# DRAFT
# HIGHWAY 36 FACILITY
# GROUNDWATER PROTECTION PROGRAM
# DESIGN AND RATIONALE

January 2, 1997

Prepared for:

**HIGHWAY 36 LAND DEVELOPMENT COMPANY**
108555 East Highway 36 HCR-1
Deer Trail, Colorado 80105-9611

Prepared by:

**MCCULLEY, FRICK & GILMAN, INC.**
providing environmental consulting and engineering services

4840 Pearl East Circle, Suite 200W
Boulder, Colorado 80301
(303) 447-1823
FAX 447-1836

# TABLE OF CONTENTS

LIST OF FIGURES . . . . . iv

LIST OF TABLES . . . . . iv

LIST OF APPENDICES . . . . . v

1.0 INTRODUCTION . . . . . 1-1
1.1 BACKGROUND . . . . . 1-1
1.2 OVERVIEW . . . . . 1-2

2.0 SITE CHARACTERIZATION . . . . . 2-1
2.1 GEOLOGY . . . . . 2-1
2.2 HYDROGEOLOGY . . . . . 2-3
2.2.1 Regional Hydrogeology . . . . . 2-3
2.2.2 Site Groundwater Conditions . . . . . 2-3
2.2.2.1 Occurrence of Groundwater . . . . . 2-4
2.2.2.2 Historic Water Level Trends . . . . . 2-5
2.2.2.3 Hydraulic Properties . . . . . 2-6
2.3 GROUNDWATER GEOCHEMISTRY . . . . . 2-8
2.3.1 Background Database . . . . . 2-8
2.3.2 Geochemical Well Groupings . . . . . 2-8
2.3.3 Geochemical Characteristics . . . . . 2-10

3.0 WASTE TREATMENT AND LANDFILL PERFORMANCE DESIGN CRITERIA . . . . . 3-1
3.1 WASTE TREATMENT OPERATIONS . . . . . 3-1
3.2 SECURE CELL DESIGN, OPERATION AND LAYOUT . . . . . 3-2
3.2.1 Final Cover Design . . . . . 3-2
3.2.2 Cell Liner Design . . . . . 3-3
3.2.3 Secure Cell Layout . . . . . 3-4
3.2.4 L3 Sand Unit Clay Barrier . . . . . 3-4
3.3 EVALUATION OF SECURE CELL PERFORMANCE . . . . . 3-4

4.0 EVALUATION AND DETECTION OF RELEASES . . . . . 4-1
4.1 RELEASE SCENARIO . . . . . 4-1
4.2 MIGRATION PATHWAY ANALYSIS . . . . . 4-3

5.0 GROUNDWATER PROTECTION PROGRAM DESIGN . . . . . 5-1
5.1 SECURE CELL MONITORING . . . . . 5-1
5.1.1 Action Leakage Rate (Hydraulic) Monitoring . . . . . 5-1
5.1.2 LCS and LDS (Chemical) Monitoring . . . . . 5-2
5.2 DESCRIPTION OF GROUNDWATER MONITORING PROGRAM . . . . . 5-3
5.2.1 Inspection and Detection Monitoring Well Networks . . . . . 5-3

5.2.2 Water Level Elevation (Hydraulic) Measurements . . . . . 5-4
5.2.3 Groundwater Monitoring . . . . . 5-4
5.2.3.1 Detection Monitoring Parameter Selection . . . . . 5-5
5.2.3.2 General Water Quality Monitoring Parameters . . . . . 5-8
5.2.4 Frequency of Groundwater Sampling . . . . . 5-8
~~5.2.5 Groundwater Sample Collection . . . . . 5-9~~

→ GW8 = 6.0

~~7~~.0 DATA EVALUATION PROCEDURES . . . . . 6-1
6.1 OVERVIEW AND GENERAL PROCEDURES . . . . . 6-2
6.1.1 Parameters . . . . . 6-2
6.1.2 Data Evaluation Methods . . . . . 6-2
6.1.3 Well Groupings . . . . . 6-3
6.1.4 Data Handling Procedures . . . . . 6-3
6.1.5 Background Database . . . . . 6-4
6.1.5.1 Definition of the Background Database for Secure Cell Monitoring . 6-4
6.1.5.2 Definition of the Background Database for Groundwater Monitoring . . . . . 6-4
6.1.5.3 Incorporation of New Data in the Background Databases . . . . . 6-5
6.2 SECURE CELL DATA EVALUATION . . . . . 6-5
6.2.1 Descriptive Statistics . . . . . 6-6
6.2.2 Trend Analyses . . . . . 6-7
6.2.3 Comparative Evaluation of Organic Data . . . . . 6-8
6.3 GROUNDWATER DATA EVALUATION . . . . . 6-9
6.3.1 Descriptive Statistics . . . . . 6-9
6.3.2 Trend Analyses . . . . . 6-10
6.3.3 Comparative Statistics . . . . . 6-12
6.4 SITEWIDE FALSE POSITIVE ERROR RATE . . . . . 6-13

7.0 REFERENCES . . . . . 7-1

## LIST OF FIGURES


| Figure | Title |
|---|---|
| 1 | Soil Boring and Hydrogeologic Data Locations |
| 2 | Cross Section A-A' with Cover and Liner Detail |
| 3 | Cross Section B-B' |
| 4 | L3 Sand Unit Isopach Map |
| 5 | Structure Contour Map - Base of L3 Sand Unit |
| 6 | Third Quarter 1996 Water Level Elevations |
| 7 | L4A Zone Hydrographs (L4-32A, L4-32EA, L4-32WA, L4-33A, L4-33EA, L4-33WA) |
| 8 | L4 Zone Hydrographs (L4-32, L4-32E, L4-32W, L4-33, L4-33W, L4-34W) |
| 9 | L4 Zone Hydrographs (L4-32, L4-32E, L4-32W, L4-33, L4-33W, L4-34W) |
| 10 | L4 Zone Hydrographs (L4-8N, L4-31, L4-41) |
| 11 | L5 Zone Hydrographs (L5-7, L5-8, L5-9, L5-10A) |
| 12 | L5 Zone Hydrographs (L5-3, L5-4, L5-5, L5-6) |
| 13 | L6 Zone Hydrographs (L6-1, L6-2, L6-3, L6-3A) |
| 14 | Geochemical Well Groupings |
| 15 | Bivariate Chemical Plots, Fourth Quarter 1995 |
| 16 | Sulfate Versus Depth to Water |
| 17 | Secure Cell Layout and New L3 Well Locations |
| 18 | Groundwater Data Collection Flow Diagram |
| 19 | Flow Diagram for Groundwater Data Evaluation Procedures |


## LIST OF TABLES


| Table | Title |
|---|---|
| 1 | Groundwater Monitoring Wells at the Highway 36 Facility |
| 2 | Hydraulic Characteristics and Estimated Average Linear Groundwater Flow Velocities |
| 3 | GW-1 Parameter List - Background Monitoring Parameters |
| 4 | Former GW-2 Detection Monitoring Parameters |
| 5 | Geochemical Well Groupings |
| 6 | F039 Hazardous Waste Constituent List |
| 7 | GW-2 Parameter List (Detection Monitoring and General Groundwater Quality Parameters) |
| 8 | Frequency of Data Collection and Evaluation |
| 9 | Groundwater Monitoring Well Data Collection |

## LIST OF APPENDICES


| Appendix | Title |
|---|---|
| A | Descriptive Statistic Examples |
| B | Descriptive Statistics for Infrequently Detected Parameters |
| C | Example Data Package for Trend Analysis of Monitoring Parameters |
| D | Example of Prediction Intervals |
| E | |

# 1.0 INTRODUCTION

The Highway 36 Land Development Company owns and operates a hazardous-waste treatment, storage and disposal facility (the Facility), which is located approximately 70 miles east of Denver and seven miles west of Last Chance, Colorado. The RCRA permitted area is located on 325 acres of Sections 25 and 36, Township 3 North, Range 57 West of the 6th P.M. Activities are performed in accordance with the Facility's Colorado Hazardous Waste RCRA Part B Permit (permit number COD9913000484).

This document presents the technical justification/rationale for a groundwater protection program at the Facility. The groundwater protection program includes multiple release detection mechanisms using information and data from the individual secure cells, interior groundwater monitoring wells, and compliance boundary monitoring wells to assess the potential for a release from the secure cells at the Facility.

## 1.1 BACKGROUND

Groundwater protection at the Facility is achieved by meeting regulatory-based technical performance standards that address (1) the types and amounts of materials that can be placed within the secure cells, (2) the design and operation of the secure cells so that leachate generation is minimized and collection and removal of leachate are maximized, and (3) routine monitoring of the volume and composition of liquids within the cell and liner system to evaluate the performance of the secure cell liner and to assess whether a release has occurred. In addition, the Facility is also required to comply with the performance standards for groundwater monitoring systems at permitted hazardous waste disposal facilities in 6 CCR 1007-3, Subpart F, Part 264. These standards require monitoring of parameters and/or constituents that provide a reliable indication of whether hazardous constituents are present in groundwater at specific time intervals to determine whether or not hazardous wastes or constituents have been released from the Facility and are affecting groundwater. As indicated in Part 264.97, (General Ground-water Monitoring Requirements), the groundwater monitoring system must consist of a sufficient number of wells installed at appropriate locations and depths to yield groundwater samples from the uppermost aquifer that:

- represent the quality of background water that has not been affected by leakage from a facility;
- represent the quality of groundwater passing the point of compliance; and
- allow for the detection of contamination when hazardous wastes or hazardous constituents have migrated from the waste management area to the uppermost aquifer.

## 1.2 OVERVIEW

This technical justification document discusses: (1) the subsurface geology at the Facility, including the extensive borehole data that delineate the spatial extent of the L3 Sand Unit; (2) the occurrence of groundwater at the Facility and the hydrogeologic characteristics that affect groundwater flow directions and rates; (3) the geochemical characteristics of groundwater in the subsurface units at the Facility; (4) the design and operation of the secure cells with respect to waste containment and groundwater protection; (5) the routine monitoring of the volume and composition of the leachate and other fluids in the secure cell to evaluate potential releases; and (6) the potential release points from the secure cells, the subsurface migration pathways for hazardous waste constituents and the sequence in which landfill fluids, if released, would be detected in the groundwater monitoring wells. The environmental site and waste management information is integrated into a conceptual model that is used to predict the movement of contaminants from the waste management units into the uppermost aquifer in the unlikely event of a release. Based on the conceptual model, a technical rationale is presented for the design of the groundwater protection program at the Facility, including the monitoring locations, frequency of monitoring and the analytical parameters, methods and detection limits. Also discussed are the techniques for evaluating the data to reach decisions regarding the performance of the secure cells and potential impacts to groundwater beneath the Facility.

# 2.0 SITE CHARACTERIZATION

## 2.1 GEOLOGY

The regional and site-specific geology has been described in detail in reports by Tweto (1979), Fox (1984 a,b,c), Colorado GeoLogic (1986 a,b,c and 1987 a,b,c,d,e,f), Deuel and Associates (1989 a,b,c) and McCulley, Frick & Gilman, Inc. (MFG, 1995a). The locations of soil borings and monitoring wells that provide subsurface geologic information at the Facility are shown on Figure 1. This figure also shows the locations of the cross-sections presented in Figures 2 and 3, which depict subsurface geology. The site geology, as characterized in previous studies, includes three stratigraphic units that lie below approximately 1 to 2 feet of silty clay topsoil. These units, from shallow to deep, include:

- Unconsolidated sediments (Silty Clay Unit and L3 Sand Unit)
- Weathered Pierre Shale
- Unweathered Pierre Shale

The unconsolidated sediments have previously been described as wind-blown loess deposits (MFG, 1995a; Tweto, 1979). The unconsolidated unit consists mostly of varying portions of calcareous clayey silt and silty clay, which are referred to as the Silty Clay Unit. The clay content and relative hardness typically increases with depth. At the Facility, the unconsolidated unit typically occurs between the ground surface and 9 to 32 feet below the ground surface (bgs). The unit is generally classified as CL according to the Unified Soil Classification System (USCS). A linear sand body has been defined within the Silty Clay Unit beneath the eastern portion of the Facility. This sand body has been designed as the L3 Sand Unit. As shown in Figure 4, the L3 Sand Unit varies in width from 350 to 700 feet and trends north-northeast/south-southwest across the Facility. Where present, the L3 Sand Unit is typically 3 to 5 feet thick, and may be up to 10 feet thick. The base of the L3 Sand Unit is shown in the structure contour map presented in Figure 5. The L3 Sand Unit fines upward with pebbles and some cobbles in the lower portion and has a gradational upper contact with the Silty Clay Unit.

The contact between the Silty Clay Unit and weathered Pierre Shale is gradational, but generally is recognized within a 6-inch to 2-foot interval. The contact is distinguished by the occurrence of bedding planes, tight fractures and an increase in induration for the weathered Pierre Shale. Where the L3 Sand Unit is present, the contact is often sharp, but may also be gradational.

The weathered portion of the Pierre Shale has an olive-brown to gray-brown color and is characterized as a moist, hard, non-calcareous unit with a blocky structure. The shale is silty with soil-like characteristics and is classified as CH according to the USCS. In the secure cell area, the weathered shale is approximately 15 to 35 feet thick. Gypsum infillings are common. Lenses of massive, gray calcite-cemented siltstone, approximately 3 to 5 feet thick and 2 to 12 feet long, have been observed (MFG, 1995a) and have been encountered infrequently at varying depths in the weathered Pierre Shale. Low-angle fractures with gypsiferous infilling and iron stains on the fracture surfaces occur frequently within the unit.

The contact between the weathered and unweathered Pierre Shale is gradational and generally occurs at depths ranging from 40 to 53 feet bgs. The weathered Pierre Shale is distinguished from the unweathered Pierre Shale by its brown color and less massive structure. The frequency of fracturing and iron staining decreases, and the material hardness increases with depth through the weathered/unweathered transition. The transitional zone varies in thickness from approximately 10 to 20 feet, and in some areas comprises a majority of the weathered shale unit.

The unweathered Pierre Shale is silty, dark to very dark gray, non-calcareous and is slightly fossiliferous. The unit is typically hard and slightly moist with a blocky structure near the upper boundary and a more massive (uniform) structure with depth (i.e., on the floor of cell excavations). Thin laminations are observed throughout the unit with occasional soft silt laminae containing traces of very fine sand. At various depths, discontinuous, gray, very hard, calcareous silt beds are present. These beds range in thickness from 2 inches to approximately 1.5 feet. Fractures are infrequent and at low angles with gypsiferous infilling (up to 1-inch thick) and iron staining on the fracture surfaces. The unweathered Pierre Shale generally has the same engineering characteristics as the weathered Pierre Shale, except that it generally is unfractured. The top of the unweathered Pierre Shale occurs at about 40 to 55 feet below the ground surface. The total thickness of the Pierre Shale at the Facility is approximately 4,300 feet (Fox, 1984a).

Structural deformation (e.g., folding, fault displacement, etc.) is not evident in any of the units encountered in the secure cell excavations (Deuel & Associates, 1989c; MFG, 1995a).

## 2.2 HYDROGEOLOGY

The regional hydrogeology and site groundwater conditions have been studied extensively by others including: Colorado GeoLogic (1986 b,c and 1987a,b,c,d,e,f), Environmental Science, Inc. (1990), Fox Consultants (1984 a,b,c), MFG (1991; 1992; 1993 a,b,c; 1994 a,b,c,d; 1995 b,c,d,e,f and 1996 a,b) and Richard and Brogden (1989).

### 2.2.1 Regional Hydrogeology

No major groundwater aquifers underlie the site, nor are any exposed at the surface. However, due to the very low permeability of the Pierre Shale, perched water often occurs in the alluvial-fill drainage swales outside of the permit area at depths ranging from 35 to 45 feet below the ground surface. Recharge to these areas comes from vertical infiltration in the immediate drainage area. As discussed further below, isolated areas of perched groundwater are also present within the permit area.

A minor amount of deep groundwater exists in the Pierre Shale bedrock. Groundwater in the Pierre Shale in the vicinity of the Facility is present at depths ranging from 250 to 390 ft below the ground surface (MFG, 1991; 1992; 1993 a,b,c; 1994 a,b,c,d; 1995b,c,d,e,f and 1996 a,b), which correspond to an elevation of approximately 4700 feet above sea level. Recharge probably comes from horizontal flow through the small fracture networks. The Pierre Shale is not considered an aquifer as evidenced by the low yields to wells and very slow recovery rates following pumping.

### 2.2.2 Site Groundwater Conditions

Previous reports discuss the occurrence and sources of groundwater, hydraulic characteristics of the subsurface geologic units and the geochemical composition and quality of groundwater. Site groundwater conditions are discussed briefly below.

2.2.2.1 Occurrence of Groundwater

The occurrence of groundwater at the Facility is based on water level data obtained from 120 monitoring wells (Table 1), of which approximately 85 are dry (MFG, 1991; 1992; 1993 a,b,c; 1994 a,b,c,d; 1995 b,c,d,e,f and 1996 a,b). The majority of the wells have been monitored quarterly since 1986. The locations of the monitoring wells are shown on Figure 1. These wells are screened in several different hydrostratigraphic units, or "Zones", that have been delineated at the Facility. These zones are described below.

- The L3 Zone is defined as the discrete lenticular sand body (i.e., the L3 Sand Unit) that occurs within the surficial Silty Clay Unit. Monitoring wells were historically installed at 50-foot intervals along the compliance boundary and in those areas where the L3 Zone is present. However, in a recent Class 2 Modification to the Part B Permit, the approach to number and location of new Level 3 Zone wells was modified (MFG, 1996c) and new Level 3 wells are located along potential fluid migration pathways in the L3 Sand Unit. Level 3 Zone wells are screened from approximately 9 to 36 feet bgs. Water has never been detected in any L3 Zone wells during ten years of quarterly monitoring.

- The L4A Zone is defined as the interface between the surficial Silty Clay Unit and the underlying weathered Pierre Shale. Monitoring wells are installed at 100-foot intervals in those areas where the L4A Zone is (or historically was) saturated. Level A Zone wells are screened from approximately 12 to 19 feet bgs. The saturated conditions requiring L4A wells occur only along the northern compliance boundary in the vicinity of a former oil field brine pond, which straddled the compliance boundary near well L4-33 (Figure 6).

- The L4 Zone is defined as the interface between the weathered Pierre Shale and the underlying unweathered Pierre Shale. Level 4 Zone wells are screened from approximately 32 to 64 feet bgs. The typical depth of the weathered/unweathered shale contact is approximately coincident with the proposed depths of the landfill cells. Monitoring wells are installed at 300-foot intervals along the compliance boundary except in those areas where the L4 Zone is (or historically was) saturated, where closer spacings (typically 100-foot intervals) are required. The saturated conditions requiring tighter spacing of the L4 Zone wells occur only along portions of the northern compliance boundary in the vicinity of a former oil field brine pond and along the part of the western compliance boundary in the vicinity of Secure Cell Numbers 1 and 2 (Figure 6). Several L4 Zone wells are also installed inside the compliance boundary adjacent to Secure Cell Numbers 1 and 2, and one L4 Zone well (L4-9W) is installed outside the compliance boundary west of Secure Cell No. 2. The occurrence of saturated conditions adjacent to Secure Cell No. 2 results from recharge of incident precipitation through the base of the Secure Cell No. 2 excavation, which was unlined from approximately August 1989 to July 1995, prior to construction of the liner system. Although

standing rainwater and snowmelt were historically pumped from Secure Cell No. 2, water remained in the excavation for a period of several days prior to removal. During this time, water apparently seeped into the weathered portion of the Pierre Shale that was exposed in the base and walls of the unlined excavation and slowly moved along the weathered/unweathered Pierre Shale interface.

- The L5 Zone represents the uppermost water-bearing unit at the Facility and is defined as the uppermost saturated portion of the unweathered Pierre Shale. Eight L5 Zone monitoring wells, installed along the compliance boundary, are screened in silty partings that occur at varying depths in the unweathered Pierre Shale. The L5 Zone wells are screened at depths of approximately 250 to 415 feet bgs.

- The L6 Zone is defined as the first occurrence of saturated conditions in the alluvial drainages outside the compliance boundary. Focused recharge in the offsite drainages results in limited areas of saturation that occur in the shallow geologic materials. Three L6 Zone wells are located in the vicinity of the Facility. The wells are screened in silt and fine sand units overlying the weathered Pierre Shale, and within the weathered Pierre Shale. Depth to water in the L6 Zone wells ranges from approximately 10 to 50 feet bgs.

The wells described above comprise the current monitoring program wells for the Facility. In addition, wells were also installed as part of a RCRA Facility Investigation (RFI) of a previously closed oil field brine pond which was associated with the Jolley-Axtell No. 2 oil well (Triegel & Associates, Inc., 1989). These wells are referred to as the BP wells. BP wells were installed in the L4 Zone and the L4A Zone and are located both inside and outside of the northern compliance boundary (Figure 1). Water quality data from the BP wells have been used historically in establishing part of the background water quality database. However, these wells are no longer included in the Facility monitoring program.

#### 2.2.2.2 Historic Water Level Trends

Historic water level trends and the groundwater level elevation data for the Facility are described and presented in the Annual Groundwater Monitoring Reports (MFG, 1992, 1993a, 1994a, 1995b and 1996b).

As discussed previously, water has never been detected in any of the 36 Level 3 wells. Hydrographs of the water level fluctuations in the other monitoring wells are presented in Figures 7 through 13. These figures also illustrate the elevations of the screened intervals and sumps for each well. Except for the L5 Zone wells, water levels for the majority of the L4A, L4 and L6 Zone wells were consistently below the screened

interval (i.e., water was present only in the 5-foot long sump of the well) or the well was dry. Water levels in the sumps of the wells (i.e., below the screened interval) do not represent true saturation levels within the geologic formations.

An evaluation of hydrographs from Facility monitoring wells indicates that groundwater levels continue to decline in the majority of shallow L4A Zone (Figure 7) and L4 Zone (Figure 8) wells that monitor the area associated with the former brine pond near the northern compliance boundary. The declining water levels in the L4A Zone wells, and most L4 Zone wells, reflect the past elimination of the primary source of water to these wells (seepage from the former brine pond). Water levels in several L4 Zone wells near Secure Cell No. 2 are increasing slightly through time (Figures 9 and 10). The water level increase in this area is probably a relic of the focused recharge of precipitation through the unlined base and walls of the Secure Cell No. 2 excavation prior to liner construction and waste disposal. As shown in Figures 11 and 12, the early water levels measured in the L5 Zone wells were erratic, indicative of the slow recovery of the wells between the quarterly sampling events. However, since 1992, due to a longer time period between sampling events, the water levels appear to be more constant than the early records indicate. The water levels in the L5 Zone wells generally were stable or increased slightly through 1995 (Figure 13). Water levels in two of the three L6 Zone wells, L6-1 and L6-2, were below the screened intervals (in the well sumps) throughout 1995. The water level in the third well, L6-3A, after increasing steadily since 1989, stabilized and began a gradual decline in the third quarter 1992. The water level in L6-3A remained relatively stable during 1995. The most probable explanation for the water level occurrence and subsequent trends observed in L6-3A is localized groundwater recharge through the unlined base of the Uncontaminated Storm Water Detention Pond (UCDP), which is located immediately up the drainage from well L6-3A, and more recent trends in precipitation at the Facility.

2.2.2.3 Hydraulic Properties

The hydraulic properties of the subsurface units at the Facility have been studied extensively by Fox (1984c) and Colorado GeoLogic (1987f). Fox (1984c) evaluated the permeability of the subsurface units as part of the initial site characterization. The permeability testing program included 30 in situ standpipe permeability tests, 31 packer tests, 2 pumping tests and 10 laboratory tests on both relatively undisturbed and

remolded samples. Colorado GeoLogic (1987f) performed a total of 34 slug tests in all wells at and near the Facility in which the static water levels were within or above the screened interval. Tests were performed in twenty-four wells in the L4A and L4 Zones, eight L5 Zone wells and two L6 Zone wells.

The saturated hydraulic conductivity values obtained during these investigations are summarized in Table 2. Average linear groundwater flow velocities for the various hydrostratigraphic units at the Facility were calculated using the hydraulic characteristics listed in Table 2 and Darcy's Law for flow in saturated media. The estimated averaged linear groundwater flow velocities for the limited areas of saturation in the L4A, L4 and L5 Zones are approximately 35, 14, and 13 feet per year, respectively. As discussed further in Section 4.2, the flow velocities in the unsaturated portions of the L4A, L4 and L5 Zones, which are generally more extensive than the areas of saturation, may be several orders of magnitude slower than the saturated flow velocities, depending upon the moisture content (sometimes down to 1/100,000 of its value at saturation) (Hillel, 1980).

Hydrogeologic conditions at the Facility result in only limited areas of saturation in the shallow hydrostratigraphic zones. In addition, there is no definable hydraulic gradient in the L5 Zone to allow upgradient/downgradient directions to be established. Therefore, the rigorous construction of potentiometric surface maps to define the groundwater flow directions within each hydrostratigraphic zone is not appropriate. However, the following general statements can be made regarding groundwater flow paths in the subsurface units at the Facility:

- Saturated conditions have never been detected in the L3 Sand Unit during ten years of quarterly monitoring. If saturated conditions were established, the primary flow direction would be in the downdip direction along the base of this unit.

- The low hydraulic conductivity of the geologic units at the Facility limits the amount of recharge to the wells between sampling events. As a result, the mound associated with the former brine pond along the northern compliance boundary has been dissipating with time since the source of the water (i.e., brine pond seepage) was eliminated in the period 1984 to 1985. In general, the perched groundwater flow direction is radially outward from the location of the former brine pond (i.e., near well L4-33). With the elimination of the driving force (head), lateral movement of perched brine pond remnants in the L4A Zone currently appears to be minimal. As indicated by the historic vertical head differences in adjacent wells completed in the upper L4A Zone and in the lower L4 Zone, the primary groundwater flow

direction now appears to be vertical, as the residual water in the surficial Silty Clay Unit drains vertically into the underlying weathered Pierre Shale.

- Water that infiltrated through the previously unlined base and sides of the Secure Cell No. 2 excavation into the L4 Zone near Secure Cell No. 2 generally migrates along the interface between the weathered and unweathered Pierre Shale toward the southwest.

- The L5 Zone represents the "uppermost aquifer" at the Facility, as that term is used in the regulatory context (40 CFR § 260.10). In a conventional hydrogeologic sense, the L5 Zone is not an aquifer, as evidenced by the low yields to wells and very slow recovery rates following purging and sampling (Figures 11 and 12). Saturated zones monitored by the L5 Zone well zones may not be hydraulically interconnected (MFG, 1992, 1993a, 1994a, 1995b and 1996b).

- Groundwater in the L6 Zone is assumed to flow horizontally along the off-site drainages, with a small amount of vertical leakage to the underlying geologic units.

## 2.3 GROUNDWATER GEOCHEMISTRY

### 2.3.1 Background Database

The background groundwater quality database consists of monitoring data that have been collected on a quarterly to annual basis at the Facility since 1986. These data include background monitoring parameters listed in Table 3, the former detection monitoring parameters listed in Table 4 and some additional general water quality parameters. Groundwater quality data collected after the first acceptance of waste at the Facility (i.e., after the fourth quarter 1991) are currently added to the background database in accordance with the procedures specified in Permit Attachment GW-9 and in the body of the Permit [Section III.A.3.b.(i)].

### 2.3.2 Geochemical Well Groupings

Groundwater quality data from the monitoring wells at the Facility are classified into six distinct groups for the purpose of characterizing the composition of groundwater at the Facility and evaluating potential releases from the secure cells. The six geochemical well groupings are presented in Table 5 and shown on Figure 14. The well groupings were developed from a comprehensive evaluation of hydrogeologic properties (e.g., depth to water, proximity to brine pond, etc.) and water chemistry data using standard geochemical

techniques such as construction of bivariate plots of the major ions and trilinear diagrams, and evaluating the appropriateness of the well groupings using a multivariate statistical procedure referred to as a discriminant function analysis. These groupings were originally presented in the Supplemental Background Data Evaluation Report, Revision No. 1 (MFG, 1991), and were verified in subsequent annual groundwater monitoring reports for the Facility (MFG, 1992, 1993a, 1994a, 1995b and 1996b).

The well groupings appear to separate wells based upon their position relative to the evolutionary flow path of the brine pond seepage (MFG, 1991). Groundwater becomes more concentrated in solutes as it moves laterally and vertically away from the brine pond through the subsurface, apparently as a result of the travel (i.e., residence) time in the subsurface geologic units and subsequent dissolution of the abundant evaporitic (e.g., gypsum, anhydrite, etc.) and other minerals (MFG, 1991). The shallow seepage waters lowest in total dissolved solids (TDS) concentrations are those from the wells located near the former brine pond. Although this seems counter-intuitive, the brine pond liquids were actually very dilute, and the term "brine" is actually a misnomer. Results of chemical analyses on water samples collected from the former brine pond for the period from January 1981 to February 1984 indicate that the oil-field water had an average TDS concentration of 1,879 mg/L (Colorado Geologic, 1986b), which is much lower than true brines with TDS concentrations greater than 100,000 mg/L. Only after the brine pond seepage migrates downward and away from the former brine pond, does the water increase in TDS, through the dissolution of evaporite minerals along the flow paths, and take on the characteristics considered typical of saline waters (i.e., TDS > than 10,000 mg/L). None of the groundwater at the Facility approaches the composition of a true brine (i.e., TDS > 100,000 mg/L).

Groups 1 wells are the shallowest and screen the least geochemically "mature" shallow groundwater at the Facility. As shown in Figure 15, the concentrations of most major cations and anions increase from the levels seen in Group 1 (and Group 6 wells, which are discussed further below) to the concentrations exhibited by wells in Group 4. Group 1 wells, which are the shallow L4A wells located adjacent to the former brine pond located along the northern compliance boundary, generally exhibit low concentrations of most major cations and anions. The wells in Groups 2 and 3, which monitor water quality in the dissipating brine pond seepage plume, are generally farther from the brine pond than Group 1 wells, or they are screened at greater depths (Figure 16). Group 4 wells produce the deepest of the "shallow" waters at the Facility, and also monitor water related, at least in part, to former oil-field activities. The wells in Group 4 that are located along the

western compliance boundary adjacent to Secure Cell No. 2 are generally the deepest of the shallow wells at the Facility and produce the most geochemically "mature" shallow water at the Facility.

Concentrations of major ions in Group 5 wells, the deep wells in the unweathered Pierre Shale (i.e., Level 5), generally plot apart from the concentrations observed in shallower wells at the Facility (Figure 15).

The concentrations of major anions and cations in Group 6 (Level 6) wells are relatively low and similar in many respects to Group 1 wells. Group 6 wells, which are completed in shallow geologic materials in the surface water drainages outside of the compliance boundary, are presumably subject to a greater recharge of dilute incident precipitation and shorter residence times than the other wells at the Facility. Consequently, groundwater in the Group 6 wells is expected to exhibit low concentrations of major ions.

The continued incorporation of new data and the re-evaluation, and possible reorganization, of well groupings are especially necessary for the purpose of evaluating natural variability and chemical evolution of the groundwater beneath the Facility, and for grouping wells on the basis of distinctive geochemical compositions associated with different hydrostratigraphic units underlying the Facility.

### 2.3.3 Geochemical Characteristics

Geochemical characteristics of the various hydrostratigraphic units have been evaluated previously in the Supplemental Background Data Evaluation Report (MFG, 1991) and the annual groundwater monitoring reports for the Facility (MFG, 1992, 1993a, 1994a, 1995b and 1996b). These evaluations included calculating the statistical parameters and data distribution for analytes and well groups, assessing seasonality, and evaluating long-term temporal trends in the data. Significant findings are summarized below.

- Only a small number of the inorganic datasets (approximately 2 percent) exhibit seasonal variability, indicating that there is not a strong seasonal process affecting groundwater quality at the Facility.
- Non-normal distributions were noted in approximately 30 percent of the inorganic datasets.

- Detection frequencies for most trace metals are generally less than 50 percent, and organic compounds have not been detected in groundwater.

- Historic data indicate that the quality of water in the shallow saturated zones at the northern Facility boundary is evolving with time as the brine ponds seepage plume moves downward and away from the location of the former brine pond. Concentrations of major ions in many of the L4 and BP wells are increasing through time, as evidenced by the presence of positively sloped linear trends in the datasets. In addition, water levels in many of the wells are declining through time. These data indicate that the brine pond seepage plume is dissipating, and that the water quality within the plume is evolving toward a composition comparable to that exhibited by the deepest of the L4 Level wells, which are near Secure Cell No. 2.

# 3.0 WASTE TREATMENT AND LANDFILL PERFORMANCE DESIGN CRITERIA

The goal of the regulatory requirements pertaining to waste treatment and the performance design criteria for hazardous waste landfills is to provide groundwater protection via long-term management of liquids. Waste treatment criteria are addressed in the Land Disposal Restrictions (LDRs) in 40 CFR Part 268 and 6 CCR 1007-3, Part 268. Broadly stated, the LDR regulations establish treatment standards (expressed as concentration limits or methods of treatment) for restricted hazardous wastes regulated under RCRA (EPA, 1989a). The technical performance design requirements and guidelines are presented in the EPA's Requirements for Hazardous Waste Landfill Design, Construction and Closure (EPA, 1989b). The landfill performance design criteria, which include operational practices and final cover design criteria minimize leachate generation. Use of the lining system and the underlying leachate collection, detection and removal systems maximize leachate collection and removal. In addition, collection of hydraulic and chemical data from the leachate collection and detection systems allows early release detection, and these data are used as the first mechanism for release detection in the groundwater protection program.

## 3.1 WASTE TREATMENT OPERATIONS

All wastes to be placed in the secure cells at the Facility are subject to LDRs. In addition to establishing treatment standards (expressed as concentration limits or methods of treatment), these regulations restrict the types and amounts of materials that can be landfilled, prevent the disposal of organic compounds and other hazardous waste constituents at concentrations exceeding specified limits, ban the disposal of bulk liquids or wastes containing free liquid, and prevent the disposal of certain waste constituents at concentrations exceeding specified limits. As a result, LDRs and waste treatment operations that are performed to meet LDRs restrict the amount and composition of leachate that can be generated.

At the Facility, each waste stream is analyzed prior to receipt. This "pre-acceptance" sample is analyzed to characterize the waste with respect to the LDR limits specified in 40 CFR 268. These results are used to assess whether the waste can be accepted, and can be placed directly into a secure cell or must be treated to meet the LDR standards prior to disposal. Treatment of hazardous waste so that the promulgated

treatment standards are achieved immobilizes the hazardous waste constituents and thereby reduces their leaching potential (EPA, 1989a). Restricted wastes are, at a minimum, subject to the waste analysis, notification and record keeping requirements of 40 CFR Part 268.7. These activities are described in the Waste Analysis Plan (WAP) in the Part B Permit.

The treatment activities at the Facility consist of stabilization, chemical precipitation, oxidation or reduction, neutralization, deactivation, solidification and immobilization. Chemical reactions during treatment result in an alkaline waste matrix with a pH typically between 7 and 12. The alkaline conditions in the waste matrix minimize the potential for leaching of waste constituents (e.g., metals) into the cell leachate, and results in the hydrolysis (i.e., destruction) of some semivolatile organic compounds. However, some acid-extractable semivolatile organic compounds, herbicides and pesticides may be leached from the alkaline waste matrix and may be detected at low concentrations in the cell leachate. Five years of analytical data from Secure Cell No.1, and recent data from Secure Cell No. 2, confirm that the leachate contains low concentrations of some acid-extractable organic compounds, herbicides, pesticides and a few trace metals. As a result of the LDRs, no volatile organic compounds have been detected in the leachate from either of the secure cells.

## 3.2 SECURE CELL DESIGN, OPERATION AND LAYOUT

Details of the secure cell design, operation and layout are presented in the Part B Permit and are discussed briefly below.

### 3.2.1 Final Cover Design

Figure 2 displays a simplified schematic diagram of the final cover design for the secure cells at the Facility. The purpose of the final landfill cover is to minimize infiltration of water into the landfill and, thus, minimize leaching of constituents from the stabilized waste. Regulations require that the cover be no more permeable than the liner system. This regulatory requirement results in infiltration rates into the landfill that are less than the potential leakage rates. As a result, a leachate mound would not develop within the landfill on top of the liner, and leakage would not increase through time. Additionally, the final cover must also be designed to meet the regulatory performance objectives related to long-term cover stability such as settlement,

surface water management and erosion control, gas control, biotic barriers, cap-liner connections, and frost penetration.

### 3.2.2 Cell Liner Design

A simplified schematic diagram of the bottom liner design for the secure cells at the Facility is shown in Figure 2. The components of the liner system on the side slope are generally similar to the bottom liner. The liner system (described from top to bottom) will consist of a protective soil layer, a leachate collection and removal system (LCS), a primary composite (soil and synthetic) liner, a leachate detection system (LDS), a secondary composite liner, and an underlying permanent sump. These components and their purpose are described briefly below:

- A protective soil layer (which is a minimum 1-foot thick for Secure Cell No. 2, and 2-feet thick for Secure Cell Nos. 3-7), which separates the waste from the underlying liner components.

- A leachate collection system (LCS) consisting of a 1-foot thick, high permeability ($1 \times 10^{-2}$ cm/s or more) sand or gravel layer and a geotextile/geonet (or double-sided geocomposite) drainage layer. The purpose of the LCS and associated drainage layer is to collect and transmit liquid above the primary composite liner to a collection sump. Removal of liquids from the LCS reduces the hydraulic head (i.e., pressure or driving force) on the primary composite liner, and thereby minimizes the volume and rate of leakage that may occur.

- A primary composite liner, consisting of an 80-mil HDPE geomembrane and 3 feet of compacted, low-permeability (i.e., $k \leq 1 \times 10^{-7}$ cm/s) clay. The purpose of this liner component is to reduce the migration of hazardous waste constituents by reducing or eliminating the rate of movement of the leachate, and increase the attenuation of leachate constituents.

- A leak detection system (LDS) consisting of a geotextile filter/geonet (or double-sided geocomposite) drainage layer. The purpose of the LDS and associated drainage layer is to facilitate the rapid collection and removal of liquids that accumulate between the primary and secondary liners. The LDS acts to detect and collect water caused by primary clay consolidation or leachate in the improbable event that leachate penetrates the primary composite liner.

- A secondary composite liner, consisting of an 80-mil HDPE geomembrane and 3 feet of compacted, low-permeability (i.e., $k \leq 1 \times 10^{-7}$ cm/s) clay.

- A permanent sump consisting of a drainage gravel layer wrapped in geotextile. The permanent sump will collect naturally-occurring vadose zone water and water from consolidation of the secondary clay liner. In the improbable event that leakage should occur through the overlying secondary composite liner, the permanent sump would allow detection, collection and removal of leachate.

The side and bottom liner components are sloping to facilitate rapid flow of fluids toward the collection sumps (i.e., LCS, LDS and permanent sump), where they can be detected and removed via a riser pipe that extends up the corner of the secure cells to the surface.

### 3.2.3 Secure Cell Layout

The conceptual secure cell layout and cell development sequence are shown in Figure 17. Generally, when an active secure cell has been filled or nearly filled to capacity, waste disposal activities will be moved to a newly constructed secure cell, and closure activities will commence on the filled secure cell. As secure cell construction proceeds, the L3 Sand Unit will be excavated in large part (see Figure 17). Removal of large portions of the L3 Sand Unit will further limit the potential for this unit to act as a migration pathway for fluids in the unlikely event that saturated conditions occur.

### 3.2.4 L3 Sand Unit Clay Barrier

In accordance with the Part B Permit, where the L3 Sand Unit is present adjacent to a secure cell, the Facility must over-excavate the L3 Sand Unit away from the secure cell and install an engineered clay barrier to seal off the unit. The engineered clay barrier must consist of recompacted material having a minimum hydraulic conductivity of at least $1 \times 10^{-8}$ cm/s and a sufficient thickness to provide a 1,000-year travel time barrier to any migration of fluids from the secure cell into the L3 Sand Unit.

## 3.3 EVALUATION OF SECURE CELL PERFORMANCE

The facility is required to perform routine monitoring of the volume and composition of the fluids in the LCS and LDS in each secure cell to evaluate potential releases. Potential sources of fluids from the LDS include: (1) precipitation that enters the leak detection layer during construction, hereafter referred to as

construction water; (2) water expelled from consolidation of the clay components of the composite primary liner during landfill operations, hereafter referred to as consolidation water; and (3) leakage through the primary liner. Potential sources of fluid have been discussed in detail in the technical papers by Gross et al. (1990) and Bonaparte and Gross (1990), and fluids may be present in the LCS and LDS during the active life of the landfill cells and for some time after closure. The potential for leakage through the primary liner is the basis for the action leakage rate (ALR) monitoring discussed below.

Highway 36 is required to submit an Action Leakage Rate (ALR) and Response Action Plan (RAP) for Secure Cells Number 2 through 7 in accordance with the requirements of 40 CFR and 6 CCR 1007-3, Parts 264.302 and 304. The ALR is based on the specific design of each cell and calculation methodologies recommended by EPA (1992a). The ALR is the maximum design flow rate, including a safety factor, that the LDS may remove without the fluid head on the bottom liner exceeding 1 foot. However, Highway 36's Part B Permit requires that the head on the bottom liner (i.e., secondary liner for Secure Cell Nos. 3 through 7) not exceed 0.67 feet. In addition to the hydraulic monitoring of the secure cells, the chemical composition of the fluids in the LCS and LDS are monitored by Highway 36 to evaluate the secure cell performance and to assess whether a release from the secure cells into the LDS has occurred. These monitoring activities are described further in Section 5.1 along with the RAP, which specifies the steps to be taken in the event the ALR is exceeded.

# 4.0 EVALUATION AND DETECTION OF RELEASES

This section integrates the characteristics of the hydrogeologic system and the waste management setting (including types of wastes and waste management operations) at the Facility into a conceptual model of the potential movement of contaminants, should a release occur, from the waste management units into the "uppermost aquifer" (i.e., the L5 Zone).

## 4.1 RELEASE SCENARIO

As discussed previously, the secure cells are designed to minimize leachate generation and maximize leachate collection and removal. The sloping liner components rapidly transmit leachate and other fluids to the LCS sump, LDS sump and permanent sump in each secure cell so that a leachate mound does not develop on the side slope. As a result, the head (driving force) is insufficient to cause leachate to leak laterally through the side slope liner at an elevation equivalent to the L3 Zone (i.e., L3 Sand Unit) or L4A Zone (i.e., the interface between the Silty Clay Unit and weathered Pierre Shale). In addition, the ALR requirement, which limits the height of the leachate mound that may develop on the secondary liner to 0.67 feet, prevents leachate in the secure cells from accumulating and rising within the liner system to an elevation equivalent to the L3 and L4A Zones. Consequently, lateral migration of leachate from within a secure cell into the L3 and L4A Zones is prevented. Furthermore, even in the improbable event that sufficient leachate were to accumulate in the secure cell up to an elevation that allowed saturated conditions to occur in the L3 Sand Unit, the engineered clay plug provides an additional, 1,000-year travel time barrier to any migration of fluids into the L3 Sand Unit.

The ALR requirement also limits the elevation of saturated conditions that could potentially be established in previously unsaturated geologic materials outside of the secure cells. Saturated conditions in geologic materials outside of a leaking landfill cell cannot exceed the maximum elevation of head that can be established within the cell (i.e., 0.67 feet above the secondary liner) because there is no driving force (i.e., head) within the cell that would cause fluids outside the cell to rise to a higher elevation. Because the secondary liner components and sumps of the secure cells are approximately 20 to 40 feet below the elevation

of the L3 and L4A Zones, it is extremely unlikely that a release from the secure cells would ever result in saturated conditions in these higher-elevation hydrostratigraphic zones.

Based on the design and construction of the secure cells, the LCS, LDS and permanent sumps are the most probable locations for a leak in the cell liner system because of the complex jointing of the HDPE in these areas and because maximum head develops on the liner in the sumps. In order for leachate to form and migrate through the liner system and out of a permanent sump into the subsurface, the following events would have to occur following placement of the final cover:

- The geocomposite drainage layer within the final cover (i.e., cap) would have to fail, allowing infiltrated water to pond on the underlying synthetic, 80-mil HDPE geomembrane liner within the cap.
- Infiltration would have to occur through the synthetic liner in the cap allowing the ponded water to seep into the underlying low-permeability clay liner within the cap.
- The low-permeability clay liner in the cap would have to absorb water until its moisture content increased to field capacity, allowing water to seep into the underlying wastes, which have been emplaced in accordance with LDRs and waste treatment operations that are designed to restrict the amount and composition of leachate that can be generated.
- Leachate that percolates through the stabilized waste would enter the LCS, where it is monitored and removed. In order for any significant head to develop on the underlying liner system, the pump and monitoring system would have to fail.
- The leachate that collects in the non-functioning LCS would have to permeate through the primary liner system, which consists of an 80-mil HDPE liner and 3 feet of compacted clay having a permeability of less than $1 \times 10^{-8}$ cm/sec.
- Any leachate that penetrates the primary liner would accumulate in the LDS sump, where it is monitored and removed in accordance with the ALR. This system would have to fail as described above for the LCS sump for any significant seepage into the secondary liner system.
- The leachate would have to permeate the secondary clay liner system, which also consists of an 80-mil HDPE liner and 3 feet of compacted clay having a permeability of less than $1 \times 10^{-8}$ cm/sec.
- Any leachate that penetrates the secondary liner system would accumulate in the permanent sump, which is also monitored.

Because of the secure cell construction and RCRA regulations pertaining to the routine monitoring and removal of fluids from the various sumps of the secure cells, it is extremely unlikely that the release scenario described above could occur or go undetected.

## 4.2 MIGRATION PATHWAY ANALYSIS

In the extremely unlikely event of a release from the permanent sumps, which are located approximately at the interface of the weathered and unweathered Pierre Shale, leachate would enter the underlying geologic materials and migrate under unsaturated flow conditions. Fluids in the unsaturated zone are subject to capillary suction (i.e., surface-tension forces between the water and the geologic materials) and gravitational forces. Greater capillary suction forces are associated with the smaller pores found in fine-grained materials (Hillel, 1980). Fine-grained materials such as the weathered and the unweathered Pierre Shale have higher capillary forces than coarser grained materials such as the L3 Sand Unit (Ertec, 1982). As a result, unsaturated conditions (under capillary suction and gravitational forces) can cause fluids to migrate downward and laterally. Where a permanent sump is located above the interface between the weathered and unweathered Pierre Shale, fluids would eventually accumulate at the interface and migrate laterally toward the L4 wells. Where a permanent sump is located below the interface between the weathered and unweathered Pierre Shale, fluids would be expected to principally migrate downward through fractures toward the L5 Zone wells.

Saturation in the L3 Sand Unit and the L4A Zone associated with the release of fluids from the secure cells is not expected to occur, and the number and location of new Level 3 monitoring wells required in the Part B Permit have recently been modified (MFG, 1996c).

# 5.0 GROUNDWATER PROTECTION PROGRAM DESIGN

This section presents an integrated approach to groundwater protection at the Facility that includes multiple release detection mechanisms based on information and data from the individual secure cells (cell leachate and sump fluids), interior groundwater monitoring wells, and compliance boundary monitoring wells. The specific objectives of the Groundwater Protection Program are to:

- Provide early detection of a release(s), if it occurs, from the secure cells.
- Allow for the detection of contamination if hazardous wastes or hazardous constituents migrate from the waste management area to the "uppermost aquifer".
- Monitor existing and/or potential fluid migration pathways and hydrostratigraphic units.
- Evaluate natural variability and chemical evolution of the different hydrostratigraphic units underlying the Facility, which have distinctive geochemical compositions.

The monitoring program for the Facility, designed to meet these objectives and the regulatory requirements, is described below.

## 5.1 SECURE CELL MONITORING

As discussed in Section 3.3, regulations require monitoring of hydraulic and chemical data from the leachate collection and detection systems in the secure cells. Monitoring of these systems allows early release detection and represents the first mechanism for detecting potential releases from the secure cells. The type and frequency of monitoring are discussed below and summarized in Table 7.

### 5.1.1 Action Leakage Rate (Hydraulic) Monitoring

As required by 40 CFR and 6 CCR 1007-3, Part 264.302 and Highway 36's Part B Permit, the Action Leakage Rate (ALR) for Secure Cells Number 2 through 7, requires that the head on the bottom liner (i.e., secondary liner for Secure Cell Nos. 3 through 7) not exceed 0.67 feet. In accordance with 40 CFR §254.303,

the volume of liquid removed from the sump of each LDS will be recorded at least once each week during the active life and closure period for the secure cells. During the post-closure care period, the volume of liquid removed from each LDS sump will be recorded at least monthly. If the liquid level in the sump stays below the pump operating level (i.e., 0.67 ft above the bottom liner in the sump) for two consecutive months, the level of liquid in the sump must be recorded at least quarterly. If the liquid level in the sump stays below the pump operating level for two consecutive quarters, the level of liquid in the sump will be recorded at least semiannually. However, if at any time during the post-closure care period the pump operating level is exceeded for a sump on quarterly or semiannual recording schedules, monthly recording of the volume of liquid removed from the sump will be reinstated. This will continue until such time that the liquid level in the sump again remains below the pump operating level for two consecutive months.

The response action plan (RAP) specifies the steps to be taken in the event the ALR is exceeded, including the initial notifications, assessment activities and follow-up reports.

### 5.1.2 LCS and LDS (Chemical) Monitoring

In addition to the hydraulic monitoring of the secure cells, the chemical composition of the fluids in the LCS and LDS is monitored by Highway 36 to evaluate the secure cell performance and to assess whether a release from the secure cells into the LDS has occurred. LCS and LDS fluids have been collected quarterly since December 1993 from Secure Cell No. 1, and since February 1996 from Secure Cell No. 2. These samples have been analyzed for F039 hazardous waste constituents, which include volatile organic compounds, semivolatile organic compounds, herbicides, pesticides and metals/metalloids (Table 6).

Chemical data from the LCS and LDS for each cell will be evaluated to assess whether landfill fluids have leaked through the primary liner into the LDS above the secondary liner. This evaluation will include visual inspection of the chemical data from the LDS for each secure cell to identify the presence of organic constituents at concentrations above the parameter-specific detection limits in GW-2 (Table 7), and a statistical analysis of the data to identify exceedances relative to historical background data and assess temporal trends in chemical composition of the cell fluids. The data evaluation procedures for evaluating the performance of the secure cells are discussed in Section 6.0. In the event that the analysis of LCS and LDS chemical data for

a secure cell suggest that a leak has occurred through the primary clay liner, Highway 36 will initiate the RAP required by Part 264.304 for an exceedance of the ALR.

## 5.2 DESCRIPTION OF GROUNDWATER MONITORING PROGRAM

### 5.2.1 Inspection and Detection Monitoring Well Networks

The groundwater monitoring program at the Facility consists of two monitoring well networks, the inspection monitoring well network and the detection monitoring well network (Table 8). Wells in the inspection monitoring well network are located within and outside of the compliance boundary (i.e., the L3, L4A, L4 and L6 Zones). The compliance boundary for the Facility is defined in the Part B Permit as the continuous surface extending down into the uppermost saturated unit within the unweathered Pierre Shale bedrock from a line at the ground surface at the outer perimeter of the waste management and disposal area (Figure 1). The purpose of the inspection monitoring well network is to monitor the existing and/or potential fluid migration pathways at the Facility and to identify potential releases prior to migration of hazardous waste constituents to the L5 Zone. The inspection monitoring well network (especially the L4 Zone wells) represents the second mechanism for detecting potential releases from the secure cells. Wells in the detection monitoring program are located on the compliance boundary of the Facility, and monitor groundwater in the uppermost continuous water-bearing unit (i.e., Level 5 wells in the unweathered Pierre Shale). The detection monitoring wells represent the third mechanism for detecting potential releases from the secure cells, and meet the performance standards for groundwater monitoring systems at permitted hazardous waste disposal facilities in 6 CCR 1007-3, Subpart F, Part 264.

Aside from the well location and completion requirements specific to the targeted monitoring zone, specifications for conducting the inspection and detection monitoring programs are essentially the same. However, a confirmed statistically significant exceedance of a monitoring parameter in an inspection monitoring well requires implementation of the Site Contingency Plan, whereas a confirmed exceedance in a detection monitoring well requires implementation of the Compliance Monitoring Program.

### 5.2.2 Water Level Elevation (Hydraulic) Measurements

Traditionally, water level elevation measurements are obtained at hazardous waste management facilities to fulfill the regulatory requirement in 40 CFR and 6 CCR 1007-3 Part 264.97(f) for determining the groundwater surface elevation each time groundwater samples are collected so that the groundwater flow direction can be determined. As discussed previously in Section 2.2.2.3, the rigorous construction of potentiometric surface maps to define the groundwater flow direction within each hydrostratigraphic zone is not appropriate because either there is no definable hydraulic gradient or the areas of saturation in the shallow hydrostratigraphic units are limited in extent.

However routine water level monitoring in all of the wells (including the BP wells) at the Facility will be performed to evaluate potential development of saturated conditions in previously dry wells and anomalous increases in historical water level measurements that may be associated with potential releases from the Facility or other causes. Because this information may be useful in evaluating potential releases from the Facility or indicate changes associated with natural conditions, water level monitoring will be performed quarterly, as indicated in Table 8. Additionally, in the event that water is encountered in a previously dry well or an anomalous increase in the water level elevation in a well is confirmed by a second measurement, an attempt will be made to purge the monitoring well to collect a representative sample for laboratory analysis. The criteria for purging a well in order to obtain a representative groundwater sample is discussed further in Section 5.2.5.

### 5.2.3 Groundwater Monitoring

In accordance with 40 CFR and 6 CCR 1007-3, Part 264.98 (a), the Facility must monitor for "indicator parameters, waste constituents or reaction products that provide a reliable indication of the presence of hazardous constituents in ground water" to fulfill the regulatory requirements for the detection monitoring program. The suitability of certain constituents from the GW-1 and former detection monitoring parameter lists (Table 3 and 4, respectively) as indicator parameters in the detection monitoring program at the Facility was evaluated by McCulley, Frick & Gilman, Inc. (MFG, 1991 and 1994e) and the U.S. Environmental

Protection Agency (EPA, 1996). The rationale for the ultimate selection of the groundwater monitoring parameters is presented below.

5.2.3.1 Detection Monitoring Parameter Selection

Ideal indicator parameters for detecting a potential release (i.e., detection monitoring parameters) should: (1) be present in the landfill leachate at concentrations elevated well above the concentrations in groundwater; (2) exhibit minimal concentration variability in groundwater both spatially and temporally; (3) be mobile and chemically nonreactive in the environment; and (4) be able to be easily analyzed in the laboratory with a high degree of precision and accuracy. Indicator parameters with these characteristics may allow good statistical discrimination between leachate and groundwater, and early detection of potential releases associated with the Facility.

Organic Compounds

Organic compounds associated with waste management activities have not been detected in groundwater samples at the Facility (MFG, 1992, 1993a, 1994a, 1995b and 1996b) or in samples collected from the leak detection systems (LDS) in the secure cells. However, organic parameters have been detected at low concentrations in the leachate collection system (LCS) of the secure cells. As discussed in Section 3.1, as a result of LDRs, organic constituents that have been detected or may be detected in the cell leachate include only select semivolatile organic compounds (base/neutral extractables, acid extractables, pesticides and herbicides); volatile organic compounds (VOCs) have not been detected, and are not expected to be detected in the leachate. Therefore, the semivolatile organic compounds are suitable indicator parameters for detecting a release from the secure cells. Table 7 lists the semivolatile organic compounds that will be used as organic detection monitoring parameters and their associated analytical methods and detection limits. The semivolatile organic compounds include acid-extractable compounds, chlorinated pesticides and chlorinated herbicides.

Inorganic Parameters

Inorganic parameters were selected as indicators parameters for detection monitoring purposes based on their concentrations in leachate from the LCS and groundwater at the Facility; environmental mobility and fate and transport characteristics; and amenability to precise and accurate laboratory analytical quantitation. As discussed in Section 2.3, the major ion compositions of the groundwater in the various hydrostratigraphic units at the Facility exhibit spatial and temporal variability. Consequently, these parameters are not suitable as indicator parameters for detection monitoring purposes. Therefore, the assessment of inorganic indicator parameters for detection monitoring purposes focused on metals/metalloids (including iron, mercury, selenium, antimony, arsenic, chromium, nickel, thallium and zinc). This assessment included the following:

- Evaluation of the Cell No.1 leachate collection system (LCS) data, and a general comparison of the LCS results to the results of the groundwater data from the Facility wells;
- Evaluation of the types of variance, if any, present in the data (i.e., event-to-event variation, spacial variation, etc.) using transformation and variance component analyses;
- Evaluation of temporal trends in individual well data (collected from the first quarter 1993 to the second quarter 1995) using least-squares linear regression of the pooled quarterly group mean concentration versus time (cumulative quarter) to identify systematic variations in the data that may affect the statistical analyses;
- Evaluation of temporal trends in well group data (collected from the first quarter 1993 to the second quarter 1995) using least-squares linear regression to identify systematic variations in the data that may affect the statistical analyses; and
- Evaluation of the completeness of the background data to statistically characterize the population distributions of the parameters from Facility wells.

The evaluation indicated that the metals/metalloids are limited in their usefulness as indicator parameters for the groundwater detection monitoring program at the Facility because: (1) they are generally not present in leachate at concentrations exceeding the concentrations in groundwater; (2) they exhibit statistically significant spatial and temporal variability; (3) they exhibit systematic event-to-event variations that suggest sampling and/or laboratory-induced variance; (4) the LCS mean concentrations calculated for many of the six candidate parameters are less than or only slightly above the Human Health Standards or Secondary Drinking Water Standards for Colorado according to the Basic Standards for Groundwater (5 CCR 1002-8 Part

3.11.0) adopted by the Colorado Department of Public Health and Environment (CDPHE) Water Quality Control Commission; and (5) they are chemically reactive in the environment. In particular, metals/metalloids are subject to attenuation by geochemical reactions and advection-dispersion mechanisms, which affect their environmental mobility as they migrate through the clay liners beneath the landfill cells and the underlying geologic materials (McCarthy and Zachara, 1989; Nicholson et al., 1983). Attenuation of these metals/metalloids by sorption to clay minerals in the liner system at the Facility is relevant because the release of leachate constituents through the liner system without any geochemical interaction with either the primary or secondary clay liner (or without being detected in the LDS or permanent sump) is considered unlikely. Specific issues associated with each constituent are summarized in MFG (1991 and 1994e) and EPA (1996).

Of the metals/metalloids that were evaluated, only arsenic was considered by the Facility to be a potentially reliable indicator/detection monitoring parameter (MFG, 1994e). Based solely on a statistical perspective, arsenic may be a suitable indicator parameter because it is not associated with temporal trends in the individual well data or well group data, and it has not been associated with false positive statistical exceedances. However, based on arsenic's fate and transport characteristics, it is considered to be a potentially unreliable detection monitoring parameter. Barium was recommended by the EPA (1996) as a suitable indicator monitoring parameter primarily because of concentrations of this parameter in the L5 Zone groundwater exhibited minimal spatial and temporal variability, or correlation with concentrations of total dissolved solids. The EPA also requested that nickel and zinc be used as indicator/detection monitoring parameters, although it was acknowledged that the use of any metal/metalloid as indicator parameters may be problematic due to attenuation and geochemical reactivity in the environment. It was further noted that metal/metalloid parameters should be used in conjunction with more reliable indicator parameters (i.e., organic parameters) and hydraulic data (i.e., water level measurements) to assess potential releases from the secure cells. By mutual consent between the EPA, CDPHE and Facility personnel, the metals/metalloids selected as parameters for the detection monitoring program at the Facility include arsenic, barium, nickel and zinc. The analytical methods and detection limits for the metal/metalloid detection monitoring parameters are listed in Table 6. The reliability of the metals/metalloids as indicator parameters will continue to be evaluated, and, as necessary, recommendations for retaining or eliminating these parameters will be presented in the annual reports.

5.2.3.2 General Water Quality Monitoring Parameters

In addition, monitoring of other general water quality parameters is warranted for the ongoing evaluation of the geochemical evolution of waters associated with the dissipation of the former brine pond seepage plumes. As discussed previously, continued monitoring of general water quality parameters is warranted to evaluate natural variability and chemical evaluation of the groundwater associated with the different hydrostratigraphic units underlying the Facility. Routine evaluation of general water quality parameters will allow the suitability of the indicator parameters to be assessed as natural groundwater compositions evolve, and may support interpretations related to statistical exceedances, should they occur. The recommended general groundwater quality monitoring parameters and associated analytical methods and detection limits are listed in Table 7.

5.2.4 Frequency of Groundwater Sampling

RCRA groundwater monitoring regulations (40 CFR 264.97 (g)) specify that the frequency for collecting groundwater samples to establish background concentrations of constituents at a site should be based on the seepage velocity of the monitored zone (to help ensure that an independent sample is collected). This conceptual approach is also appropriate for establishing the frequency for collecting routine groundwater samples from monitoring wells at the Facility to evaluate whether hazardous wastes or hazardous constituents have been released from the secure cells and have affected groundwater. As indicated in Table 2, the average groundwater flow rates for the L4A, L4 and L5 Zones are estimated to be relatively slow (approximately 35, 14 and 13 feet per year, respectively), and potential releases of contaminants could be easily detected, and leakage problems remedied, on the basis of semiannual monitoring.

L6 Zone wells, which are located along alluvial drainages outside the compliance boundary, are screened within and/or across the Silty Clay Unit and weathered Pierre Shale. Hydraulic conductivity measurements are not available for the L6 Zone wells. However, due to the slow potential groundwater flow rates in these geologic units and the fact that potential releases should first be detected in the inspection wells located along or within the compliance boundary, monitoring of the L6 wells more frequently than the L4A and L4 Zone wells is unnecessary. Therefore, semiannual monitoring of the L6 Zone wells is appropriate.

As discussed previously, all of the Level 3 Zone wells have been dry throughout the period of monitoring. In the event that saturated conditions develop in the L3 Sand Unit and water is detected in an L3 Zone well (as identified during quarterly water level monitoring), the source of the saturation will be evaluated and an appropriate frequency for groundwater sampling established.

### 5.2.5 Groundwater Sample Collection

Per EPA guidance (EPA, 1986 and 1992b), appropriate procedures should be used to obtain water level measurements and groundwater samples for laboratory analysis to ensure that the data are usable for making decisions regarding potential releases from hazardous waste facilities. Both field and laboratory data must be accurate and representative of actual site conditions in order to be usable for decision making purposes. This section discusses the practical aspects of field data and sample collection methods at the Facility.

In practice, the majority of the shallow wells (i.e., L4A, L4 L6 and BP wells) at the Facility are dry or have water levels that are below the bottom of the screened interval (i.e., within the 5-foot long sump at the base of the well). The water in the sumps results from the slow accumulation of seepage over a period of months between sampling events. Water elevation measurements in the sumps do not represent the elevation of the water table surface within the geologic materials, and the stagnant water samples collected from the sumps may not represent the actual quality of the groundwater in the geologic formation because of the potential for geochemical transformations that may occur as a result of exposure to the atmosphere (Wood, 1976). Additionally, in some wells, when water is present in the well at an elevation above the screened interval, the geologic materials barely yield sufficient water during purging and sample collection to provide representative groundwater samples. Because these wells purge dry or do not recharge sufficiently during the sampling process, geochemical transformations potentially occur, and the chemical data are not representative of the chemistry of the water in the geologic formation. As water levels decline or go dry in many of the wells that monitor the dissipating brine pond seepage, wells that once provided valid and representative hydraulic and chemical data may no longer do so.

Appropriate field methods for acquisition of water level measurements and water quality samples from monitoring wells are presented in Figure 19 and discussed below. All monitoring wells will be inspected quarterly for the presence of water and to obtain water level measurements. When a well is dry (i.e., there is no measurable water), the well will be recorded as dry in the Facility's database. When water is present below the bottom of the screened interval in a well (i.e., in the sump), the water level elevation will be recorded. Although these data do not represent the elevation of the potentiometric surface in the geologic unit, the data may be used to evaluate temporal changes in hydrologic conditions. Because the chemistry of stagnant water in a sump does not represent the chemistry of groundwater in the formation, no groundwater sample will be collected from such wells. When water is present above the bottom of the screened interval of a well, the water level elevation will be recorded and the data may be used to assess the elevation of the water table surface within the geologic formation. The decision to collect a sample for laboratory analysis from these wells during the semiannual sampling event will be based on the ability of the well to yield sufficient groundwater to provide a representative sample, based on the following purging criteria: (1) wells that do not recover to 90 percent or more of the initial static water level elevation within 48 hours of purging are not considered capable of yielding representative groundwater samples, and will not be sampled; (2) wells that do recover to 90 percent or more of the initial static water level elevation within 48 hours of purging are considered capable of yielding representative groundwater samples, and groundwater samples will be obtained for laboratory analysis and further data evaluation.

# 6.0 DATA EVALUATION PROCEDURES

This section summarizes the methods and procedures related to the evaluation and statistical testing of LCS/LDS and groundwater monitoring data at the Highway 36 Facility.

The application of statistical analyses to the monitoring data requires consideration of various site-specific factors. Site-specific considerations that affect the LCS/LDS data evaluation procedures include: (1) potential differences in the chemistry of the leachate in each secure cell LCS as a result of different waste composition; (2) potential temporal changes in leachate composition and constituent concentrations in the LCS fluids; (3) the occurrence of trace metals and other natural constituents in the secure cell LDSs resulting from consolidation water expelled from the clay components of the composite primary liner; and (4) a high frequency of detectable results for many parameters in the LCS fluids versus a high frequency of non-detectable results for many parameters in the LDS fluids. Site-specific considerations that affect the groundwater data evaluation procedures include: (1) the inability to perform upgradient versus downgradient comparisons in the hydrostratigraphic units underlying the Facility because either there is no observable hydraulic gradient or the extent of saturation is not sufficient to allow such comparisons; (2) multiple hydrostratigraphic units with distinct groundwater chemistries; (3) historical disposal of oil-field brine water, which affects groundwater chemistry in a portion of the site; (4) stratigraphic units with low transmissivities, which results in numerous wells that yield insufficient water to allow routine analysis of all parameters; and (5) a high frequency of non-detectable results for many parameters.

This section presents the various data evaluation and statistical procedures, along with example calculations provided in Appendices A through D, in a format that will help those without a statistical background to understand the data analyses and interpretation. However, this section does not fully and comprehensively explain statistical concepts and techniques. Therefore, certain statistical analyses, interpretations and conclusions may require explanation by qualified persons with a knowledge of statistics and the waste management scenario and groundwater conditions at the Facility.

## 6.1 OVERVIEW AND GENERAL PROCEDURES

Parts III.B.3. through III.B.7. of the Part B Permit describe the requirements for data reporting, analysis, and the sequence of actions required when statistically significant events are noted. Portions of this document relevant to the selection and application of groundwater data evaluation procedures are summarized below.

### 6.1.1 Parameters

The parameters in the LCS/LDS fluids of the secure cells that will be evaluated are the F039 hazardous waste constituents (Table 6). The F039 parameter list is a large, comprehensive list of hazardous waste constituents that will be used to characterize the composition of the secure cell fluids and to identify new leachate constituents that may be useful for monitoring purposes at the Facility. The groundwater monitoring parameters that will be evaluated are specified in Permit Attachment GW-2 (Table 7). The groundwater monitoring parameters include detection monitoring parameters, which are used to evaluate a possible release from the Facility, and general groundwater quality parameters, which are used to assess and track the natural geochemical evolution of groundwater in the hydrostratigraphic units underlying the site.

### 6.1.2 Data Evaluation Methods

Descriptive statistics, trend analyses, and comparative statistics will be used, where appropriate, to evaluate monitoring data. Descriptive statistics will be generated to characterize the various data sets and to select appropriate statistical test methods. Trend analyses will be performed to identify temporal changes in the data sets that may result from natural changes in the composition of the secure cell fluids and groundwater in the hydrostratigraphic units at the Facility and to evaluate the suitability of the current indicator parameters for making evaluations regarding potential releases from the secure cells. Comparative statistical analyses will be performed to identify significant changes in water quality that may indicate a release from the secure cells. All statistical tests will be performed at the 95 percent and 99 percent level of significance. These statistical analyses will be performed according the frequency specified in Table 8.

### 6.1.3 Well Groupings

Data for each GW-2 parameter in Table 7 will be pooled by well group for descriptive and comparative statistical analyses (except trend analyses which will be used to evaluate trends in individual wells) in accordance with the criteria specified in Part IV.B.1.d. of the Permit. As discussed previously, groundwater monitoring wells are grouped on the basis of distinctive geochemical compositions of water associated with different hydrostratigraphic units underlying the Facility. The rationale for the specific well groupings was summarized briefly in Section 2.3.2 and is discussed in detail in the Supplemental Background Data Evaluation Report: Revision No. 1 (MFG, 1991) and existing annual reports.

The continued pooling of data by geochemical well group, incorporation of new data and the re-evaluation, and possible reorganization, of well groupings are especially necessary for evaluating natural variability and chemical evolution of the groundwater beneath the Facility. In addition, as water levels decline and monitoring wells in the shallow hydrostratigraphic units go dry, pooling of data by well group will help ensure that the populations (i.e., number of observations) that are being statistically evaluated are sufficiently large that the false positive error rate (i.e., the probability of falsely concluding that the site has affected groundwater when it has not) does not become too large. The rationale for any proposed modifications to the well groupings will be presented in the annual reports, or other reports, as necessary.

### 6.1.4 Data Handling Procedures

The following data handling procedures will be used:

- When parameter concentrations are not quantified below the detection levels presented in GW-2, simple substitution of one half the parameter-specific detection level will be used to modify the data set for graphical presentation and, where necessary, to perform the statistical analyses.
- Plots of logarithmic data, such as pH and log-transformed data, may be shown on semi-log plots to facilitate linear trend analysis.
- Parameter values for duplicate samples will not be averaged for statistical analyses; the original value will be used, unless rejected as a result of poor quality.

- Because there is little, if any, significance to an evaluation of temporal trends until there are an adequate number of quantified or detected results, trend analyses are not required for monitoring parameters that have less than 10 detections in the background database.

### 6.1.5 Background Database

#### 6.1.5.1 Definition of the Background Database for Secure Cell Monitoring

The background database for a given secure cell will comprise all data obtained from the LCS and LDS, after fluid removal operations first began, that meet the following two criteria:

- An evaluation of the data indicates that a release from the secure cell did not occur; and
- An evaluation of the QC data indicates that no significant QC deviations occurred.

#### 6.1.5.2 Definition of the Background Database for Groundwater Monitoring

The background database for groundwater monitoring will comprise (1) data collected prior to July 27, 1991, when waste disposal operations first began at the Facility (i.e., pre-operational data), and (2) data obtained after July 27, 1991 (i.e., post-operational data), that meet the following two criteria:

- A statistical evaluation of the data indicates that a release from the Facility did not occur; and
- An evaluation of the QC data indicates that no significant QC deviations occurred.

Inclusion of post-operational data (1) provides a larger background data set and (2) increases the overall reliability of the background data set by incorporating a larger proportion of data whose quality is documented and known. Also, due to the limited amount of groundwater beneath the Facility and the fact that the current sources of such water are well defined, it is appropriate to continue to update the background database in order to account for the natural variability and chemical evolution of the groundwater beneath the Facility, as long as that water is not affected by Facility-disposed wastes.

#### 6.1.5.3 Incorporation of New Data in the Background Databases

In the absence of a release from the Facility (as determined by the comparative statistical analyses) or significant QA/QC problems, new sampling event data will automatically be incorporated into the background database for each well group prior to the next sampling event. The following procedures will be used to evaluate new data for incorporation into the background database.

- Data validation procedures are addressed in GW-4. These procedures are consistent with the EPA Laboratory Data Validation Functional Guidelines for Evaluating Organic and Inorganic Analyses (EPA, 1988). In the event that data of questionable quality are identified, samples will either be reanalyzed or resampling may be recommended. The QC and other data will be evaluated to reach decisions regarding the useability of the original data. Errors, corrections, or deletions will be reported and discussed in the semiannual reports.

- Descriptive statistics and trend analyses will also be used to identify data that may be of questionable quality. Notable changes in descriptive statistics and trend analyses will prompt a review of the QC data and supporting documentation to determine what may have caused the change. When changes in descriptive statistics or trend analyses occur, QC data will be reviewed to determine whether poor data quality may have been a contributing factor.

- Data that show no statistically significant difference (i.e., 95 percent level of significance) from previous background data will be included in the background database. Data that show a statistically significant difference from the background will not be included unless those data are shown to be truly valid and representative based on an evaluation of the next sampling event data.

## 6.2 SECURE CELL DATA EVALUATION

The evaluation of chemical data for secure cell fluids will include descriptive statistics, trend analyses and a comparative evaluation of organic parameters. The descriptive statistics and trend analysis for organic and inorganic parameters will be performed to evaluate temporal changes in the composition of the secure cell fluids. The results of these analyses will be presented in each annual report. As the leachate composition in the secure cells naturally evolves and significant differences are noted between sampling event data and background data, the suitability of the current detection monitoring parameters will be re-evaluated and appropriate changes recommended. The comparative evaluation of organic data for the secure cells will be performed quarterly to facilitate early detection of releases from the secure cells.

### 6.2.1 Descriptive Statistics

Descriptive statistics will be calculated annually for each F039 parameter listed in Table 6 for the LCS and LDS in each secure cell. These statistics will be qualitatively compared to previously computed values to identify any significant changes in the chemical composition of the secure cell fluids. The cause for any observable changes, if observed, will be assessed and the validity of the data further evaluated as described in Section 6.1.5.

The following descriptive statistics will be utilized to describe the characteristics of the data sets for parameters having a high proportion of detectable results (> 50 percent):

Frequency of Detection
Mean
Median
Standard Deviation
Variance
Maximum Value
Minimum Value
Skewness

Methods for calculating these statistics and their meaning or significance are discussed in Appendix A.

Data sets having a low proportion of detected results (i.e., detection frequencies <50 percent) are non-normally distributed. When simple substitution is applied to a data set with a low proportion of detected results, a large proportion of the numerical values used to statistically describe the distribution of the data set are estimated values. In these cases, descriptive statistics are no longer strictly valid. Therefore, results for parameters that are infrequently detected (<50 percent) will be tabulated, and the frequency of detection and the number of detections that fall within specified concentration ranges will be determined. The format for the table presenting these data is illustrated in Appendix B.

### 6.2.2 Trend Analyses

For each LCS and LDS, analyses of temporal trends will be performed and evaluated annually for each individual F039 parameter listed in Table 6 when sufficient data exist (as defined in Section 6.1.4) to allow meaningful interpretations.

Trend analyses involve plotting the analytical data for each individual LCS and LDS against time and evaluating linear trends by least squares regression analysis. The trend plots and linear regression lines will be compared to the past year's analyses, and a narrative description of the significance of trends will be presented in each annual report. The cause of significant changes in the slope or fit of the regression line, if observed, will be assessed and the validity of the data further evaluated as described in Section 6.1.5. When sufficient data are available, this assessment may also include an evaluation of serial dependence.

A typical data package for trend analysis is shown in Appendix C. The data package will include a trend plot and least-squares-linear regression analysis. Data used to prepare the trend plots will be tabulated and presented with the trend plot.

Trend analysis of infrequently detected LCS/LDS monitoring parameters (detection frequencies $<50$ percent) will follow the same format as described above, with one exception. Instead of analyzing individual parameters, the trends will be plotted and regression lines evaluated for the data sets outlined below, as applicable.

1. Acid-extractable organic compounds in Table 6 for each well, if applicable.

   Frequency of detectable concentrations of organic compounds below 50 parts per billion (ppb) during each sampling event.

   Frequency of detectable concentrations of organic compounds above 50 ppb during each sampling event.

2. Pesticides and Herbicides in Table 6 for each well group, if applicable.

   Frequency of detections at any concentration above the detection levels in GW-2 during each sampling event.

3. Metals/Metalloids in Table 6, if applicable.

   Frequency of detections at any concentration above the detection levels in GW-2 during each sampling event.

This information can be obtained easily from the organic data summary sheets illustrated in Appendix B. Trend plots will not be required until there have been at least 10 consecutive sampling events in which requisite detections occurred.

### 6.2.3 Comparative Evaluation of Organic Data

As discussed previously, although F039 organic parameters have been detected in the leachate in the secure cells (i.e., in the LCSs), these parameters have never been detected in the LDSs. To assess a potential release from a secure cell, the LDS sampling event data for each secure cell will be reviewed quarterly to determine if an F039 organic parameter has been detected at a concentration exceeding the parameter-specific detection level. If an organic parameter is detected in the LDS, the relevant QC data and supporting documentation will be reviewed to assess the validity of the organic detection. All or part of the data may be recommended to be excluded from the database, at least until the organic detection is confirmed or rejected by resample or subsequent sampling information. Confirmed detections of organic parameters in the LDS will be reported.

## 6.3 GROUNDWATER DATA EVALUATION

### 6.3.1 Descriptive Statistics

Descriptive statistics are calculated for each groundwater parameter listed in Permit Attachment GW-2 for each group of wells each time the wells are sampled.

Descriptive statistics will be included in semiannual reports. These statistics will be qualitatively compared to previously computed values to identify any significant changes at the 95 percent and 99 percent level of significance. The cause for any significant changes, if observed, will be assessed and the validity of the data further evaluated as described in Section 6.1.5.

General Groundwater Quality and Inorganic Detection Monitoring Parameters

The following descriptive statistics will be utilized to describe the characteristics of the data sets for the general groundwater quality and inorganic detection monitoring parameters:

Frequency of Detection
Mean
Median
Standard Deviation
Variance
Maximum Value
Minimum Value
Skewness

Methods for calculating these statistics and their meaning or significance are discussed in Appendix A.

Organic Detection Monitoring Parameters

Organic constituents associated with waste management activities have never been detected in groundwater at the Facility, *. The occurrence of detectable organic parameters in groundwater at the Facility is extremely rare. Consequently, the organic parameter data sets are characterized by a very high (>95 percent) proportion of non-detected results. When simple substitution is applied to a data set with a large proportion of non-detected results, a large proportion of the numerical values used to statistically describe the distribution of the data set are estimated values. In these cases, descriptive statistics are no longer strictly valid. Data sets having a high proportion of non-detected results (>50 percent) are non-normally distributed when simple substitution is used to replace nondetect results. Therefore, detected organic parameters the frequency of detection and the number of detections that fall within specified concentration ranges will be tabulated. The format for the data table and listing of compounds is illustrated in Appendix B.

### 6.3.2 Trend Analyses

For each groundwater parameter listed in GW-2 (Table 7), trend analyses will be performed and evaluated annually for each individual well when sufficient data exist (as defined in Section 6.1.4) to allow meaningful interpretations. Other organic compounds may be analyzed for temporal trends if statistical excursions trigger resampling of wells or for characterization of new wells.

General Groundwater Quality and Inorganic Detection Monitoring Parameters

Trend analyses involve plotting the analytical data for each individual well against time and evaluating linear trends by least squares regression analysis. The trend plots and linear regression lines will be compared to the past year's analyses, and a narrative description of the significance of trends will be presented in each annual report. The cause of significant changes in the slope or fit of the regression line, if observed, will be assessed and the validity of the data further evaluated as described in Section 6.1.5. When sufficient data are available, this assessment may also include an evaluation of seasonality and serial dependence.

A typical trend data package, using background data is shown in Appendix C. The data package will include a trend plot and least-squares linear-regression analysis. Data used to prepare the trend plots will be tabulated and presented with the trend plot.

Organic Detection Monitoring Parameters

Trend analysis of organic detection monitoring parameters will follow the same format as for the general groundwater quality and inorganic detection monitoring parameters, with one exception. Instead of analyzing individual parameters, the trends will be plotted and regression lines evaluated for the data sets outlined below, as applicable.

1. Acid-extractable organic compounds in Table 7 for each well, if applicable.

   Frequency of detectable concentrations of organic compounds below 50 parts per billion (ppb) during each sampling event.

   Frequency of detectable concentrations of organic compounds above 50 ppb during each sampling event.

2. Pesticides and Herbicides in Table 7 for each well group, if applicable.

   Frequency of detections at any concentration above the detection levels in GW-2 during each sampling event.

This information can be obtained easily from the organic data summary sheets illustrated in Appendix B. Trend plots for organic compounds will not be required unless there has been at least 10 consecutive sampling events in which requisite organic detections occurred.

### 6.3.3 Comparative Statistics

Prediction intervals will be used to compare groundwater sampling event data to background data, as defined in Section 6.1.5. Groundwater sampling event data for each GW-2 parameter (pooled by well group) will be compared to the prediction interval calculated for each group of wells based on representative background data for each well group. Statistical excursions are indicated if the concentration of a parameter falls above the upper prediction limit for the well group based on the background data.

For parameters with less than 50 percent non-detectable results (i.e., fewer non-detectable results than detectable results), parametric prediction limits will be calculated. In order to obtain the parametric prediction limit, a test of normality will first be performed on the background data and the data transformed as necessary to achieve a normal distribution. The Shapiro-Wilk test, or other appropriate statistical test, will be used to evaluate the normality of data distributions at the 95 percent level of significance. An upper prediction limit will then be calculated for the appropriate distribution (i.e., normal or log-normal distribution) to provide coverages (confidence probabilities) of 95 percent and 99 percent. When parameter concentrations are not quantified below the detection levels specified in GW-2, simple substitution of one-half the parameter-specific detection level will be used to modify the data set for calculation of the parametric prediction interval.

Non-parametric intervals will be used for data sets that are non-normal, including all data sets with more than 50 percent non-detectable results, and those that cannot be power-transformed to a normal distribution for statistical evaluation. The non-parametric prediction limit will be equivalent to the maximum background concentration (maximum measurement value in the background data set) or, for background data sets with no detectable results, the detection levels specified in GW-2. Examples of parametric and non-parametric prediction intervals are presented in Appendix D.

For the purposes of the comparative statistics, more than one exceedance of a prediction limit for the organic parameters within the same family of organic compounds will count only as one exceedance for reporting purposes. Statistical exceedances for organic parameters are treated in this manner because detections of more than one compound within a family does not represent an independent measurement. In other words, the likelihood of detecting two parameters in a family is greater than would be expected solely

on the basis of random chance. Organic families are initially defined as (1) acid-extractable organic compounds and (2) pesticides and herbicides. The rationale for any changes to the definition of organic families will be presented within annual groundwater monitoring reports and within any sampling event report in which the organic families are redefined.

Comparative statistical analyses of the general groundwater quality parameters in GW-2 will be performed solely for the purpose of evaluating natural variability and chemical evolution of the groundwater beneath the site, and for grouping wells on the basis of distinctive geochemical compositions associated with different hydrostratigraphic units underlying the Facility. Interpretations will be presented in the semiannual reports. As groundwater beneath the Facility evolves naturally and significant differences are noted between the sampling event data and the background data set, the prediction intervals for the general groundwater quality parameters may need to be recalculated based on more recent data so that current conditions are better represented. The need to redefine prediction limits for the general groundwater quality parameters, and the procedures for doing so, will be discussed in semiannual reports, as necessary.

Comparative statistical analyses of the detection monitoring parameters in GW-2 will be performed for the purpose of identifying statistically significant differences between the sampling event data and the background data that may be indicative of a release from the Facility. In the event of a statistical exceedance, the relevant QC data and supporting documentation will be reviewed to assess the validity of the data resulting in the statistical exceedance. All or part of the data may be recommended to be excluded from the database, at least until the exceedance is confirmed or rejected by resample or subsequent sampling information. Statistically significant exceedences will be reported, and will be excluded from the database unless justification is provided to the CDPHE for including that data in the background data set.

## 6.4 SITEWIDE FALSE POSITIVE ERROR RATE

The purpose of the detection monitoring program is to detect potential groundwater impacts resulting from releases from the site at the earliest possible time while simultaneously minimizing the probability of falsely concluding that the site has affected groundwater when it has not (minimize $\alpha$, or the false positive rate). EPA (1992b) recommends that the site-wide false positive rate for the detection monitoring program

be maintained at 0.05 (or 5 percent), which provides a 95 percent level of confidence (1-$\alpha$) that contamination will be detected. In practice, statistical comparisons are typically performed for each individual parameter during any given evaluation period at a site. Each of these individual statistical comparisons typically has a fixed level of confidence (e.g., 95 percent) and a corresponding false positive rate (e.g., 5 percent). When the number of statistical comparisons is moderate to large (as a result of multiple parameters and wells), the false positive rate associated with the site as a whole can be quite high. This means that if enough tests are run, there will be a significant chance that at least one test will indicate contamination, even when no actual contamination has occurred.

To minimize the site-wide false positive rate, the EPA recommends the following methods. The number of tested parameters may be limited to only those most useful for identifying contamination in order to reduce the overall number of comparisons that are made. In addition, the false positive rate of the individual statistical comparison tests may be lowered, while maintaining adequate statistical power to detect releases when they do occur.

The Facility has evaluated the background parameters listed in GW-1 to identify suitable parameters for the detection monitoring parameters listed in GW-2. The GW-2 parameters were selected based on:

- knowledge of parameters present in leachate;
- contrast between concentrations in background groundwater and leachate; and
- potential for groundwater transport of those parameters (solubility, transport rate, persistence in environment).

By limiting statistical testing to a few parameters that appear to be reliable indicators of a release, the overall site-wide false positive rate can be controlled while satisfying regulatory requirements and assuring reliable identification of groundwater contamination, if it occurs.

Lowering the false positive rate of each individual comparative statistical test to achieve a site-wide false positive rate of 5 percent has the potential adverse effect of lowering the statistical power of the test to detect real contamination. Consequently, complex calculations (referred to as power curve simulations) are

required to ensure that adequate statistical power is maintained. Because excessive false positive occurrences have not occurred at the site in the past, these involved power curve simulations are not justified at this time. If, in the future, there appears to be an excessive number of false positive occurrences over several periods of statistical analysis, then consideration may be given to performing these calculations as an additional measure to control the site-wide false positive error rate.

# 7.0 REFERENCES


Bonaparte, R. and Gross, B.A., 1990. "Field Behavior of Double-Liner Systems", *Water Containment Systems* Construction, Regulation, and Performance, ASCE Geotechnical Special Publication No. 26, Nov. 1990, pp. 52-83.

Colorado GeoLogic, Inc., 1986a. Evaluation of Geophysical Logging Techniques, Highway 36 Site, January.

Colorado GeoLogic, Inc., 1986b. Report Covering the Installation of Monitoring Wells and Comparison of Geology and Hydrogeology With That Previously Found in the Geotechnical Evaluation of the Highway 36 Site, November 3, 1986.

Colorado GeoLogic, Inc., 1986c. Final Report on Three Deep Pierre Shale Wells (Level 5 Wells WW-3, WW-4 and WW-5) November.

Colorado GeoLogic, Inc., 1987a. Final Report on Level 3 Well Drilling Program, Highway 36 Project, May 7, 1987.

Colorado GeoLogic, Inc., 1987b. Final Report on Level 4 Well Drilling Program, Highway 36 Project, May 6, 1987.

Colorado GeoLogic, Inc., 1987c. Final Report on Level 5 Well Drilling Program, Highway 36 Project, May.

Colorado GeoLogic, Inc., 1987d. Final Report on Drainage Confirmation Drilling and Level 6 Monitor Well Installation, Highway 36 Project, August.

Colorado GeoLogic, Inc., 1987e. Final Report on Level 4 Offset Well Drilling Program, Highway 36 Project, August.

Colorado GeoLogic, Inc., 1987f. Draft Report on Results of Slug Withdrawal Tests, Highway 36 Project, November.

Deuel & Associates, Inc., 1989a. Report on L4-9 Offset Monitor Well Drilling Program, January.

Deuel & Associates, Inc., 1989b. Report on L4-34 Offset Monitor Well Drilling Program, January.

Deuel & Associates, Inc., 1989c. Geologic Map of Cell No.1, Highway 36 Land Disposal Company Facility, October.

Environmental Science, Inc., 1990. Installation of Monitor Wells L4-39 and L4-40, August.

Ertec, Inc., 1982. Program Management Assistance, Predictive Flow Models for the Proposed Highway 36 Land Development Company Facility, Adams County, Colorado. May 18, 1982. EPA Contract No. 68-01-6515, Work Order R-008-004.

Fox Consultants, Inc., 1984a. Geotechnical Characterization of the First Cell of a Proposed Waste Disposal Facility Site Located in Adams County Near Last Chance, Colorado. February 20, 1984.

Fox Consultants, Inc., 1984b. Verification Drilling Results for the Initial Cell at the Proposed Highway 36 Land Disposal Corporation Hazardous Waste Treatment and Disposal Facility Site, Southeastern Adams County, Colorado.

Fox Consultants, Inc., 1984c. Geologic and Groundwater Characterization of the Proposed Highway 36 Land Development Company Facility Located in Eastern Adams County, Colorado. May 18, 1984.

Gross, B.A., Bonaparte, R., and Giroud, J.P., 1990. "Evaluation of Flow from Landfill Leakage Detection Layers", *Proceedings, Fourth International Conference on Geotextiles,* Vol. 2, The Hague, June 1990, pp. 481-486.

Hillel, D., 1980. Soil and Water - Physical Principals and Processes, Academic Press, New York. 1980.

McCarthy, J.F. and Zachara, J.M., 1989. Subsurface Transport of Contaminants. Environmental Science & Technology. Vol. 23, No. 5, pp.496-502.

McCulley, Frick & Gilman, Inc. (MFG), 1991. Supplemental Background Data Evaluation Report, Highway 36 Land Development Company Treatment, Storage and Disposal Facility: Report prepared for the Highway 36 Land Development Company, Revision No. 1, November.

McCulley, Frick & Gilman, Inc. (MFG), 1992. 1991 Annual Groundwater Monitoring Report: Highway 36 Land Development Company, Treatment, Storage and Disposal Facility.

McCulley, Frick & Gilman, Inc. (MFG), 1993a. 1992 Annual Groundwater Monitoring Report: Highway 36 Land Development Company, Treatment, Storage and Disposal Facility, December.

McCulley, Frick & Gilman, Inc. (MFG), 1993b. Groundwater Monitoring Report, Second Quarter 1993: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, June.

McCulley, Frick & Gilman, Inc. (MFG), 1993c. Technical Memorandum: February 1993 Well Installation Program, January.

McCulley, Frick & Gilman, Inc. (MFG), 1994a. 1993 Annual Groundwater Monitoring Report: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, April.

McCulley, Frick & Gilman, Inc. (MFG), 1994b. Groundwater Monitoring Report, First Quarter 1994: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, July.

McCulley, Frick & Gilman, Inc. (MFG), 1994c. Groundwater Monitoring Report, Second Quarter 1994: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, September.

McCulley, Frick & Gilman, Inc. (MFG), 1994d. Groundwater Monitoring Report, Third Quarter 1994: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, December.

McCulley, Frick & Gilman, Inc. (MFG), 1994e. Letter to Mike Cooper, Concord Resources Group, Regarding Status Report: Revision of H36LDC Detection Monitoring Program Parameters and Statistical Evaluation Procedures, February.

McCulley, Frick & Gilman, Inc. (MFG), 1995a. Technical Memorandum - Secure Cell No. 2 Geologic Mapping Investigation, Highway 36 Land Development Company, Treatment, Storage and Disposal Facility.

McCulley, Frick & Gilman, Inc. (MFG), 1995b. 1994 Annual Groundwater Monitoring Report: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, March.

McCulley, Frick & Gilman, Inc. (MFG), 1995c. Groundwater Monitoring Report, Fourth Quarter 1994: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, January.

McCulley, Frick & Gilman, Inc. (MFG), 1995d. Groundwater Monitoring Report, First Quarter 1995: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, June.

McCulley, Frick & Gilman, Inc. (MFG), 1995e. Groundwater Monitoring Report, Second Quarter 1995: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, August.

McCulley, Frick & Gilman, Inc. (MFG), 1995f. Groundwater Monitoring Report, Third Quarter 1995: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, November.

McCulley, Frick & Gilman, Inc. (MFG), 1996a. Groundwater Monitoring Report, Fourth Quarter 1995: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, January.

McCulley, Frick & Gilman, Inc. (MFG), 1996b. 1995 Annual Groundwater Monitoring Report: Highway 36 Land Development Company Treatment, Storage and Disposal Facility, March.

McCulley, Frick & Gilman, Inc. (MFG), 1996c. Class 2 Permit Modification Request, Technical Rationale for New Level 3 Monitoring Wells, December.

Nicholson, R.V, J.A. Cherry and Reardon, E.J. 1983. Migration of Contaminants in Groundwater at a Landfill: Case Study. Hydrogeochemistry. Journal of Hydrology. Vol. 63. pp. 131-176.

Richard, M.G. and Brogden, M.L., 1989. Last Chance Groundwater Study, Second Year's Summary Report Covering the Period September 1986 to August 1988, Part II, Analytical Data and Discussion. Unpublished report submitted to the Colorado Department of Health, August.

Tweto, O., 1979. Geologic Map of Colorado: U.S. Geological Survey.

Triegel & Associates, Inc., 1989. RCRA Facility Investigation Report, Brine Pond, Highway 36 Site, Adams County, Colorado.

U.S. Environmental Protection Agency (EPA), 1986. RCRA Ground-Water Monitoring Technical Enforcement Document. OSWER-9950.1.

U.S. Environmental Protection Agency (EPA), 1988a. Laboratory Data Validation: Functional Guidelines for Evaluating Inorganic Analyses - Office of Emergency and Remedial Response, Washington, D.C.

U.S. Environmental Protection Agency (EPA), 1988b. Laboratory Data Validation: Functional Guidelines for Evaluating Organic Analyses. Office of Emergency and Remedial Response, Washington, D.C.

U.S. Environmental Protection Agency (EPA), 1989a. Stabilization/Solidification of CERCLA and RCRA Wastes. Physical Tests, Technology Screening , and Field Activities. EPA/625/6-89/022.

U.S. Environmental Protection Agency (EPA), 1989b. Requirements for Hazardous Waste Landfill Design, Construction and Closure Seminar Publication. EPA 1625/4-89/022.

U.S. Environmental Protection Agency (EPA), 1992a. Action Leakage Rates for Leak Detection Systems. EPA/580-R-92004.

U.S. Environmental Protection Agency (EPA), 1992b. RCRA Ground-Water Monitoring: Draft Technical Guidance. Office of Solid Waste. EPA/530-R-93-001.

U.S. Environmental Protection Agency (EPA), 1992c. Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Draft Addendum to Interim Final Guidance. Office of Solid Waste. July.

U.S. Environmental Protection Agency (EPA), 1994. Test Methods for Evaluation Solid Waste, Physical/Chemical Methods, SW-846, 3rd Edition Revision.

U.S. Environmental Protection Agency (EPA), 1996. Comments on the Highway 36 Draft Revisions. Letter from Mike Gansecki, Environmental Engineer, USEPA to Tanell Roberts, Colorado Department of Health and Environment. August 6, 1996.

Wood, W.W., 1976. Guidelines for Collection and Field Analysis of Groundwater Samples for Selected Unstable Constituents. Techniques of Water Resource Investigations of the U.S. Geological Survey. Book 1, Chapter D2.

# TABLES

**Table 1**
**Groundwater Monitoring Wells at the Highway 36 Facility**
**Highway 36 Land Development Company**

| L3 SERIES | L4A SERIES | L4 SERIES | L5 SERIES | L6 SERIES | BP SERIES |
|---|---|---|---|---|---|
| L3-2 | L4-32A | L4-1 | L5-3 | L6-1 | BP-1 |
| L3-3 | L4-32EA | L4-2 | L5-4 | L6-2 | BP-2 |
| L3-6 | L4-32WA | L4-3 | L5-5 | L6-3A | BP-4 |
| L3-7 | L4-33A | L4-4 | L5-6 | | BP-5 |
| L3-8 | L4-33EA | L4-5 | L5-7 | | BP-6 |
| L3-9 | L4-33WA | L4-6 | L5-8 | | BP-7 |
| L3-10 | | L4-8 | L5-9 | | BP-8 |
| L3-11 | | L4-8N | L5-10A | | BP-10 |
| L3-12 | | L4-9 | | | BP-10A |
| L3-13 | | L4-9S | | | BP-11 |
| L3-15 | | L4-9N | | | BP-11A |
| L3-16 | | L4-9W | | | BP-12 |
| L3-17 | | L4-10 | | | BP-12A |
| L3-19 | | L4-11 | | | BP-13 |
| L3-22 | | L4-12 | | | BP-13A |
| L3-24 | | L4-13 | | | |
| L3-25 | | L4-14 | | | |
| L3-26 | | L4-15 | | | |
| L3-27 | | L4-16 | | | |
| L3-28 | | L4-17 | | | |
| L3-29 | | L4-18 | | | |
| L3-30 | | L4-19 | | | |
| L3-31 | | L4-20 | | | |
| L3-32 | | L4-21 | | | |
| L3-33 | | L4-22 | | | |
| L3-34 | | L4-23 | | | |
| L3-35 | | L4-24 | | | |
| L3-36 | | L4-25 | | | |
| L3-37 | | L4-26 | | | |
| L3-38 | | L4-27 | | | |
| L3-39 | | L4-28 | | | |
| L3-40 | | L4-29 | | | |
| L3-41 | | L4-30 | | | |
| L3-42 | | L4-31 | | | |
| L3-43 | | L4-32 | | | |
| L3-44 | | L4-32E | | | |
| | | L4-32W | | | |
| | | L4-33 | | | |
| | | L4-33E | | | |
| | | L4-33W | | | |
| | | L4-34 | | | |
| | | L4-34W | | | |
| | | L4-34E | | | |
| | | L4-35 | | | |
| | | L4-36 | | | |
| | | L4-37 | | | |
| | | L4-38 | | | |
| | | L4-39 | | | |
| | | L4-40 | | | |
| | | L4-41 | | | |
| | | L4-42 | | | |

**Table 2**
**Hydraulic Characteristics and Estimated Average Linear Groundwater Flow Velocities**
**Highway 36 Land Development Company**

| Geologic Unit | Hydrostra-tigraphic Zone | Saturated Hydraulic Conductivity[1] | | Hydraulic Gradient[2] (foot/foot) | Assumed Effective Porosity[3] | Average Linear Groundwater Flow Velocity (feet/year) [4] |
|---|---|---|---|---|---|---|
| | | Range (cm/s) | Average (cm/s) | | | |
| L3 Sand Unit[5] | Level 3 | NA | $1x10^{-3}$ | NA | NA | NA |
| Silty Clay Unit | Level 4A | $1.13 \times 10^{-4}$ to $6.60 \times 10^{-6}$ | $3.41 \times 10^{-5}$ | 0.10 | 0.1 | 35 |
| Weathered Pierre Shale | Level 4 | $1.32 \times 10^{-6}$ to $4.63 \times 10^{-5}$ | $1.35 \times 10^{-5}$ | 0.10 | 0.1 | 14 |
| Unweathered Pierre Shale | Level 5 | $1.13 \times 10^{-6}$ to $5.54 \times 10^{-6}$ | $2.75 \times 10^{-6}$ | 0.045 | 0.01 | 13 |
| Variable | Level 6 | $2.88 \times 10^{-5}$ to $3.89 \times 10^{-5}$ | $3.38 \times 10^{-5}$ | NA | NA | NA |

Notes:

(1) Saturated hydraulic conductivity data from Fox (1984c) and Colorado GeoLogic (1987f).

(2) Hydraulic gradients for the L4A and L4 Zones represent the upper range of hydraulic head differences currently observed between adjacent L4A and L4 wells. Hydraulic gradient for L5 Zone represents the hydraulic head difference between wells L5-5 and L5-6, which is the maximum hydraulic head difference in the L5 Zone wells.

(3) Assumed effective porosity based on information presented in Freeze and Cherry (1979).

(4) Average linear groundwater flow velocity based on Darcy's Law:

$$v = \frac{Ki}{n_e}$$

where: v = average linear groundwater flow velocity (feet/year)
k = hydraulic conductivity (feet/year)
i = hydraulic gradient (ft/ft)
$n_e$ = effective porosity

(5) Average saturated hydraulic conductivity for the L3 Sand Unit is estimated based on material type. Saturation has never been detected in any of the 36 Level 3 wells.

**Table 3**
**GW-1 Parameter List - Background Monitoring Parameters**
**Highway 36 Land Development Company**

| | |
|---|---|
| Antimony | Sodium |
| Beryllium | Sulfate |
| Copper | Ammonia ($NH_3$ or $NH_4^+$) |
| Arsenic | Nickel |
| Barium | Thallium |
| Cadmium | Zinc |
| Chromium | 2, 4-D |
| Fluoride | 2,4,5-TP Silver |
| Lead | Radium |
| Mercury | Gross Alpha |
| Chloride | Gross Beta |
| Iron | Coliform Bacteria |
| Manganese | Turbidity |
| Nitrate (as N) | Specific Conductance |
| Selenium | Total Organic Carbon (TOC) |
| Silver | Total Organic Halides (TOX) |
| Endrin | Purgeable Organics |
| Lindane | Non-purgeable Organics |
| Methoxychlor | Total Alkalinity |
| Toxaphene | Chlorinated Pesticides/PCB |
| pH | Phosphorous Pesticides |
| Phenols | |

Note: From Attachment GW-1 to the RCRA Part B Permit for the Highway 36 Land Development Company Hazardous Waste Treatment, Storage and Disposal Facility, updated June 1994.

**Table 4**
**Former GW-2 Detection Monitoring Parameters**
**Highway 36 Land Development Company**

| | |
|---|---|
| Chloride | Total Alkalinity |
| Iron, dissolved | Purgeable Organics[1] |
| Manganese, dissolved | Total Organic Halide (TOX) |
| Turbidity | Phenols |
| pH | Sodium, dissolved |
| Specific Conductance | Sulfate |
| Total Organic Carbon (TOC) | Nitrate (as N) |

---

Notes: From Attachment GW-2 to the RCRA Part B permit for the Highway 36 Land Development Company Hazardous Waste Treatment, Storage and Disposal Facility, dated September 1990.

[1] The purgeable organics include 28 different volatile organic compounds as specified in the Ground-Water Monitoring Data Evaluation Procedures Report, dated July 1, 1987.

**Table 5**
**Geochemical Well Groupings**
**Highway 36 Land Development Company**

| GROUP | WELL NUMBERS |
|---|---|
| 0 | L4-16, L4-31 |
| 1 | L4-32EA, L4-33WA |
| 2 | L4-32A, L4-32WA, L4-33EA, L4-41 |
| 3 | L4-32, L4-32E, L4-32W, L4-33, L4-33A, L4-33W, L4-34, L4-34W |
| 4 | L4-8, L4-8N, L4-9, L4-9N, L4-9S, L4-9W |
| 5 | L5-3, L5-4, L5-5, L5-6, L5-7, L5-8, L5-9, L5-10A |
| 6 | L6-1, L6-2, L6-3, L6-3A |

Note: Monitoring wells L4-16 and L4-31 are not classified into Groups due to insufficient data. For presentation purposes only, data from these wells are pooled into Group 0.

# F039 Hazardous Waste Constituent List
# Highway 36 Land Development Company

## ORGANICS

**Acid Extractables**

Phenol
2-Chlorophenol
4-Nitrophenol
2,4-Dimethyl phenol
2,4-Dichlorophenol
2,6-Dichlorophenol
2,4,5-Trichlorophenol
2,4,6-Trichlorophenol
2,3,4,6-Tetrachlorophenol
2,4-Dinitrophenol
Pentachlorophenol
2-sec-Butyl-4,6-dinitrophenol
p-Chloro-m-cresol

**Chlorinated Pesticides**

Aldrin
Alpha-BHC
Beta-BHC
Delta-BHC
Gamma-BHC (Lindane)
Chlordane
o,p'-DDD
p,p'-DDD
o,p-DDE
p,p-DDE
o,p-DDT
p,p-DDT
Dieldrin
Endosulfan I
Endosulfan II
Endosulfan sulfate
Endrin
Endrin aldehyde
Heptachlor
Heptachlor epoxide
Methoxychlor
Toxaphene

**Chlorinated Herbicides**

2,4-D
2,4,5-TP (Silvex)
2,4,5-T

**Volatile Organic Compounds (VOCs)**

Acetone
Acetonitrile
Acrolein
Acrylonitrile

**F039 Hazardous Waste Constituent List**
**Highway 36 Land Development Company**

Benzene
Bromodichloromethane
Bromoform (Tribromomethane)
Bromomethane (methyl bromide)
n-Butyl alcohol
Carbon tetrachloride
Carbon disulfide
Chlorobenzene
Chlorodibromomethane
Chloroethane
Chloroform
Chloromethane (Methyl chloride)
1,2-Dibromo-3-chloropropane
1,2-Dibromoethane (EDB)
Dibromomethane
m-Dichlorobenzene
o-Dichlorobenzene
p-Dichlorobenzene
Dichlorodifluoromethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethylene
trans-1,2-Dichloroethylene
1,2-Dichloropropane
cis-1,3-Dichloropropene
trans-1,3-Dichloropropene
1,4-Dioxane
Ethyl acetate
Ethyl benzene
Ethyl cyanide
Ethyl ether
Ethyl methacrylate
Ethylene oxide
Fluorotrichloromethane
Iodomethane
Isobutanol
Methacrylonitrile
Methanol
Methylene chloride
Methyl ethyl ketone
Methyl isobutyl ketone
Methyl methacrylate
1,1,1,2-Tetrachloroethane
1,1,2,2-Tetrachloroethane
Tetrachloroethylene
Toluene
1,2,4-Trichiorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichlorethylene
1,2,3-Trichloropropane

**F039 Hazardous Waste Constituent List**
**Highway 36 Land Development Company**

1,1,2-Trichloro-1,2,2-trifluoroethane
Vinyl chloride
Xylene(s)

**Semivolatile Organic Compounds (SVOCs)**

Acenaphthalene
Acenaphthene
Acetophenone
2-Acetylaminofluorene
4-Aminobiphenyl
Aniline
Anthracene
Aramite
Aroclor 1016
Aroclor 1221
Aroclor 1232
Aroclor 1242
Aroclor 1248
Aroclor 1254
Aroclor 1260
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)-fluoranthene
Benzo(g,h,i)-perylene
Benzo(a)pyrene
4-Bromophenyl phenylether
Butyl benzylphthalate
p-Chloroaniline
Chlorobenzilate
2-Chloro-1,3-butadiene
bis(2-Chloroethoxy) methane
bis(2-Chloroethyl) ether
bis(2-Chloroisopropyl) ether
2-Chloronaphthalene
3-Chloropropylene
Chrysene
o-cresol(Below is 2,3,4 Methylphenol)
Cresol (m-and p-isomers)
Cyclohexanone
2,4-Dichlorophenoxyacetic acid
Dibenz(a,h) anthracene
Dibenzo(a,e)pyrene
Diethyl phthalate
Dimethyl phthalate
Di-n-butyl phthalate
1,4-Dinitrobenzene
4,6-Dinitro-o-cresol (2-Methylphenol)
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Di-n-octyl phthalate
Di-n-propylnitrosoamine

**F039 Hazardous Waste Constituent List**
**Highway 36 Land Development Company**

Diphenylamine
1,2-Diphenyl hydrazine
Diphenyl nitrosamine
Disulfoton
bis(2-Ethylhexyl) phthalate
Famphur
Fluoranthene
Fluorene
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachlorodibenzo-furans
Hexachlorodibenzo-p-dioxins
Hexachloroethane
Hexachloropropene
Indeno(1,2,3-c,d)pyrene
Isodrin
Isosafrole
Kepone
Methapyrilene
3-Methylcholanthrene
4,4-Methylene-bis-(2-Chloroaniline)
Methyl methansulfonate
Methyl parathion
Naphthalene
2-Naphthylamine
2-Nitroaniline
Nitrobenzene
5-Nitro-o-toluidine
N-Nitrosodiethylamine
N-Nitrosodimethylamine
N-Nitroso-di-n-butylamine
N-Nitrosomethylethylamine
N-Nitrosomorpholine
N-Nitrosopiperidine
N-Nitrosopyrrolidine
Parathion
Pentachlorobenzene
Pentachlorodibenzo-furans
Pentachlorodibenzo-p-dioxins
Pentachloronitrobenzene
Phenacetin
Phenanthrene
Phorate
Phthalic anhydride
Pronamide
Pyrene
Pyridine
Safrole
1,2,4,5-Tetrachlorobenzene
Tetrachlorodibenzo-furans

**F039 Hazardous Waste Constituent List**
**Highway 36 Land Development Company**

Tetrachlorodibenzo-p-dioxins
Tris-(2,3-dibromopropyl)phosphate
TOC (ug/L)
TOX (ug/l)

## INORGANICS

**Metals/Metalloids**

Antimony
Arsenic
Barium
Beryllium
Cadmium
Chromium (Total)
Copper
Lead
Mercury
Nickel
Selenium
Silver
Thallium
Vanadium
Zinc

**Others**

Cyanides (Total)
Fluoride
Sulfide

# GW-2 Parameter List
## Highway 36 Land Development Company

**DETECTION MONITORING PARAMETERS [1]**

### ORGANICS

| Parameter | Analytical Method | Detection Level |
|---|---|---|
| **Acid Extractables** | 8270[2] | |
| Phenol | | 10 μg/L |
| 2-Chlorophenol | | 10 μg/L |
| 4-Nitrophenol | | 20 μg/L |
| 2,4-Dimethylphenol | | 10 μg/L |
| 2,4-Dichlorophenol | | 10 μg/L |
| p-Chloro-m-cresol | | 10 μg/L |
| 2,4,6-Trichlorophenol | | 10 μg/L |
| 2,4-Dinitrophenol | | 50 μg/L |
| 4-Nitrophenol | | 50 μg/L |
| 4,6-Dinitro-2-Methylphenol | | 50 μg/L |
| Pentachlorophenol | | 50 μg/L |
| **Chlorinated Pesticides** | 8080[2], 8081[2] | |
| Aldrin | | 0.05 μg/L |
| Alpha-BHC | | 0.05 μg/L |
| Beta-BHC | | 0.05 μg/L |
| Delta-BHC | | 0.05 μg/L |
| Gamma-BHC (Lindane) | | 0.50 μg/L |
| Chlordane | | 0.50 μg/L |
| 4,4'-DDD | | 0.10 μg/L |
| 4,4'-DDE | | 0.10 μg/L |
| 4,4'-DDT | | 0.10 μg/L |
| Dieldrin | | 0.10 μg/L |
| Endosulfan I | | 0.05 μg/L |
| Endosulfan II | | 0.10 μg/L |
| Endosulfan Sulfate | | 0.10 μg/L |
| Endrin | | 0.10 μg/L |
| Endrin Aldehyde | | 0.10 μg/L |
| Heptachlor | | 0.05 μg/L |
| Heptachlor Epoxide | | 0.05 μg/L |
| Methoxychlor | | 0.50 μg/L |
| Toxaphene | | 1.0 μg/L |
| **Chlorinated Herbicides** | 8150[2], 8151[2] | |
| 2,4-D | | 0.20 μg/L |
| 2,4,5-TP (Silvex) | | 0.02 μg/L |
| 2,4,5-T | | 0.02 μg/L |

### INORGANICS - METALS/METALLOIDS

| Parameter | Analytical Method | Detection Level |
|---|---|---|
| Arsenic (Dissolved) | 6010[2]/6020[2]/7061[2] | 0.05 mg/L |
| Barium (Dissolved) | 6010[2]/6020[2]/7061[2] | 0.05 mg/L |
| Nickel (Dissolved) | 6010[2]/6020[2]/7061[2] | 0.05 mg/L |
| Zinc (Dissolved) | 6010[2]/6020[2]/7061[2] | 0.05 mg/L |

**GW-2 Parameter List**
**Highway 36 Land Development Company**

GENERAL GROUNDWATER QUALITY PARAMETERS

Note: General Groundwater Quality Parameters are used solely for the purpose of evaluating natural variability and chemical evolution of the groundwater beneath the Facility.

**PHYSICAL**

| Parameter | Analytical Method | Detection Level |
|---|---|---|
| pH (field) | 150.1/9040[2] | N/A |
| Specific Conductivity (field) | 120.1/9050[2] | 1 $\mu$mhos/cm |
| Turbidity (field) | 180.1[1] | 1.0 NTU |

**METALS/METALLOIDS**

| Parameter | Analytical Method | Detection Level |
|---|---|---|
| Iron (Dissolved) | 6010[2] | 0.05 mg/L |
| Manganese (Dissolved) | 6010[2]/6020[2] | 0.05 mg/L |
| Sodium (Dissolved) | 6010[2] | 1.0 mg/L |

**INORGANICS, NON-METALICS**

| Parameter | Analytical Method | Detection Level |
|---|---|---|
| Alkalinity, total | 310.1[1] | 10 mg/L |
| Chloride | 325.2[1]/9251[2]/9056[2] | 3 mg/L |
| Nitrogen, Nitrate plus Nitrite | 354.1[1]/353.2[1]/353.3[1]/9056[2] | 0.1 mg/L |
| Sulfate | 375.4[1]/9038[2]/9056[2] | 5.0 mg/L |

**ORGANICS**

| Parameter | Analytical Method | Detection Level |
|---|---|---|
| Total Organic Carbon (TOC) | 415.1[1]/9060[2] | 1.0 mg/L |
| Total Dissolved Solids (TDS) | EPA 160.1[2] | 2.0 mg/L |

---

**REFERENCES:**

1. *Methods for Chemical Analysis of Water and Wastes,* March 1983, USEPA, 600/4-70-020 and additions thereto.

2. *Test Methods for Evaluating Solid Waste, Physical/Chemical Method,* January 1995, Third Edition, Update III, USEPA SW-846 and updates and additions thereto.

Table 8
Frequency of Data Collection and Evaluation
Highway 36 Land Development Company

| Monitoring Location | Monitoring Program | Data Collection Frequency | | Data Evaluation Frequency | | |
|---|---|---|---|---|---|---|
| | | Hydraulic Measurements[1] | Sampling and Lab Analysis (if appropriate)[2] | Descriptive Statistics[3] | Comparative Statistics[4] | Trend Analyses[5] |
| Secure Cell LCS and LDS | Secure Cell Performance Monitoring | Weekly/ Monthly/ Quarterly | Quarterly | Annually | Quarterly | Annually |
| BP Wells | Inspection Monitoring | Quarterly | NA[6] | NA | NA | NA |
| Level 3 Wells | Inspection Monitoring | Quarterly | Semiannually | Semiannually | Semiannually | Annually |
| Level 4A Wells | Inspection Monitoring | Quarterly | Semiannually | Semiannually | Semiannually | Annually |
| Level 4 Wells | Inspection Monitoring | Quarterly | Semiannually | Semiannually | Semiannually | Annually |
| Level 5 Wells | Detection Monitoring | Quarterly | Semiannually | Semiannually | Semiannually | Annually |
| Level 6 Wells | Inspection Monitoring | Quarterly | Semiannually | Semiannually | Semiannually | Annually |

Notes:

(1) Hydraulic measurements for the Secure Cells consist of action leakage rate (ALR) monitoring performed in accordance with 40 CFR and 6 CCR 1007-3, Part 264.302. Hydraulic measurements for the groundwater monitoring wells consist of water level measurements in accordance with 6 CCR 1007-3, Part 264.97(f).

(2) The laboratory analytical parameters for the Secure Cell LCS and LDS are the F039 hazardous waste constituents. The laboratory analytical parameters for the groundwater monitoring wells include the GW-1 and GW-2 parameters. As discussed in Section 5.2.5, many of the monitoring wells at the Facility do not yield sufficient groundwater to provide representative samples. Consistent with 6 CCR 1007-3, Part 264.97, groundwater samples are not collected from these wells for laboratory chemical analysis.

(3) Descriptive statistics are used to describe the characteristics of the data sets and to select appropriate statistical testing procedures.

(4) Comparative statistical evaluations are used to identify statistical exceedances that may be indicative of a potential release from a secure cell.

(5) Trend analyses are used to evaluate the chemical evolution of the secure cell fluids, and to assess the suitability of the groundwater detection monitoring parameters.

(6) NA means not applicable.

**Figures**

Available upon request

# APPENDIX A

## DESCRIPTIVE STATISTIC EXAMPLES

A. FREQUENCY OF DETECTION:

The frequency of detection is determined by dividing the number of parameter measurements which are greater than the detection limit by the total number of parameter measurements available. The frequency of detection can be expressed as either a fraction, ratio or percent, as shown below.

Chloride values, in mg/l:

653.5
1175.0
778.0
1054.25
956.0

Number of measurements greater than the detection limit = 5

Total number of measurements = 5

Frequency of Detection $\frac{5}{5} = 1 = 100\%$

The frequency of detection can be used to evaluate the number of non-detected results in a data set that required replacement with numerical values in order to compute other descriptive statistics such as the mean. Used in this manner, the validity of the descriptive statistics can be evaluated, because when the percentage of non-detected results are high (>50%), classic descriptive statistics based on normally-distributed data are no longer strictly valid (See Appendix B for descriptive statistics for infrequently detected parameters).

| Phenol | Lab Result | Value used for calculating the mean |
|---|---|---|
| | < 10 μg/l | 5 |
| | < 10 μg/l | 5 |
| | < 10 μg/l | 5 |
| | < 10 μg/l | 5 |
| | < 10 μg/l | 5 |

Number of Measurements greater than the detection limit = 0

Number of Total Measurements = 5

Frequency of Detection $\frac{0}{5} = 0 = 0\%$

Calculation of the Mean (see B below for detailed explanation)

$$Mean = \frac{5 + 5 + 5 + 5 + 5}{5} = 5 \ \mu g/l$$

Because calculation of the mean and other descriptive statistics require substituting real numerical values for non-detected results, situations may arise such as this where the computed descriptive statistics do not provide meaningful information. In this case, the mean concentration of phenol is, apparently, 5 $\mu$g/l. However, the frequency of detection is zero (i.e., the compound has never actually been detected). In circumstances where the frequency of detection is low, the percentage of non-detected results is high. When the frequency of detection is low (<50%) descriptive statistic are no longer strictly valid.

B. MEAN:

The mean, as used in this statistical calculation is the arithmetic mean, or ordinary average. It is defined as the sum of all of the values in the data set divided by the number of values in the data set. The mean indicates the center of the data set, and is accurate for data having units such as weight, length, temperature, with equally spaced intervals.

Chloride values, in mg/l:

653.5
1175.0
778.0
1054.25
956.0

$$\text{Mean} = \frac{653.5 + 1175.0 + 778.0 + 1054.25 + 956.0}{5} = \frac{4616.75}{5} = 923.4$$

C. MEDIAN

The median is the middle value, which has an equal number of values above and below it. It is a value which is not significantly affected by the end points of the series of values, but is simply the middle value observed. If data is truly symmetrical, the median and the mean will be the same, or coincide. If the data are not symmetrical, the median and the mean will be different. The median is a better measure of central value for data with unequal value intervals, such as pH. It is not a very useful statistic otherwise, as it does not lend itself to further mathematical treatment.

Chloride values, in mg/l:

653.5
1175.0
778.0
1054.25
956.0

Arranged in ascending order:

| | |
|---|---|
| 653.5 | Smallest value |
| 778.0 | |
| 956.0 | Middle value = Median. |
| 1054.25 | |
| 1175.0 | Largest value |

D. STANDARD DEVIATION:

The standard deviation is the most commonly used measure of the dispersion or spread of data. The standard deviation is the root mean square of the deviations or differences of each sample value from the mean. For normally distributed data, 95.45% of the values will fall between two standard

deviations either side of the mean, and 99.73% of the values will fall between three standard deviations either side of the mean. This knowledge is very useful in examining the probability of a single data point being representative, or belonging to the same set of data represented by the sample data set. The standard deviation is used in determining the variance, and for setting confidence levels for seeing how well data are grouped around the mean value.

Chloride values, in mg/l:

653.5
1175.0
778.0
1054.25
956.0

Mean Chloride Value from page A-2 = 923.4 mg/L

1. Set up a table and calculate differences and squared differences as shown below:

| VALUE | DIFFERENCE FROM MEAN | DIFFERENCE SQUARED |
|---|---|---|
| 653.5 | 635.5 - 923.35 = - 269.85 | 72819.023 |
| 1175.0 | 1175.0 - 923.35 = 252.0 | 63504.0 |
| 778.0 | 778.0 - 923.35 = - 145.35 | 21126.623 |
| 1054.25 | 1054.25 - 923.35 = 130.9 | 17134.81 |
| 956.0 | 956.0 - 923.35 = 32.65 | 1066.0225 |

2. Calculate: Sum of Squared Differences = 175650.48

3. $\frac{\text{Sum of Squared Differences}}{\text{Number of Values -1}} = \frac{175650.48}{5-1} =$ 43912.62

4. Square Root of Above Number = Std. Dev. = 209.6

E. VARIANCE:

As presented in these analyses, the variance is the square of the standard deviation. This number is actually the sample variance, and indicates how widely dispersed the data is. If the data show very small differences, the variance will be small. If the data have a wide range of values, the variance will be large. This is an exaggeration of the standard deviation to express data dispersion. It is most useful in comparing the dispersion of a small sample set of data to a much larger population data set to see if the sample set is truly representative of the population.

Chloride values, in mg/l:

653.5
1175.0
778.0
1054.25
956.0

Mean Chloride Value from page A-2 = 923.35 mg/L

Std. Dev. = 209.6

Variance = 209.553 x 209.553 = 43912.6

F. MAXIMUM AND MINIMUM VALUES:

These are the highest (maximum) and lowest (minimum) values in the sample set of data. They indicate the range of data and the dispersion possible about the mean. These are the extreme ends of the data set, but they do not necessarily correspond to a given statistical range, as is described by the mean plus or minus factors of the standard deviation. It is often useful to see if the maximum and/or minimum lie within two or three standard deviations to see if any of the data is outside the 95% or 99% confidence intervals.

Chloride values, in mg/l:

653.5
1175.0
778.0
1054.25
956.0

| -3SD | -2SD | MEAN | +2SD | +3SD |
|---|---|---|---|---|
| 295 | 419 | ↑-----923-----↑ | 1342 | 1552 |
| | | 653.5 1175.0 | | |

G. SKEWNESS

Skewness is a measure of the departure from symmetry of a distribution. A perfectly symmetrical distribution would have the same number of value intervals below and above the median and mean values, which would be the same. Small samples tend to have less symmetry than large populations, so the median and mean seldom are the same. The skewness defines whether there are more value intervals below the median (a negative number), or more value intervals above the median (a positive number), and gives some idea of how far the median is to one side or the other from the mean (the magnitude of the skewness number).

The most common measure of skewness is given by the equation:

$$\text{Skewness} = \frac{\text{mean - mode}}{\text{standard deviation}}$$

Since we haven't defined the mode, a similar equation which can be used and we have defined terms for is:

$$\text{Skewness} = \frac{3\,(\text{mean - median})}{\text{standard deviation}}$$

Other methods are often used for determining the skewness, utilizing quartiles, percentiles, and third moments. Because skewness is not a critical descriptive statistic used for other calculations, and since it is not an absolute scaler number, it does not need to be calculated, but may be presented to describe the general shape of the data distribution.

## H. KURTOSIS

Kurtosis describes the degree of peakedness of a distribution curve. A value at or near zero indicates that the distribution has a peak near the normal height. A negative number indicate a flatter distribution than normal, and a high positive number indicates a relatively high peak and narrow dispersion of data.

Kurtosis is calculated from moments about the mean, and is not conveniently calculated manually. As with the skewness, the kurtosis is a statistic which describes the distribution pattern of the data set, and is not really useful for absolute measure. Using standard statistical software packages this statistic may be calculated to facilitate a better understanding of the sample distribution, but it is not of use in doing probability analysis, and will not be manually calculated.

## I. STANDARD ERROR

The standard error in this case is the sampling distribution of means. It is a measure of how much of the standard deviation is due to sampling error as compared to sample dispersion. As the number of data points gets larger, the standard error gets smaller. The sampling error of means is nearly normal with 30 or more data points even when the data are not normally distributed. As adequate data are developed with time to do trend analyses, the standard error will help indicate whether data sets are becoming more normally distributed, or whether they are showing less normal distribution.

| | |
|---|---|
| Chloride values, in mg/l: | 653.5 |
| | 1175.0 |
| | 778.0 |
| | 1054.25 |
| | 956.0 |

Mean Chloride Value from page A-2 = 923.4 mg/L

Std. Dev. = 209.6

$$\textit{Standard Error} = \frac{\textit{Standard Deviation}}{\textit{Square Root of the number of data points}} = \frac{209.448}{\sqrt{5}}$$

$$= \frac{209.448}{2.236} = 93.7$$

## J. COEFFICIENT OF VARIATION

The coefficient of variation is simply a measure of relative dispersion, whereas the standard deviation is a measure of absolute dispersion. This number is given as a percentage, and shows how large the standard deviation is relative to the mean.

| | |
|---|---|
| Chloride values, in mg/l: | 653.5 |
| | 1175.0 |
| | 778.0 |
| | 1054.25 |
| | 956.0 |

Mean Chloride Value from page A-2 = 923.4 mg/L

Std. Dev. = 209.6

$$\text{Coefficient of Variation} = \frac{\text{Standard Deviation}}{\text{Mean}} = \frac{209.6}{923.4} = 0.23$$

$$= 22.684\ \%$$

The smaller this number, the closer the values are together, indicating better agreement and less variability. Larger numbers indicate wider variability of data within the sample set.

# APPENDIX B

## DESCRIPTIVE STATISTIC FOR INFREQUENTLY DETECTED PARAMETERS

ACID-EXTRACTABLE ORGANIC PARAMETERS
(If Applicable)

WELL GROUP: _____

SAMPLING DATE: _____

Number of Wells Sampled: _____

Number of acid-extractable analyses run: _____

Number of detections below 50 ppb: _____
(50 ppb for tentative or unknowns)
Number of detections greater than or equal to 50 ppb: _____

LIST OF DETECTED COMPOUNDS

| Well No. | Parameter Detected | S,T,U * | Concentration | M.D.L. |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

* S, T, and U are Semivolatile, Tentatively identified, and Unknown, respectively.

PESTICIDE AND HERBICIDE PARAMETERS
(If Applicable)

WELL GROUP: _____

SAMPLING DATE: _____

Number of Wells Sampled: _____

Number of Pesticide/Herbicide analyses run: _____

Number of detections greater than or equal to the parameter-specific detection level: _____

LIST OF DETECTED COMPOUNDS

| Well No. | Parameter Detected | P,H,U * | Concentration | M.D.L. |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

* P,H, and U stand for Pesticide, Herbicide and Unknown, respectively.

INORGANIC PARAMETERS
(If Applicable)

WELL GROUP: _____

SAMPLING DATE: _____

Number of Wells Sampled: _____

Number of inorganic analyses run: _____

Number of detections greater than or equal to the parameter-specific detection level: _____

LIST OF DETECTED COMPOUNDS

| Well No. | Parameter Detected | M,O * | Concentration | M.D.L. |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

* M and O stand for metal/metalloid and other general water quality parameters.

# APPENDIX C

# EXAMPLE DATA PACKAGE FOR TREND ANALYSIS

# LEAST SQUARE LINEAR REGRESSION ANALYSIS

## TREND LINE DETERMINATION

The least square regression line is the best fit of a straight line to the data plotted against time. This is called a time series plot, and the regression line is called a trend line. The equation for such a straight line has the form:

$$Y = mX + b$$

In this equation, Y is the dependent variable; the constant m is the slope and represents the change in Y divided by the corresponding change in X; X is the independent variable time; and the constant b is the value of Y when X = 0 and is called the Y intercept.

1. To make the calculation of the trend line easier, and to make plots consistent from one time to the next, the time scale should be plotted in months and years, starting with January of 1986 as the first unit of the X axis. Each month should then be assigned a consecutive number, i.e. February, 1986 = 2; March, 1986 = 3;... January, 1987 = 13; April 1987, = 16; etc. A table of date to number conversions is listed below for the first five years. The sequence can be extended indefinitely.

| | | |
|---|---|---|
| 1. Jan. 1986 | 21. Sep. 1987 | 41. May 1989 |
| 2. Feb. 1986 | 22. Oct. 1987 | 42. Jun. 1989 |
| 3. Mar. 1986 | 23. Nov. 1987 | 43. Jul. 1989 |
| 4. Apr. 1986 | 24. Dec. 1987 | 44. Aug. 1989 |
| 5. May 1986 | 25. Jan. 1988 | 45. Sep. 1989 |
| 6. Jun. 1986 | 26. Feb. 1988 | 46. Oct. 1989 |
| 7. Jul. 1986 | 27. Mar. 1988 | 47. Nov. 1989 |
| 8. Aug. 1986 | 28. Apr. 1988 | 48. Dec. 1989 |
| 9. Sep. 1986 | 29. May. 1988 | 49. Jan. 1990 |
| 10. Oct. 1986 | 30. Jun. 1988 | 50. Feb. 1990 |
| 11. Nov. 1986 | 31. Jul. 1988 | 51. Mar. 1990 |
| 12. Dec. 1986 | 32. Aug. 1988 | 52. Apr. 1990 |
| 13. Jan. 1987 | 33. Sep. 1988 | 53. May 1990 |
| 14. Feb. 1987 | 34. Oct. 1988 | 54. Jun. 1990 |
| 15. Mar. 1987 | 35. Nov. 1988 | 55. Jul. 1990 |
| 16. Apr. 1987 | 36. Dec. 1988 | 56. Aug. 1990 |
| 17. May 1987 | 37. Jan. 1989 | 57. Sep. 1990 |
| 18. Jun. 1987 | 38. Feb. 1989 | 58. Oct. 1990 |
| 19. Jul. 1987 | 39. Mar. 1989 | 59. Nov. 1990 |
| 20. Aug. 1987 | 40. Feb. 1989 | 60. Dec. 1990 |

3. To find out what the constants for the trend line equation are, we must solve two other equations. To do this, it is necessary to set up a table of the data and data multiples. A blank table is shown below, and a completed example is on page C-5.

| N | X | Y | $X^2$ | XY | $Y^2$ |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 10 | | | | | |
| 11 | | | | | |
| 12 | | | | | |
| 13 | | | | | |
| 14 | | | | | |
| 15 | | | | | |
| 16 | | | | | |
| 17 | | | | | |
| 18 | | | | | |
| 19 | | | | | |
| 20 | | | | | |
| 21 | | | | | |
| 22 | | | | | |
| 23 | | | | | |
| 24 | | | | | |
| 25 | | | | | |
| 26 | | | | | |
| 27 | | | | | |
| 28 | | | | | |
| 29. | | | | | |
| 30 | | | | | |
| Totals: | | | | | |

The N value is the number of data points (or pairs) used for the calculation of the trend line.

Once the data table has been filled out, and all of the columns (but the N column) have been added up, the following equations can be solved:

$$m = \frac{N\,(\text{sum } XY) - (\text{sum } X)(\text{sum } Y)}{N(\text{sum } X^2) - (\text{sum } X)^2}$$

$$b = \frac{(\text{sum } Y)\,(\text{sum } X^2) - (\text{sum } X)(\text{sum } XY)}{N(\text{sum } X^2) - (\text{sum } X)^2}$$

Once these two equations have been solved, the equation; $\underline{Y = mX \times b}$, can be written with the constant values inserted, and the line can be plotted on the trend data graph.

If m is a negative number, then the trend line will slope downward, or show a decreasing trend. If m is a positive number, then the trend line will slope up, or show an increasing trend. Comparing the most recent trend line slope to past slopes will tell whether the trend is increasing or decreasing with time. If m is equal to zero, the line is perfectly flat, having no slope.

The trend line can be expected to change, especially in the first few years, due to seasonal variation and other factors which affect the values of parameter concentrations. After two to three years (8-12 sets of data), enough of these variations will have been included so that the affect of a single data point will not significantly affect the trend, but a continual trend will cause a constant change each time the data are plotted.

An example trend line calculation and data set is shown on the next page.

The trend line determination will assist in evaluation of new data for inclusion in the background database. It is not a trigger mechanism for assessment since it provides a qualitative rather than an absolute quantitative characteristic of the data.

# EXAMPLE TREND LINE CALCULATION

DATA: From page 23, Chloride Data (*some assumed data sets)

| DATE | X VALUE (pg.C-2) | CHLORIDE VALUE (Mean, mg/L) |
|---|---|---|
| 10/86 | 10 | 914.25 |
| 01/87 | 13 | 929.25 |
| 04/87 | 16 | 917 |
| 07/87 | 19 | 931 |

| N | X | Y | $X^2$ | XY | $Y^2$ |
|---|---|---|---|---|---|
| 1 | 10 | 914.25 | 100 | 9142.5 | 835853 |
| 2 | 13 | 929.42 | 169 | 12082.5 | 863822 |
| 3 | 16 | 917 | 256 | 14672 | 840889 |
| 4 | 19 | 931 | 361 | 17689 | 866761 |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 10 | | | | | |
| 11 | | | | | |
| 12 | | | | | |
| 13 | | | | | |
| 14 | | | | | |
| 15 | | | | | |
| Total: 4 | 58 | 3692 | 886 | 53586 | 3407325 |

$$m = \frac{N\,(\text{sum } XY) - (\text{sum } X)\,(\text{sum } Y)}{N\,(\text{sum } X^2) - (\text{sum } X)^2} = \frac{4(53586) - (58)(3692)}{4(886) - (58)(58)} = \frac{200}{180} = 1.156$$

$$b = \frac{(\text{sum } Y)(\text{sum } X^2) - (\text{sum } X)(\text{sum } XY)}{N\,(\text{sum } X^2) - (\text{sum } X)^2} = \frac{(3692)(886) - (58)(53586)}{4(886) - (58)(58)} = 906.24$$

$$Y = mX + b = 1.156\,X + 906.24$$

# APPENDIX D

# EXAMPLE OF

# PREDICTION INTERVALS

A prediction interval is a statistical interval calculated to include one or more future observations from the same population with a specified confidence. The interval is constructed to contain k future observations at a specified confidence.

A. PARAMETRIC PREDICTION LIMITS

1. Calculate the upper prediction limit for the background data set. The two data sets in Table 1 are background chloride concentrations in two different well groups. Only the background data are used to calculate the prediction limit. For each well group, compute the number of background values, the mean and the standard deviation.

2. Determine the distribution of each data set. Test the assumption of normality using the Shapiro-Wilk test at the 95 percent confidence level.

3. The results of the Shipiro-Wilk test indicate that the assumption of normality cannot be rejected for the Well Group A data ($W > W_{crit}$), but can be rejected for the Well Group B data ($W < W_{crit}$). Therefore, the Well Group A data are normally distributed but the Well Group B data are not.

Table 1. Background Concentrations of Chloride in Well Groups A and B

| Well Group A | | | Well Group B | | |
|---|---|---|---|---|---|
| Date | Monitor Well | Chloride (mg/L) | Date | Monitor Well | Chloride (mg/L) |
| 1/2/92 | MWA-1 | 653 | 1/2/92 | MWB-2 | 950 |
| 1/2/92 | MWA-2 | 1175 | 1/2/92 | MWB-3 | 820 |
| 1/2/92 | MWA-4 | 950 | 1/2/92 | MWB-5 | 680 |
| 1/2/92 | MWA-5 | 778 | 6/15/93 | MWB-1 | 600 |
| 6/15/93 | MWA-1 | 1854 | 6/15/93 | MWB-2 | 1050 |
| 6/15/93 | MWA-4 | 950 | 6/15/93 | MWB-3 | 950 |
| 6/15/93 | MWA-5 | 700 | 6/15/93 | MWB-4 | 1150 |
| 12/22/93 | MWA-1 | 1000 | 6/15/93 | MWB-5 | 775 |
| 12/22/93 | MWA-2 | 950 | 12/22/93 | MWB-2 | 610 |
| 12/23/93 | MWA-3 | 750 | 12/22/93 | MWB-3 | 750 |
| 12/23/93 | MWA-5 | 1000 | 12/22/93 | MWB-5 | 780 |
| 6/10/94 | MWA-1 | 650 | 6/10/94 | MWB-1 | 1290 |
| 6/10/94 | MWA-2 | 1100 | 6/10/94 | MWB-2 | 730 |
| 6/10/94 | MWA-3 | 600 | 6/10/94 | MWB-3 | 1120 |
| 6/10/94 | MWA-4 | 700 | 6/10/94 | MWB-4 | 1800 |
| 6/10/94 | MWA-5 | 800 | 6/10/94 | MWB-5 | 1000 |
| 12/20/94 | MWA-1 | 900 | 12/20/94 | MWB-2 | 1050 |
| 12/20/94 | MWA-5 | 1000 | 12/20/94 | MWB-3 | 800 |
| 6/5/95 | MWA-1 | 1100 | 6/5/95 | MWB-1 | 930 |
| 6/5/95 | MWA-2 | 1200 | 6/5/95 | MWB-2 | 900 |
| 6/5/95 | MWA-5 | 1300 | 6/5/95 | MWB-3 | 1400 |
| N | | 21 | | | 21 |
| Mean | | 958 | | | 958 |
| Standard Deviation | | 285 | | | 286 |

4. Log transform the values in the Well Group B data set by taking the natural log of each value.

Table 2. Log-transformed Chloride Concentrations

| Well Group B Chloride (mg/L) | Well Group B Log (Chloride mg/L) |
|---|---|
| 950 | 6.86 |
| 20 | 6.71 |
| 680 | 6.52 |
| 600 | 6.40 |
| 1050 | 6.96 |
| 950 | 6.86 |
| 1150 | 7.05 |
| 775 | 6.65 |
| 610 | 6.41 |
| 750 | 6.62 |
| 780 | 6.66 |
| 1290 | 7.16 |
| 730 | 6.59 |
| 1120 | 7.02 |
| 1800 | 7.50 |
| 1000 | 6.91 |
| 1050 | 6.96 |
| 800 | 6.68 |
| 930 | 6.84 |
| 900 | 6.80 |
| 1400 | 7.24 |
| Mean | 6.83 |
| Standard Deviation | 0.27 |

Again, test the assumption of normality, using the log-transformed values, with the Shapiro-Wilk test at the 95 percent confidence level.

5. The results of the Shapiro-Wilk test run on the log-transformed Well Group B data indicate that the assumption of normality cannot be rejected( $W > W_{crit}$). Therefore, the Well Group B data appear log-normally distributed.

6. In order to calculate the upper prediction limit at a specified confidence, the number of future comparisons (k) must be specified. For Well Group A, four observations, one sample from each

of four wells, will be compared to the prediction limit. For Well Group B, five observations will be compared to the prediction limit.

Table 3. Current Chloride Concentrations in Well Groups A and B

| Well Group A (k = 4) | | | Well Group B (k = 5) | | |
|---|---|---|---|---|---|
| Date | Monitor Well | Chloride (mg/L) | Date | Monitor Well | Chloride (mg/L) |
| 6/15/96 | MWA-1 | 1550 | 6/16/96 | MWB-1 | 780 |
| 6/15/96 | MWA-2 | 980 | 6/16/96 | MWB-2 | 860 |
| 6/16/96 | MWA-4 | 1100 | 6/16/96 | MWB-3 | 1400 |
| 6/15/96 | MWA-5 | 600 | 6/15/96 | MWB-4 | 1350 |
| | | | 6/15/96 | MWB-5 | 950 |

For the normally distributed background data, Well Group A, calculate the 95 percent upper prediction limit using the following equation:

$$UL_{0.95} = \bar{x} + t_{n-1,k,0.05} SD \sqrt{1 + \frac{1}{n}}$$

where $\bar{x}$ = the mean and SD = standard deviation of the background values. For Well Group A, n = 21 and k = 4.

For the log-normally distributed data, Well Group B, calculate the 95 percent upper prediction limit using the following equation:

$$UL_{0.95} = \exp\left[\bar{y} + t_{n-1,k,0.05} SD_y \sqrt{1 + \frac{1}{n}}\right]$$

where $\bar{y}$ = the mean of log-transformed background values and SDy = standard deviation of the log-transformed background values. For Well Group B, n = 21 and k = 5.

Values of t for different degrees of freedom, n-1, and numbers of future comparisons, k, are provided on Table 4 from Appendix B of EPA (1989).

Table 4. 95th Percentiles of the Bonferroni t-Statistics, t ($\nu$, $\alpha$/k)

where: $\nu$ = degrees of freedom associated with the mean squares error
k = number of comparisons (future observations)
$\alpha$ = 0.05, the experimentwise error level

| k | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| a/k | 0.05 | 0.025 | 0.0167 | 0.0125 | 0.01 |
| $\nu$ | | | | | |
| 4 | 2.13 | 2.78 | 3.20 | 3.51 | 3.75 |
| 5 | 2.02 | 2.57 | 2.90 | 3.17 | 3.37 |
| 6 | 1.94 | 2.45 | 2.74 | 2.97 | 3.14 |
| 7 | 1.90 | 2.37 | 2.63 | 2.83 | 3.00 |
| 8 | 1.86 | 2.31 | 2.55 | 2.74 | 2.90 |
| 9 | 1.83 | 2.26 | 2.50 | 2.67 | 2.82 |
| 10 | 1.01 | 2.23 | 2.45 | 2.61 | 2.76 |
| 15 | 1.75 | 2.13 | 2.32 | 2.47 | 2.60 |
| 20 | 1.73 | 2.09 | 2.27 | 2.40 | 2.53 |
| 30 | 1.70 | 2.04 | 2.21 | 2.34 | 2.46 |
| $\infty$ | 1.65 | 1.96 | 2.13 | 2.24 | 2.33 |

*Source: For $\alpha$/k = 0.05, 0.025 and 0.01, the percentiles were extracted from the t-table (Table 6, Appendix B) for values of F = 1-$\alpha$ of 0.95, 0.975 and 0.99, respectively. For $\alpha$/k = 0.05/3 and 0.05/4, the percentiles were estimated using "A Nomograph of Student's t" by Nelson, L.S. 1975. Journal of Quality Technology, Vol. 7, pp. 200-201.*

*Modified from EPA (1992c).*

7. For Well Group A, the upper prediction limit is computed as:

$$UL_{0.95} = 958 + 2.40(285)\sqrt{1 + \frac{1}{21}}$$

$$UL_{0.95} = 958 + 700 = 1{,}658 \ mg/L$$

For Well Group B, the upper prediction limit is computed as:

$$UL_{0.95} = \exp\left[6.83 + 2.53(0.274)\sqrt{1 + \frac{1}{21}}\right]$$

$$UL_{0.95} = \exp\,[6.83 + 0.71] = 1{,}882 \ mg/L$$

8. Compare each new observation from Well Group A to the upper prediction limit for Well Group A, 1,658 mg/L, and report exceedances of the limit. In this example, there are no exceedances of

the prediction limit, and one may conclude with 95 percent confidence that the four new observations are from the same population as the 21 background observations.

9. Compare each new observation from Well Group B to the upper prediction limit for Well Group B, 1,882 mg/L, and report exceedances of the limit. In this example, there are no exceedances of the prediction limit, and one may conclude with 95 percent confidence that the five new observations are from the same population as the 21 background observations.

B. NONPARAMETRIC PREDICTION LIMITS

1. For non-normally distributed background data sets (neither normal nor log normal) and for background data sets with more than 50 percent nondectable results, calculate the nonparametric prediction limit.

2. Determine the maximum value of the background data and use this value to estimate the upper prediction limit. In the following example, the prediction limit is set to the maximum of the n=24 samples, or 0.011 mg/L.

Table 5. Background Benzene Concentrations for Well Group C

| Sample Date | Benzene (mg/L) | Sample Date | Benzene (mg/L) | Sample Date | Benzene (mg/L) |
|---|---|---|---|---|---|
| 1/2/92 | <0.005 | 6/12/92 | 0.010 | 5/25/93 | <0.005 |
| 1/2/92 | <0.005 | 12/30/92 | <0.005 | 5/24/93 | <0.005 |
| 1/2/92 | 0.006 | 12/30/92 | <0.005 | 5/24/95 | 0.011 |
| 1/5/92 | <0.005 | 12/30/92 | <0.005 | 12/13/93 | <0.005 |
| 6/11/92 | <0.005 | 12/30/92 | <0.005 | 12/13/93 | <0.005 |
| 6/11/92 | <0.005 | 12/30/92 | <0.005 | 12/12/93 | <0.005 |
| 6/12/92 | <0.005 | 5/25/93 | <0.005 | 12/12/93 | <0.005 |
| 6/12/92 | <0.005 | 5/25/93 | <0.005 | 12/13/93 | <0.005 |

Table 6. Current Benzene Concentrations in Well Group C

| Sample Date | Benzene (mg/L) |
|---|---|
| 6/25/96 | <0.005 |
| 6/25/96 | <0.005 |
| 6/25/96 | <0.005 |
| 6/26/96 | 0.007 |
| 6/26/96 | <0.005 |

3. Compute the significance level ($1-\alpha$) and false positive rate ($\alpha$) associated with the prediction limit from the following equation:

$$(1-\alpha) = n/(n+k)$$

The number of background measurements is 25 ( n=25); and the number of future measurements is the number of samples from Well Group C monitoring wells (k = 5). Therefore, the significance level ($1-\alpha$) of the upper prediction limit is 0.833 and the false positive rate ($\alpha$) associated with the limit is 0.167.

4. Compare each new measurement from Well Group C to the upper prediction limit and report exceedances of the limit.

5. For Well Group C, none of the new observations exceeds the upper prediction limit for benzene (0.011 mg/L). Therefore, one may conclude with 83 percent confidence that the five new observations are from the same population as the 24 background observations.

**Highway 36 Land Development Company**
**Deer Trail, Colorado**

# APPENDIX E

## Monitoring Well Location and Construction Specifications

## GROUNDWATER PROTECTION PROGRAM DESIGN AND RATIONALE

### Monitoring Well Location and Construction Specifications

## I. GENERAL REQUIREMENTS AND PERFORMANCE STANDARDS

The following criteria must be met for the monitoring wells to be used in the Detection and Inspection Monitoring Programs.

A. The groundwater monitoring well array must consist of a sufficient number of wells, installed at appropriate locations and depths to yield groundwater samples from the uppermost aquifer below the facility where saturated conditions exist or may be likely to occur in the future. Spacing criteria are specified in sections II through V. of this section. An experienced geologist or professional engineer shall supervise all work and report preparation.

1. For the purpose of this permit, the uppermost aquifer is defined as the entire volume of soil, weathered and unweathered bedrock between the ground surface and the uppermost water producing strata within unweathered shale bedrock.

2. Relatively more permeable strata must be monitored with greater number of wells than less permeable strata.

3. Multiple saturated strata below the same point(s) shall be monitored with well clusters which allow sampling of each saturated stratum above unweathered bedrock.

B. Groundwater samples obtained from monitoring wells must be representative of groundwater in the geologic formation surrounding each well.

1. Groundwater samples must not be adversely affected by well construction materials. Initial well casings and screens may be NSF/ASTM certified polyvinyl chloride (PVC).

2. A minimum of one sample from each source of water introduced into wells to complete drilling work, logging, cleaning, or for any other reason, shall be analyzed for the parameters in the Groundwater Protection Program Design and Rationale, Table 3.

3. All equipment and materials (except filter pack and sealants) introduced into a well bore must be steam cleaned, or washed with hot water and laboratory detergent (e.g. Alconox or equivalent) and thoroughly rinsed with distilled water, prior to introduction.

C. Well intakes must be designed and constructed to allow sufficient groundwater flow to the well for sampling; minimize the passage of formation, filter pack, or

other materials into the well; and ensure sufficient structural integrity to prevent collapse of the well.

1. All screen material must be factory slotted.

2. Filter pack material shall be installed between the formation and screen.

   a. Filter material shall be clean quartz sand or chemically inert beads (e.g. silica or glass).

   b. Filter pack should not extend more than two feet above the screen.

   c. Filter pack grain size and screen slot size shall be chosen to optimize the performance of the well as specified above.

3. Each well completed in a saturated zone must be developed to restore the natural hydraulic conductivity of the formation adjacent to the screen and to remove turbidity.

   a. Surge blocks, bailers or pumps may be used for development. Compressed air surging shall not be used.

   b. Wells shall be repeatedly developed as specified in the TEGD, to remove turbidity to a maximum of five Nephelometric Turbidity Units to the extent possible.

4. Monitoring wells completed in zones which do not produce water shall not be developed at the time of installation.

   a. Upon discovery of water in a previously dry well at an elevation above the bottom of the screen in the course of monitoring or inspection, the well shall be developed as specified in section C.3. above.

   b. If the previously dry well cannot be adequately developed solely due to lack of available ground water, the well shall be sampled as specified in the Groundwater Sampling and Analysis Plan and the well shall be inspected monthly for the next two months to determine if the water surface elevation has changed. If the water surface elevation has then risen above the bottom of the screen, further development shall be attempted.

   c. If a previously dry well has not been successfully developed after three attempts (conducted after quarterly or interim monthly inspections as specified in 4.a. and b. above), the well shall either be replaced with a well screened at an elevation two feet or more below the original well screen, or a technical justification report shall be submitted to the Department within 180 days.

D. Sealants

1. At least two feet of bentonite pellets followed by bentonite-Portland cement mixtures of anti-shrink cement mixtures must be used as sealants in the annular space above the screen and filter pack, to within ten feet from the surface.

   a. A tremie pipe shall be used to place cement or other slurry in the annular space.

2. The upper ten feet (approximately) of the annular space shall be sealed with cement, blending into a concrete apron extending at least three feet around the surface casing.

E. Steel surface casing with locking security caps shall be provided for all wells, whether dry or water producing.

F. Completion and development reports for each well must include at least the following information.

1. Date(s) of drilling, completion and development.

2. Drilling method and fluid(s) used.

   a. Reference to source and analysis of any introduced water.

3. Well location, referenced to site within grid 0.5 foot.

4. Bore and casing(s) diameter(s).

5. Total depth, within 0.1 foot.

6. Drilling and lithologic logs.

7. Casing and sump material specification and size.

   a. Reference material certification.

8. Screen material, slot size and type, installed depth to top of screen and length.

9. Casing and screen joint type.

10. Filter pack material source, complete grain size analysis and D10 grain size estimated from specifications provided by sand supplier.

11. Filter pack volume.

12. Filter pack placement method.

13. Sealant material source(s), type(s), mix design.

14. Sealant volume.

15. Sealant placement method.

16. Surface seal design.

17. Well development procedures, including equipment and methods used, total daily amounts of water removed, recovery rates, and turbidity and water surface elevation measurements during development.

18. Description of protective cap.

19. Surveyed ground and well reference elevations (concrete apron, top of surface and well casings).

20. Detailed drawing of well, with dimensions.

G. Abandoned wells and borings shall be plugged to avoid providing a potential preferential flow conduit.

1. Abandoned wells shall be either auger-reamed to remove the casing, screen and filter pack, or pressure grouted across the screened interval with expanding neat cement.

2. Boreholes not used to construct monitoring wells, and reamed or grouted wells, shall be filled within five feet or less from the surface with tamped bentonite pellets or bentonite-cement slurry.

## II. LEVEL 5 WELLS - DETECTION MONITORING WELLS

A. The permittee shall install and maintain 8 Detection monitoring wells approximately equally spaced around the compliance boundary, and screened across the uppermost water producing strata within unweathered shale or claystone bedrock.

1. Level 5 wells shall be installed and all background data collected before receipts of wastes at the facility.

B. Air rotary technique shall be employed to drill Level 5 boreholes.

1. Temporary surface casing may be installed in auger borings not to exceed 30 feet in depth.

2. Air supply shall be filtered or provided with an efficient separator to minimize water or compressor oil introduced into the well bore.

3. Auger and air cutting shall be continuously inspected and logged. Cuttings shall be observed carefully to detect and quantify sand content.

4. Cores shall be taken at each lithologic change and through anticipated water producing strata.

5. Potable water may be used to complete drilling, cleaning and geophysical logging of boreholes after the first water producing zone is penetrated.

C. Schedule 80 polyvinyl chloride casing and screen with flush threaded couplings may be used in the monitoring program, as long as performance standards (for representative samples of groundwater) are met.

1. PVC material shall meet National Sanitation Foundation and/or ASTM material specifications.

2. Construction material shall be at a minimum four inch nominal diameter.

3. Screens shall be a maximum of 20 feet in length, centered at the first water producing zone penetrated during drilling.

## III. LEVEL 4 WELLS - INSPECTION MONITORING WELLS

A. Highway 36 shall install and maintain Inspection monitoring wells screened at the interface between weathered and unweathered shale or claystone.

1. Level 4 wells completed in unsaturated zones shall be spaced at approximately 300 foot intervals at the compliance boundary and adjacent to each secure cell. Level 4 wells completed in saturated water producing zones shall be spaced at maximum 100 foot intervals. Adjacent sides of adjoining secure cells will be monitored by a single row of L-4 wells.

2. Level 4 wells shall be installed at the compliance boundary and around Cells 1 and 2 of the site development plan, and all background data collected, prior to receipt of wastes at the facility.

3. Additional Level 4 wells shall be installed around each future cell location in each following site development phase on a schedule which will allow collection of complete (4 quarters) background sample data from the wells, prior to receipt of wastes in any cell.

4. Upon discovery of water in a previously dry Level 4 well above the base of the well screen Highway 36 shall:

a. Except as provided for in "b" below, drill step-out borings at 100 foot spacings along the compliance boundary or adjacent to a secure cell on either side of the well. The step-out borings shall be left open for a minimum of 24 hours and backfilled according

to I.G. if dry. If groundwater is present then the boring(s) shall be completed as Level 4 monitoring wells. Step-out borings and/or Level 4 wells shall be completed in each of the four directions until dry conditions are verified in the step-out borings.

b. If Highway 36 believes that a condition other than groundwater flow caused the previously dry well to begin producing water, Highway 36 may submit a technical justification report for not performing the step-out borings and/or well completions required by "a" above. The technical justification report shall be 90 days of the finding water in the previously dry well.

c. If the Department does not accept the technical justification, the Department will notify Highway 36 of such in writing. Within 45 days of receipt of such notification Highway 36 shall begin the installation of step-out borings and/or monitor wells as described in "a" above.

B. Air rotary or hollow stem auger techniques shall be employed to drill Level 4 wells. If air rotary technique is utilized the procedure specified in II.B. shall be utilized.

C. PVC casing and screen may be used, as specified for Level 5 wells in section II.C., except:

1. Level 4 screens shall be 10 feet or less in length, centered at the weathered/unweathered bedrock interface.

## IV. LEVEL 3 WELLS - INSPECTION WELLS

A. The permittee shall install and maintain Inspection monitoring wells screened in saturated shallow weathered shale or overlying soils, and in saturated or dry sand zones.

1. One Level 3 well will be located in the approximate center of the L-3 Sand Unit between the northeast corner of proposed Secure Cell No. 3 and the southwest corner of porposed Secure Cell No. 5. The actual position of this well may be modified slightly as necessary to accommodate actual secure cell construction, placement of access roads, or other facility features. A second Level 3 well will be located in the center of the L-3 Sand Unit between Secure Cell No. 5 and Secure Cell No. 4. These strategically located Level 3 wells will allow detection of any fluids that may be present in the L-3 Sand Unit and will help to maximize the amount of useable information while minimizing redundant data collection. These Level 3 wells, in conjunction with the existing monitoring well network, and any future L-4A and L-4 wells associated with each new secure cell, will provide early release detection and protection of groundwater beneath the Facility.

2. Upon discovery of water in a previously dry Level 3 well above the base of the well screen Highway 36 shall:

   a. Except as provided for in "b" below, drill step-out borings at 100 foot spacings along the compliance boundary or adjacent to a secure cell on either side of the well. The step-out borings shall be left open for a minimum of 24 hours and backfilled according to I.G. if dry. If groundwater is present in Level 3 strata as defined above, then the boring(s) shall be completed as Level 3 monitoring wells. Step-out borings and/or Level 3 wells shall be completed in each of the four directions until either dry conditions are verified or Level 3 strata are no longer encountered in the step-out borings.

   b. If Highway 36 believes that a condition other than groundwater flow caused the previously dry well to begin producing water, Highway 36 may submit a technical justification report for wet performing the step-out borings and/or well completions required by "a" above. The technical justification report shall be submitted within 90 days of the finding water in the previously dry Level 3 well.

   c. If the Department does not accept the technical justification, the Department will notify Highway 36 of such in writing. Within 45 days of receipt of such notification Highway 36 shall begin the installation of step-out borings and/or Level 3 monitor wells as described in "a" above.

B. Level 3 sand strata and shallow perched zone well bores shall be continuous core drilled, sampled by split spoon or equivalent, then augured to complete the boring.

   1. Cores shall be bagged and stored, available for Department inspection.

C. PVC casing and screen material may be used, as specified in section II.C. as long as performance standards are met.

   1. Screened intervals for dry sand zone wells shall not extend above the sand, and not exceed ten feet in length, beginning one to two feet below the bottom of the sand lens and extending upward to penetrate into the sand.

   2. Screened intervals for shallow saturated zone wells shall not exceed ten feet in length, centered at the stable water table elevation determined immediately after drilling of the wells.

## V. LEVEL 6 WELLS - INSPECTION WELLS

A. The permittee shall install monitoring wells outside the Compliance Boundary in the natural drainages south, east and northwest of the Facility at the points nearest the Compliance Boundary where saturated conditions are determined to exist above unweathered shal.

B. Confirmation of the well locations shall be provided by dry borings no more than 100 feet uphill from the well.

1. Dry borings shall be drilled to the same bottom elevation as the well.

2. Dry borings shall be observed for at least 24 hours to determine whether any water has entered the hole.

C. Wells shall be located no more than 20 feet away from the center of the natural drainage channel.

1. The wells shall be provided with a minimum three foot stickup and protective casing.