	7-15	15
33	Annually	<1	<1	63.6-73.6	73.6
40	Annually	<1	<1	5.0-61.5	61.5
65	Annually	<1	<1	13-33	38.2
66	Annually	<1	<1	10-15	14.82
67	Quarterly	20.6	2.5-20.6	10-15	18
68	Semi-annually	<1	<1	10-15	14.5
73	Quarterly	14	9.2-14	34-39	41
74	Quarterly	38.5	14.1-38.5	28.5-38.5	42
75	Semi-annually	4.8	<1-4.8	19-29	27.2
77	Annually	2.2	<1-2.2	177-230	230
80	Annually			20-40	40
82	Annually	4.7	2.6-4.7	156-360	370
86	Annually	<1	<1	130-232	232
97	Annually	3.5	<1-3.5	8-33	34
98	Semi-annually	5.6	<1-5.6	10-30	30
99	Annually	3.4	<1-3.4	13-53	55
100	Annually	3	<1-3	193-203	204
101	Semi-annually	2	<1-2	38-48	50.54
102	Semi-annually	1.3	<1-1.3	187-197	200
103	Semi-annually	4.8	<1-4.8	17.2-27.2	29.2
104	Semi-annually	20.6	<1-20.6	36.6-46.5	48.5
105	Semi-annually	22.4	10-22.4	182-192	195.5
106	Quarterly	6	1.1-6	13.7-23.7	26.2
107	Quarterly	57.2	23.3-57.2	176-186	190
108	Semi-annually	<1	<1	36-46	50
109	Semi-annually	3.3	<1-3.3	187-197	205
111	Semi-annually	9	1.6-9	9-48	49
112	Semi-annually	17	1.4-17	18-58	59
113	Semi-annually	29	1.5-29	no log	
119	Annually	<1	<1	4.5-29.6	29.6
133	Quarterly	30.7	5-30.7	23-53	53
137	Quarterly	44.5	2.6-44.5	120-125	126.4
138	Quarterly	51.4	1.3-51.4		37.1
139	Semi-annually	5.1	1.5-5.1		
140	Semi-annually	6.5	3.3-6.5		55.3
141	Semi-annually	7.7	<1-7.7		39.9
142	Quarterly	28.7	3.5-28.7	21-41	38.95
143	Annually	3.7	<1-3.7		33.71
144	Annually	3.7	1.8-3.7		33.12
145	Semi-annually	6.3	<1-6.3		39.75
146	Semi-annually	5.7	<1-5.7		
147	Annually	1.2	1-1.2		50.1
148	Annually	3.7	3.2-3.7		35.75
153	Annually	<1	<1	no log	29.1
155	Annually	<1	<1	no log	39.5
156	Semi-annually	2.5	2.5	no log	48.62
111A	Quarterly	380	1.2-380	12.63-52.63	53 app.
112A	Semi-annually	11	2.3-11	no log	
112B	Annually	<1	<1	no log	
122A	Semi-annually	5.3	2.8-5.3	3.0-13.0	13
122B	Semi-annually	5.6	2-5.6	3.0-7.0	10
122C	Annually	2.3	<1-2.3	3.0-13.0	12.91
123C	Semi-annually	<1	<1	60-85	84.53

Table G-1
Groundwater Monitoring Program

Well ID	*Sample Program*	*Maximum PCE (ppb)*	*Range PCE (ppb)*	*Screen Interval (ft)*	*TD (ft)*
126A	Annually	<1	<1	7-17	
126B	Annually	<1	<1	7-17	
133A	Semi-annually	11.7	11.7	23-53	53
133B	Semi-annually	5.5	5.5	23-53.5	53.5
133C	Semi-annually	20	20	23-53.5	53.5
133D	Semi-annually	<1	<1	23-53	53
133E	Semi-annually	16.3	16.3	23-53.5	53.5
133F	Quarterly	338	1.8-338	25-50	50
133G	Quarterly	36.5	36.2-36.5	28-53.5	53.5
133H	Quarterly	448.9	11.9-448.9	28-53.5	53.5
133I	Semi-annually	2.1	<1-2.1	28-53.5	53.5
133J	Quarterly	1108	165.3-1108	28-53.5	53.5
133K	Quarterly	235.1	35.9-235.1	28-53.5	53.5
133L	Quarterly	216.3	6.4-216.3	22-47	47
133M	Quarterly	49	28.5-49	22-47	47
133N	Annually	<1	<1	28-53.5	53.5
133O	Annually	<1	<1	17-42	42
25E	Annually	1.4	1.4	6-16	16
33B	Annually	1.7	1.7	no log	69.5
33C	Annually	2	2	no log	78
3A	Annually	2.7	<1-2.7	no log	20.71
3D	Annually	2.8	<1-2.8	no log	21.08
44A	Annually	<1	<1	40-85	85
44C	Annually	<1	<1	no log	74.4
56A	Semi-annually	<1	<1	no log	27.75
56B	Annually	<1	<1	186-224	225
76A	Quarterly	1.6	<5-1.6	20-25	30
79A	Annually	2.8	1.6-2.8	no log	
79B	Annually	1.6	1.6	no log	
79D	Annually	2.2	2.2	10-15	
79F	Annually	3.3	3.3	13-18	
79H	Annually	2.3	1.0-2.3	17-22	
79I	Annually	1.4	1.4	14-19	
79J	Annually	1.8	1.8	11-14	
79K	Annually	2.3	1.1-2.3	19-24	
99A	Semi-annually	8.3	<1-8.3	no log	
99B	Annually	4	<1-4	no log	
99C	Semi-annually	10.5	<1-10.5	no log	
99D	Annually	4.2	<1-4.2	no log	
99E	Annually	1.9	<1-1.9	no log	
99F	Semi-annually	18.9	15.3-18.9	no log	
99G	Semi-annually	7.5	2-7.5	no log	
99H	Annually	4	<1-4	no log	
99I	Semi-annually	23.9	15-23.9	no log	

Table G-2
Groundwater Monitoring Program Summary

Parameter	Analytical Method	Units
Field Parameters		
Groundwater Elevation/Water Levels	N/A	Feet and hundredths (mean sea level)
Temperature	N/A	Degrees Centigrade
Specific Conductance	EPA 120.1	micromhos/cm
PH	EPA 9040/9045	pH units
Turbidity	EPA 180.1	Turbidity units
Dissolved Oxygen	field meter	mg/L
Redox potential	field meter	millivolts
Monitoring Parameters		
Total Dissolved Solids	EPA 160.1	mg/L
Alkalinity	EPA 310.1	mg/L
Chloride	EPA 300	mg/L
Sulfate	EPA 375.3	mg/L
Total Organic Carbon	EPA 9060	mg/L
Nitrate/Nitrite	EPA 35333.2	mg/L
Ethane, Ethene, Methane	EPA 3810	mg/L
Ferrous Iron	Hack field kit	Mg/L
Dissolved Iron	EPA6010	mg/L
Dissolved Manganese	EPA 6010	mg/L
Volatile Organic compounds, including PCE	EPA 8260B	µg/L

Data Reporting

The process of data reporting is a critical element of the overall CTM Remediation District remediation program. The details related to reporting the groundwater monitoring data will be clearly defined based on ongoing discussions among Washoe County Department of Water Resources, the Nevada Division of Environmental Protection (NDEP), and the Washoe County Health Department (WCHD). At a minimum, an annual groundwater monitoring program report will be prepared which summarizes the results of groundwater monitoring for the previous 12 months. The reports will present groundwater level and water quality data in tabular form.

Program Modifications

The groundwater monitoring program will be evaluated on an annual basis. Based on the acquisition of more data regarding the PCE contamination conditions (e.g., ongoing groundwater monitoring, further soils or groundwater investigations, installation of additional wells, etc.), modifications may be made to the monitoring program. As an example, the Remediation Plan includes provisions for characterization of potential PCE source areas. As part of these characterization efforts, additional groundwater monitoring wells may be installed.