DEPARTMENT OF THE AIR FORCE

HEADQUARTERS 27th FIGHTER WING (ACC)
CANNON AIR FORCE BASE, NEW MEXICO

W. P. Ard, Colonel, USAF
Commander, 27th Support Group
100 S DL Ingram Blvd Suite 200
Cannon AFB NM 88103

RECEIVED
JAN 9 1990

Ms. Barbara Hoditschek
New Mexico Environment Department
Hazardous and Radioactive Materials Bureau
2052 Galisteo St.
Santa Fe NM 87502

Dear Ms. Hoditschek

Enclosed please find our final post closure plan for Landfill 5, Cell 3 (it is labeled Draft Version 2). It incorporates all previous approved responses to the 28 Feb 95 Notice of Deficiencies. This letter and plan constitute our formal post-closure care permit application for Landfill 5, Cell 3.

If you have any questions, please call Mr. Sanford Hutsell, of my environmental flight, at (505) 784-4348.

Sincerely

W. P. ARD, Colonel, USAF
Commander, 27th Support Group

Attachment:
Final Post-Closure Care Plan

cc:
EPA Region VI (D. Neleigh)
NMED (C. Lundstrom)
NMED (R. Kern)
HQ ACC CES/ESVW w/o Atch (M. Calvert)

PARSONS ENGINEERING SCIENCE, INC.

406 West South Jordan Parkway, Suite 300 • South Jordan, Utah 84095 • (801) 572-5999 • Fax: (801) 572-9069

June 22, 1995

Mr. Sanford Hutsell
27 CES/CEV
111 Engineers Way
Cannon AFB, NM 88103

Re: Air Force Contract F33615-89-D-4003, Order 142; Period 02
Project Name: RCRA Plans and Permits, Cannon AFB, New Mexico

Dear Mr. Hutsell,

Parsons Engineering Science, Inc. is pleased to enclose 10 copies each of the report entitled *"Draft Version #2 Cannon Air Force Base Landfill 5, Cell 3 Post-Closure Plan"* per your request. This report represents our second and final deliverable item to you in accordance with the statement of work for the above-referenced task order.

Parsons Engineering Science looks forward to the opportunity to work with you in the future. If you have any questions pertaining to this submittal, please feel free to contact me at your convenience.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

Ingrid Deklau
Project Manager

LIBRARY

Draft Version #2
CANNON AIR FORCE BASE
LANDFILL 5, CELL 3
POST-CLOSURE PLAN

Command 27 FW
Cannon Air Force Base
100 South D.L. Ingram Blvd., Suite 100
Cannon AFB, New Mexico 88103-5214

June 22, 1995

Draft Version #2
LANDFILL POST-CLOSURE PLAN
Landfill 5, Cell 3
Cannon Air Force Base, New Mexico

Submitted By:

Parsons Engineering Science, Inc.
Salt Lake City, Utah

June 22, 1995

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LIST OF ACRONYMS

°F	degrees Fahrenheit
% R	Percent Recovery
ADA	Average depth in feet after purging
ADB	Average depth in feet before purging
AFB	Air Force Base
AICUZ	Air Installation Compatible Use Zone
ANOVA	Analysis of Variance
ANSI	American National Standards Institute
CAFB	Cannon Air Force Base
CEV	CAFB Environmental Management Office
CFR	Code of Federal Regulations
cm/sec	Centimeters per Second
COC	Chain of Custody
DOT	Department of Transportation
DW	Depth of Well
EPA	U.S. Environmental Protection Agency
eV	Electron Volt
EW	Elevation of top of well
ft	feet
gal	gallon(s)
GC/MS	Gas Chromatograph/Mass Spectrometer
gpm	gallons per minute
GW	Groundwater
HCl	Hydrochloric Acid
HDPE	High Density Polyethylene
HEPA	High Efficiency Particular Air (cartridges)
HMTC	Hazardous Materials Technical Center

LIST OF ACRONYMS (CONTINUED)

HNO_3	Nitric Acid
HPLC	High Performance Liquid Chromatography
IDLH	Immediately Dangerous to Life or Health
I/M	Inspection and Maintenance
kV	Kilovolt
LCS	Laboratory Control Samples
LEL	Lower Explosive Limit
MDL	Method Detection Limit
ml	milliliter
mph	miles per hour
MS	Matrix Spike
MSD	Matrix Spike Duplicate
MW	Monitoring Well
NGVD	National Geodetic Vertical Datum of 1929
NIST	National Institute for Standards and Testing
NMED	New Mexico Environment Department
NTU	Nephelometric Turbidity Units
O/M	Operation and Maintenance
OEHL	Occupational and Environmental Health Lab
OSHA	Occupational Safety and Health Administration
PCBs	Polychlorinated Biphenyls
PEL	Permissible Exposure Limit
PID	Photo Ionization Detector
ppm	parts per million
PQL	Practical Quantitation Limit
PV	Purge Volume
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance/Quality Control
RA	Regional Administrator

LIST OF ACRONYMS (CONTINUED)

RCRA	Resource Conservation and Recovery Act
RPD	Relative Percent Difference
SOP	Standard Operating Procedure
SSDL	Statistically Significant Detection Limit
SVOC	Semi-Volatile Organic Compound
TEGD	Technical Enforcement Guidance Document
TOC	Total Organic Carbon
TOX	Total Organic Halogen
USCOE	U.S. Army Corps of Engineers
VOC	Volatile Organic Compound
WV	Well Volume

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SECTION 1

INTRODUCTION

1.1 PURPOSE

This Post-Closure Plan for Cell 3 of Landfill 5, located at Cannon Air Force Base (CAFB), is designed to satisfy all federal and state regulatory requirements for such documents. Cell 3 is subject to closure requirements because it received hazardous waste after November 19, 1980, the effective date of the Resource Conservation and Recovery Act (RCRA). The post-closure care program will consist of an inspection and maintenance (I/M) program and a groundwater monitoring program. The inspection and maintenance program is designed to ensure the integrity of the protective cover. The groundwater monitoring program is designed to verify that there is no contaminant migration from the landfill into the underlying aquifer.

The following sections describe the I/M and groundwater monitoring program. Section 1 provides facility and site descriptions. Section 2 outlines performance standards and objectives of the various structures associated with closure of Cell 3, such as the geocomposite soil cap. Inspection and maintenance schedules and activities for these structures are included in Sections 3 and 4, respectively. A description of the proposed groundwater monitoring system and details of the groundwater monitoring program, including data evaluation and statistical procedures, are included in Sections 5 and 6, respectively. Procedures and techniques for sample collection, preservation, and shipment, as well as chain of custody, are described in Section 7. Analytical parameters, methods, and laboratory quality assurance procedures are discussed in Section 8, and Section 9 includes a health and safety plan for the groundwater monitoring program.

The post-closure care activities will continue for 30 years following the receipt of the final closure certification for Cell 3 of Landfill 5. The CAFB Environmental Management (CEV) Office is responsible for post-closure care.

1.2. FACILITY DESCRIPTION

This section provides a brief description of CAFB including the facility mission and location, and the physical geography, land use, and climate of the surrounding area.

1.2.1 Facility Mission

CAFB has been assigned to the Tactical Air Command (currently the Air Combat Command) since 1951. Since 1971, CAFB's primary mission has been to develop and maintain an F-11 Tactical Fighter Wing capable of day, night, and all-weather combat operations and to provide replacement training of combat aircrews for tactical organizations worldwide.

1.2.2 Facility Location

CAFB is located in southern Curry County, approximately seven miles west of the City of Clovis, New Mexico. The base is situated on approximately 4,320 acres of land located south of the intersection of U.S. Highway 84/60 and New Mexico Highway 277. The vicinity map of

CAFB is shown in Figure 1.1, and a location map of Landfill 5 is presented in Figure 1.2. Base related employment totals approximately 4,900 positions, which include approximately 4,000 uniformed military personnel.

1.2.3 Physical Geography

CAFB is located in the Southern High Plains region of the Great Plains physiographic province. This region is typified by smooth and gently sloping, undulating surface topography. In the vicinity of CAFB, elevations range from 4,250 feet in the southwest corner of the base to 4,350 feet above National Geodetic Vertical Datum of 1929 (NGVD) at the northwest corner of the base. The most prominent geomorphic features in the vicinity of CAFB are blowouts and broad, widely spaced valleys. Blowouts are broad shallow depressions which form as the result of soil erosion by wind.

During periods of rainfall, runoff collects in blowouts to form ephemeral playa lakes. Playas have no external surface drainage. Water is lost by evapotranspiration and percolation through the soil; without subsequent precipitation, playa lakes persist for only a few days or weeks. Three playas are located within the base boundaries. A playa located near the southwest corner of CAFB collects the majority of the storm water runoff from the base.

Stream valleys in the region tend to be fairly broad and widely spaced. Streams are ephemeral and drainages are poorly developed. No streams exist on or near CAFB.

1.2.4 Land Use

Land use is primarily agricultural within Curry County. As of 1992, total land area in the county was 897,000 acres with 837,200 designated as farm land. Lands surrounding CAFB are classified as irrigated farm land with principal crops including corn, grain, sorghum, wheat, barley, oats, alfalfa, cotton, and various vegetables. Cattle ranching and dairy farming occur throughout the county.

The use of CAFB as a military installation is highly specialized and land use cannot be significantly altered (e.g., converted to private, commercial, or residential use) without the approval of the U.S. Congress and the Secretary of Defense. Currently, no land use or zoning controls restrict the type or amount of construction in the proximity of CAFB. However, the U.S. Air Force has designated Air Installation Compatible Use Zones (AICUZs) around CAFB and provides recommendations for compatible uses in areas subject to noise and accident hazards. Future land use is not expected to differ significantly from current land use practices (Radian, 1993).

1.2.5 Climate

The climate of east-central New Mexico is classified as tropical semi-arid. Average monthly temperatures range from a January low of 39 degrees Fahrenheit (°F) to a July high of 78°F. Extreme daily temperatures range from -11°F to 106°F. Average monthly precipitation ranges from 0.4 inches in winter to 2.7 inches in July. Mean annual precipitation is approximately 15 inches. Prevailing winds are from the west at an average of 8 miles per hour (mph) (Woodward Clyde, 1992).

FIGURE 1.1
VICINITY MAP
CANNON AFB, NEW MEXICO

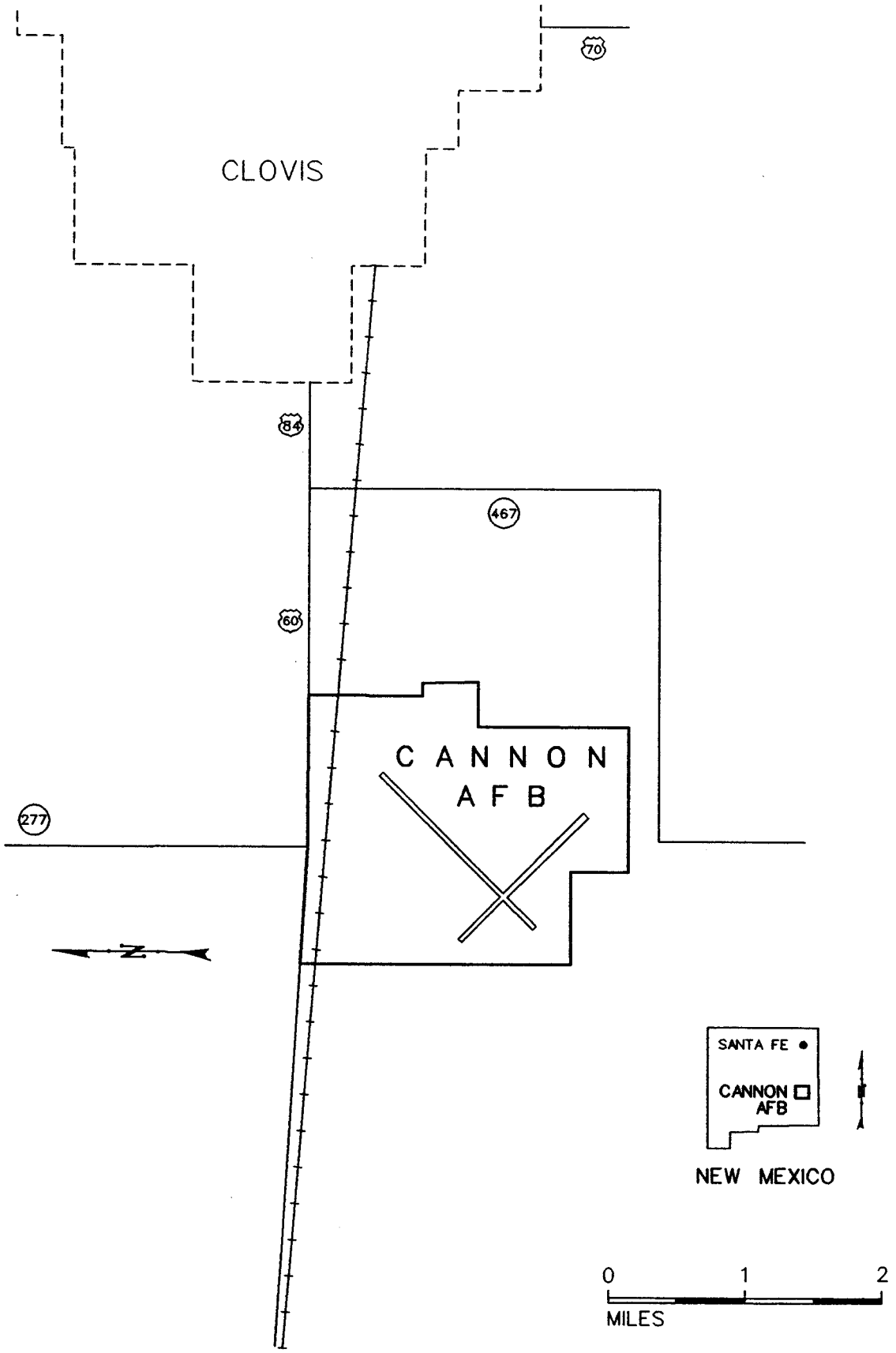

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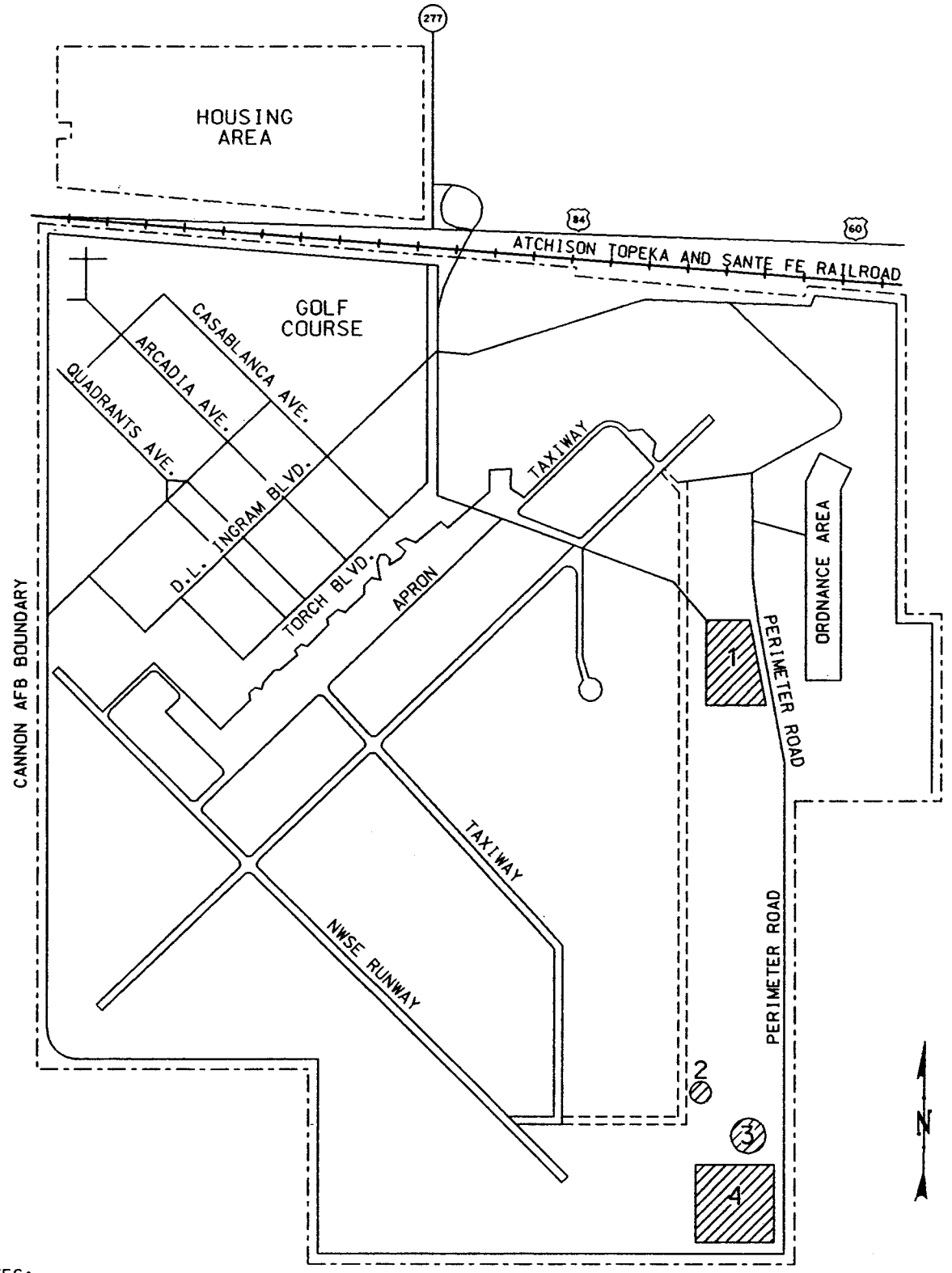
FIGURE 1.2
LOCATION MAP OF LANDFILL 5
CANNON AFB, NEW MEXICO



NOTES:

1. WASTEWATER LAGOONS
2. FIRE DEPARTMENT TRAINING AREA #3
3. FIRE DEPARTMENT TRAINING AREA #4
4. LANDFILL NO. 5

0 1000 2000
SCALE IN FEET

Adapted from Woodward-Clyde

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1.3 LANDFILL 5 DESCRIPTION

This section provides a summary of the site history including site location, background, geology, and hydrogeology.

1.3.1 Location

Landfill 5 occupies about 40 acres in the southeastern part of CAFB. It is approximately 200 feet from the boundary fence of the base and bordered on the north by Fire Training Area No. 4. Cell 3 is part of Landfill 5 and is located in the eastern portion of the landfill, as shown in Figure 1.3. The ground surface elevation in the vicinity of the landfill is approximately 4,263 feet above NGVD.

1.3.2 Background

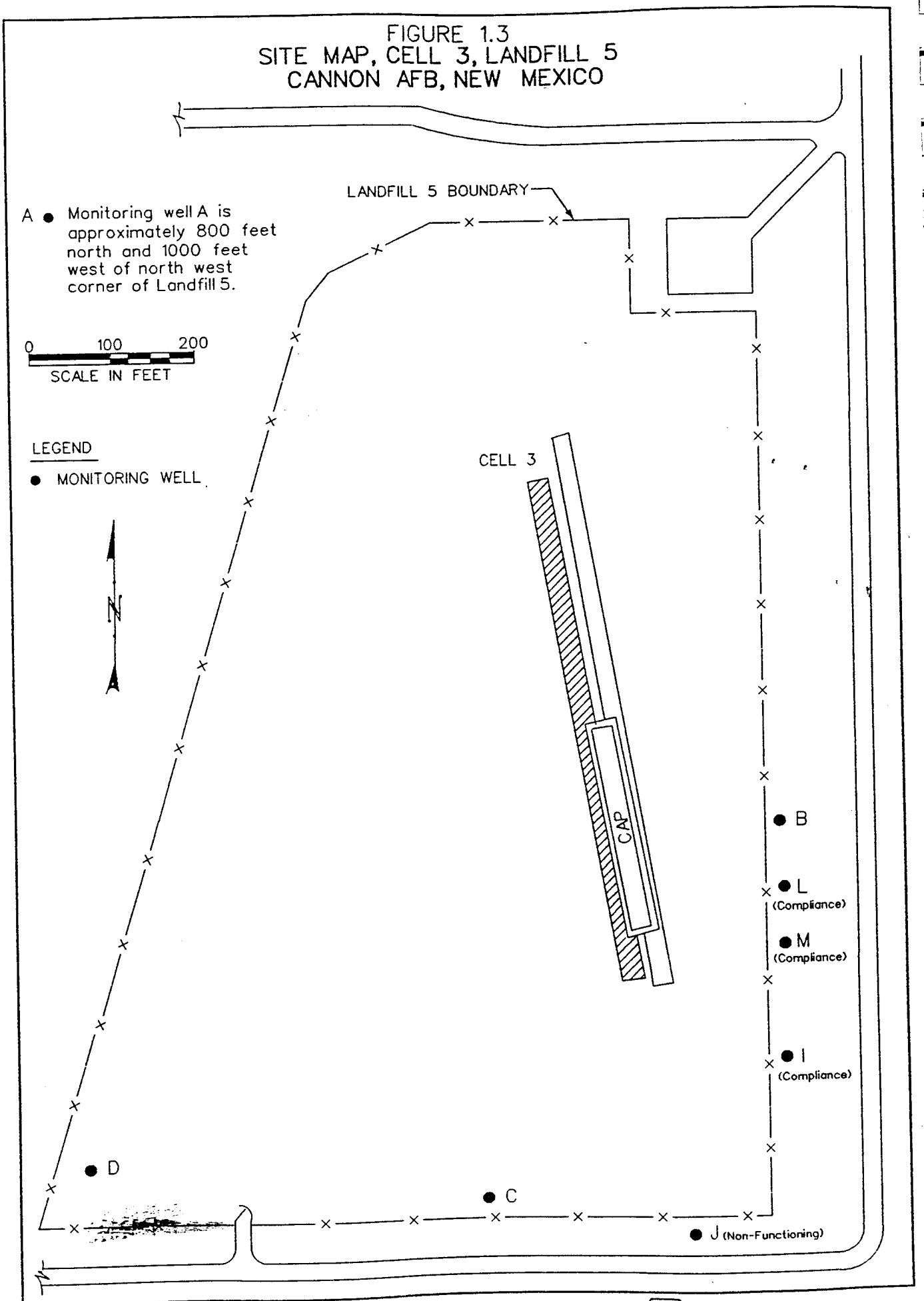
Landfill 5 is currently inactive and was in use since 1968, however the section of the landfill containing Cell 3 was closed to further dumping in 1983. From 1972 until the section was closed, unburned wastes were buried there. This closed section has an estimated 19 covered trenches.

Cell 3 is RCRA regulated because it received hazardous waste after the effective date of RCRA in 1980. While Cell 3 was in use, CAFB started disposing of hazardous wastes off base at permitted facilities and ceased on-site disposal. Therefore, cells constructed after Cell 3 should not have received any hazardous waste.

Waste materials received at Cell 3 may have included domestic solid waste, waste oils and solvents, paint, paint removers and thinners, pesticide containers, and various empty cans and drums. Until mid-1981, approximately 5 to 10 drums per month of waste oils and solvents were disposed (Woodward Clyde, 1992). Currently Landfill 5 is inactive and serves only as a storage area for investigation derived wastes from various projects around the base.

Closure of Cell 3 consisted of placing an impermeable cap over the cell, separate fencing for security, and a series of monitoring wells to detect contaminant migration in accordance with New Mexico Environment Department (NMED) and U. S. Environmental Protection Agency (EPA) requirements. The first round of wells was set and sampled in 1985. Additional wells have been set and sampling has taken place periodically since 1985. There has been no indication of significant groundwater contamination or degradation of groundwater quality in any of the wells that could be attributed to Cell 3 of Landfill 5.

A clay and flexible membrane cap was constructed over a portion of Cell 3 in 1989. Following completion of the cap it became apparent that the cap did not adequately cover Cell 3. Landfill 5 was investigated in March 1991 to determine the exact location of all cells within the landfill. The results indicated that the cells are much longer than the CAFB Landfill Management Plan, dated 1977, stated. A more detailed excavation of Cell 3 was conducted from 14-17 January 1992. The results indicated that the cell is approximately 800 feet long and 45 feet wide. A geocomposite soil cap and vegetative cover has since been completed over the entire area of Cell 3.



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1.3.3 Geology

The near-surface stratigraphic units of interest at CAFB include the Ogallala Formation of Tertiary age which lies as an uncomformity over the Dockum Group "redbeds" of Triassic age as shown in Figure 1.4.

The Dockum group consists of three formations. The stratigraphically lowest unit is the Santa Rosa Sandstone. Overlying the Santa Rosa Sandstone are the Chinle and Redonda formations. The Chinle and Redonda Formations are composed mainly of red shales with lesser interbedded sands and are known locally as "redbeds." The top of the Dockum Group is marked by an erosional unconformity having relief of up to several hundred feet (Woodward Clyde, 1992).

The Ogallala Formation was laid down by stream and overbank deposits formed within coalescing alluvial fans. These fans form a broad bajada along the eastern flank of the Rocky Mountains. As is typical of alluvial deposits, Ogallala internal stratigraphy varies vertically and horizontally over short distances.

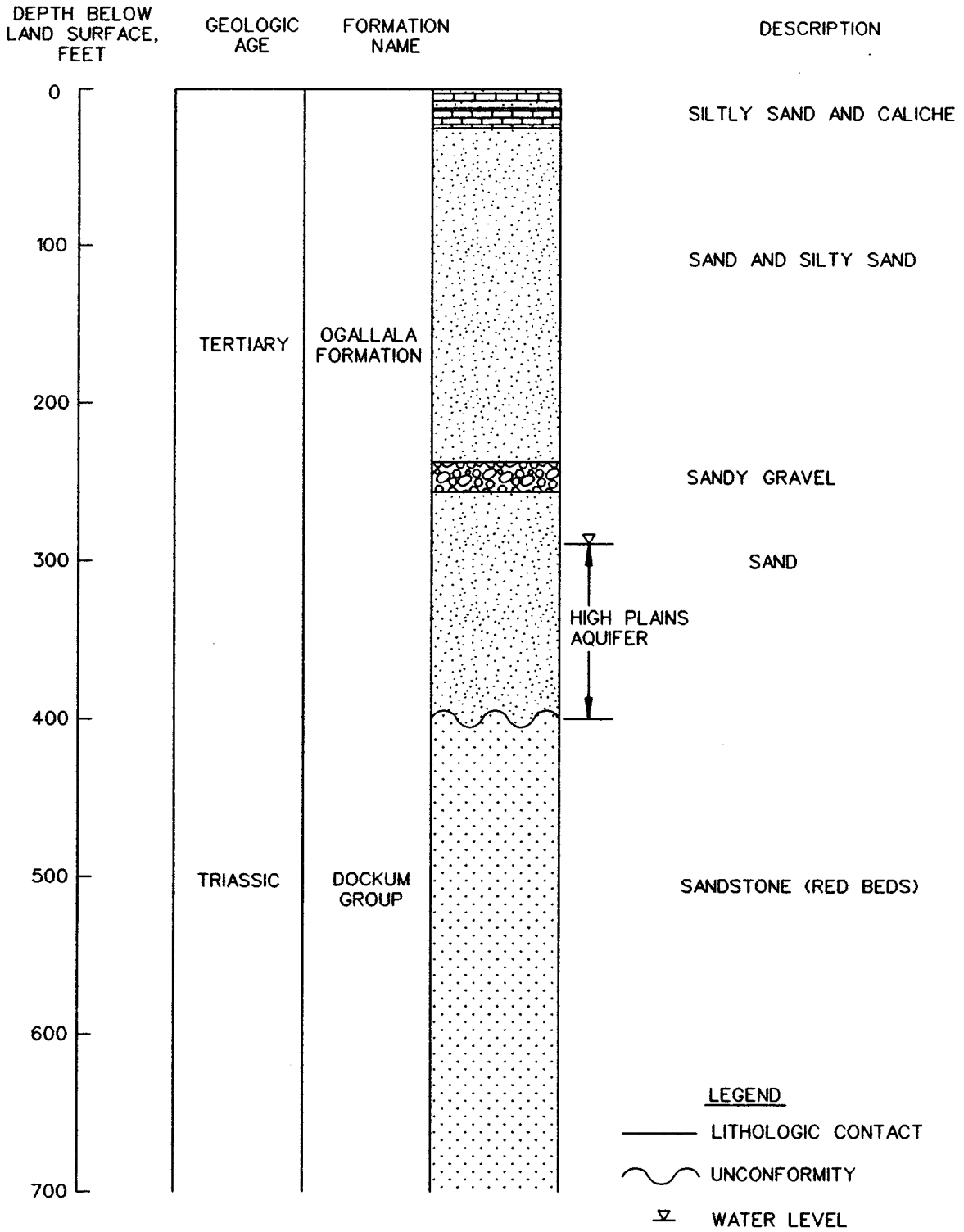
Boring logs from the installation of monitoring well (MW)-A, MW-B, MW-C, and MW-D were used to construct hydrogeologic cross sections in the vicinity of Landfill 5 as displayed in Figures 1.5, 1.6, and 1.7. These figures indicate that the landfill is underlain by Ogallala fluvial deposits consisting primarily of well to moderately sorted sand and moderately to poorly sorted gravels, with scattered, relatively thin (5 to 25 feet thick) layers of silt, clay, and caliche. Driller's logs obtained from CAFB indicate that the Ogallala Formation varies from 360 feet to 415 feet in thickness. The Ogallala dips gently and monoclinally to the southeast in the vicinity of CAFB.

Design and construction details are included in Appendix A for MW-A, MW-I, MW-L, and MW-M. These borings indicate that the Ogallala Formation exhibits variability both near the surface and at depth of saturation.

Near the surface, a series of silt, silty sand, and sand layers have been modified by the formation of layers of caliche to approximately 65 feet. Below this layer, the Ogallala is predominantly composed of unconsolidated sands, but it does contain some minor silt and clay units and some consistent gravel layers. Overall, these sands are non-calcareous, however, a variable degree of calcite cementation was evident in most borings. The thickness of this unit ranges from approximately 120 to 165 feet.

Resting below the sandy unit are relatively thin clay and silt deposits ranging from approximately 5 to 25 feet in thickness. A relatively thin (10 to 30 feet thick) deposit of poorly sorted, unconsolidated sands and gravels follows, and lies above a deposit of medium- to coarse-grained, slightly silty sands ranging from 100 to 115 feet in thickness. The lowermost deposit consists of coarse-grained, moderately to well cemented sands and sandy, well cemented gravels. The thickness of this unit is unknown because the unit was not fully penetrated during drilling.

FIGURE 1.4
GENERALIZED GEOLOGIC COLUMN
CANNON AFB, NEW MEXICO



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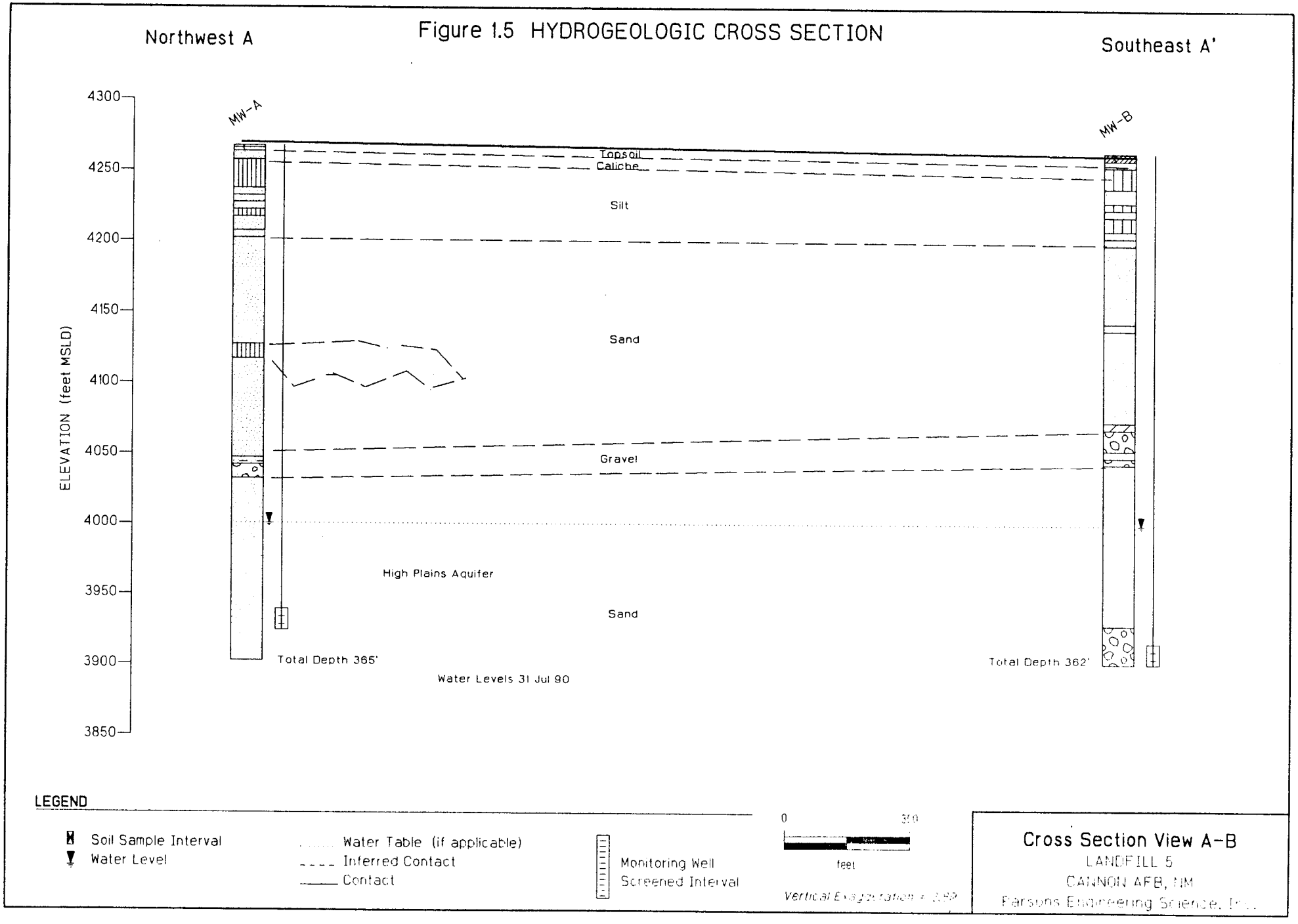


Figure 1.5 HYDROGEOLOGIC CROSS SECTION
Northwest A
Southeast A'
MW-A
MW-B
ELEVATION (feet MSLD)
4300
4250
4200
4150
4100
4050
4000
3950
3900
3850
Topsoil
Caliche
Silt
Sand
Gravel
High Plains Aquifer
Sand
Total Depth 365'
Total Depth 362'
Water Levels 31 Jul 90
LEGEND
Soil Sample Interval
Water Level
Water Table (if applicable)
Inferred Contact
Contact
Monitoring Well
Screened Interval
0
30
feet
Vertical Exaggeration = 2.89
Cross Section View A-B
LANDFILL 5
CANNON AFB, NM
Parsons Engineering Science, Inc.

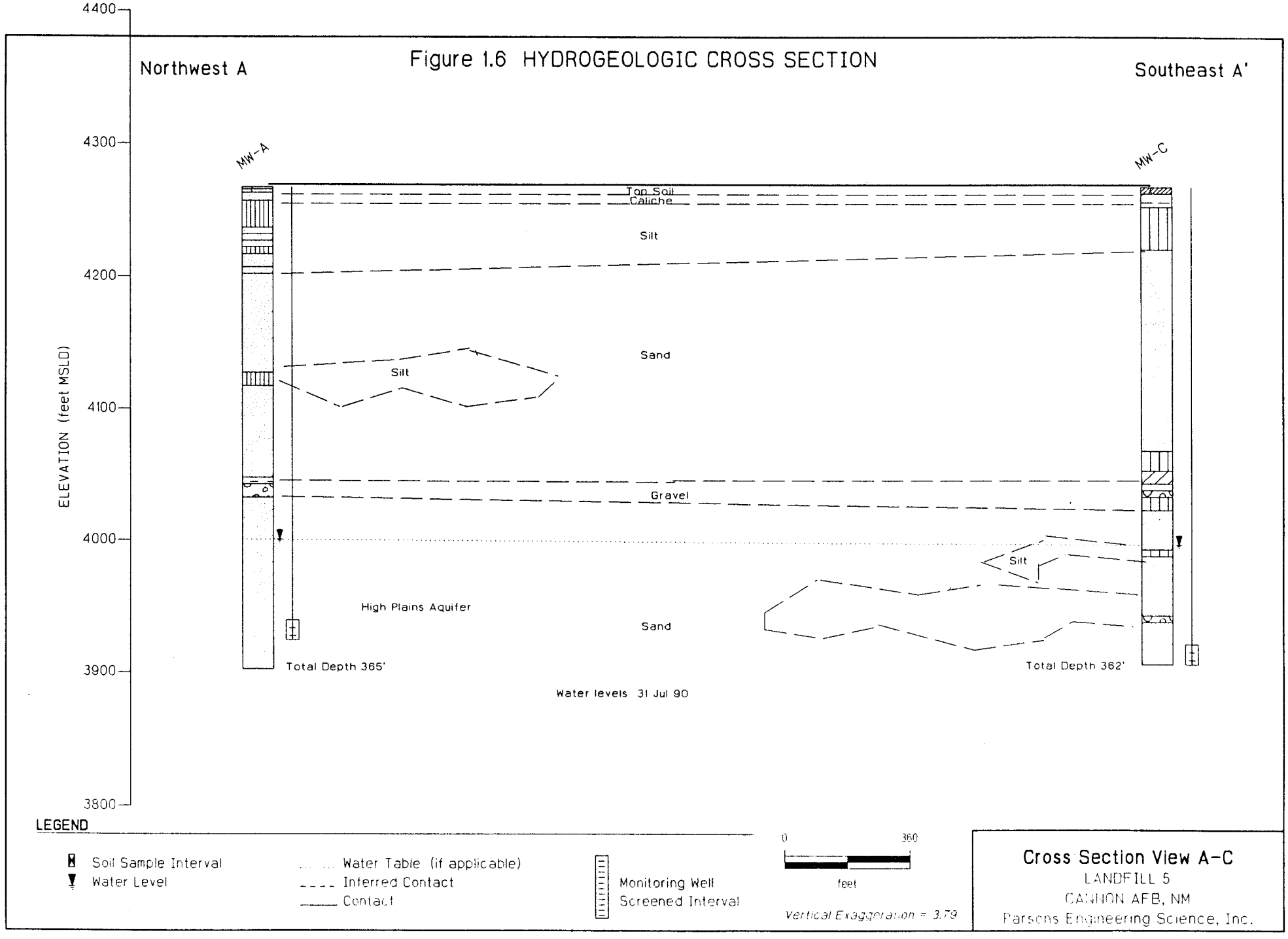


Figure 1.6 HYDROGEOLOGIC CROSS SECTION
Northwest A
Southeast A'
MW-A
MW-C
ELEVATION (feet MSLD)
4400
4300
4200
4100
4000
3900
3800
Top Soil
Caliche
Silt
Sand
Silt
Gravel
Silt
High Plains Aquifer
Sand
Total Depth 365'
Total Depth 362'
Water levels 31 Jul 90
LEGEND
Soil Sample Interval
Water Level
Water Table (if applicable)
Inferred Contact
Contact
Monitoring Well
Screened Interval
0
360
feet
Vertical Exaggeration = 3.79
Cross Section View A-C
LANDFILL 5
CANNON AFB, NM
Parsons Engineering Science, Inc.

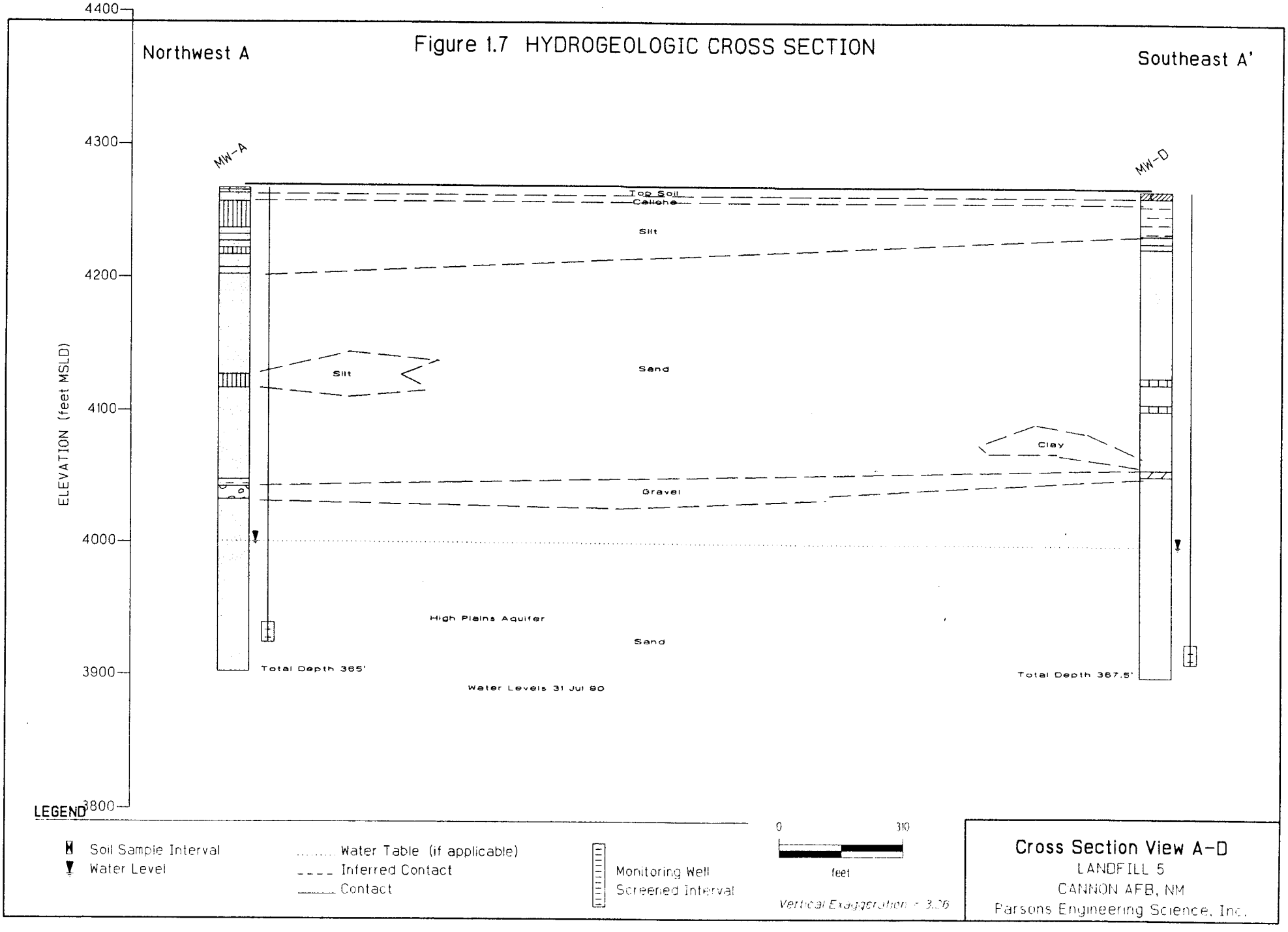


Figure 1.7 HYDROGEOLOGIC CROSS SECTION
Northwest A
Southeast A'
ELEVATION (feet MSLD)
4400
4300
4200
4100
4000
3900
3800
MW-A
MW-D
Top Soil
Caliche
Silt
Silt
Sand
Clay
Gravel
High Plains Aquifer
Sand
Total Depth 365'
Total Depth 367.5'
Water Levels 31 Jul 90
LEGEND
Soil Sample Interval
Water Level
Water Table (if applicable)
Inferred Contact
Contact
Monitoring Well
Screened Interval
0
310
feet
Vertical Exaggeration = 3.26
Cross Section View A-D
LANDFILL 5
CANNON AFB, NM
Parsons Engineering Science, Inc.

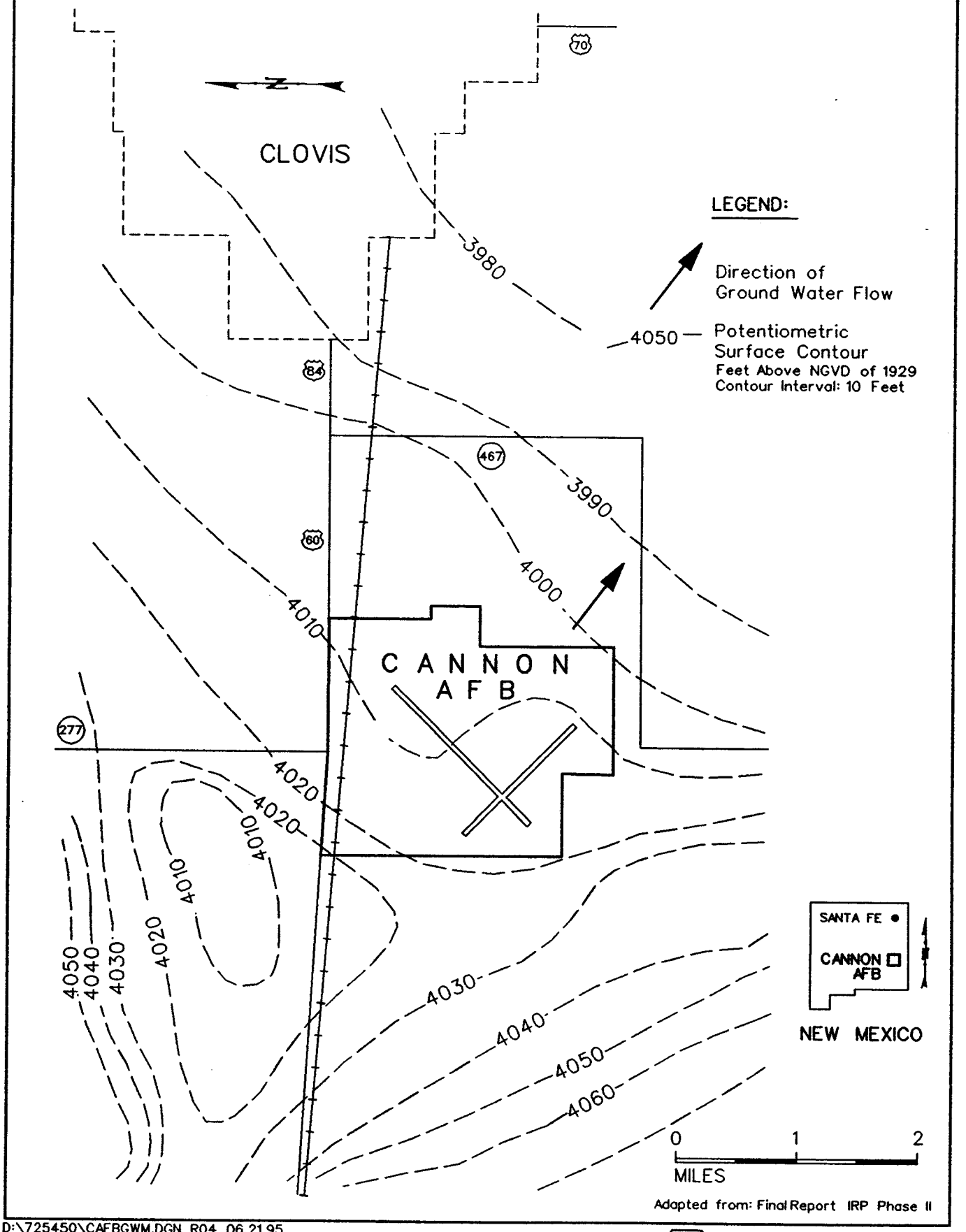
1.3.4 Hydrogeology

The site is underlain by the Ogallala Formation, which contains the High Plains aquifer of the High Plains regional groundwater system. The High Plains groundwater system extends from New Mexico to South Dakota and is mostly contained in the Ogallala Formation. Regional groundwater flow is to the southeast, as shown in Figure 1.8.

The lower portion of the Ogallala Formation, known as the High Plains aquifer, is the primary regional aquifer in the site vicinity for both potable and irrigation water. Throughout east central New Mexico, the underlying Dockum Group redbeds serve as the aquifer's basal confining layer. The High Plains aquifer is a water table, or unconfined aquifer, which locally may be semi-confined. The High Plains aquifer has a southeasterly regional gradient of about $2x10^{-3}$ to $3x10^{-3}$ (Woodward-Clyde, 1992).

Table 1.1 includes water level data for MW-A, MW-B, MW-C, MW-D, MW-I, MW-L, and MW-M. Utilizing static water level measurements, groundwater potentiometric surface contour maps were constructed as shown in Figures 1.9 - 1.16. Calculations of the three point problems for each figure are included under the last tab in Appendix A. The potentiometric surface maps indicate that the direction of groundwater flow is relatively uniform to the southeast. The hydraulic gradient ranged from 1.95×10^{-3} to 2.92×10^{-3}. Seasonal variation in groundwater elevation over time is illustrated in groundwater elevation graphs included in Figures 1.17 - 1.23 for each monitoring well.

FIGURE 1.8
REGIONAL GROUNDWATER SURFACE - JANUARY-FEBRUARY 1982
CANNON AFB, NEW MEXICO



Adapted from: Final Report IRP Phase II

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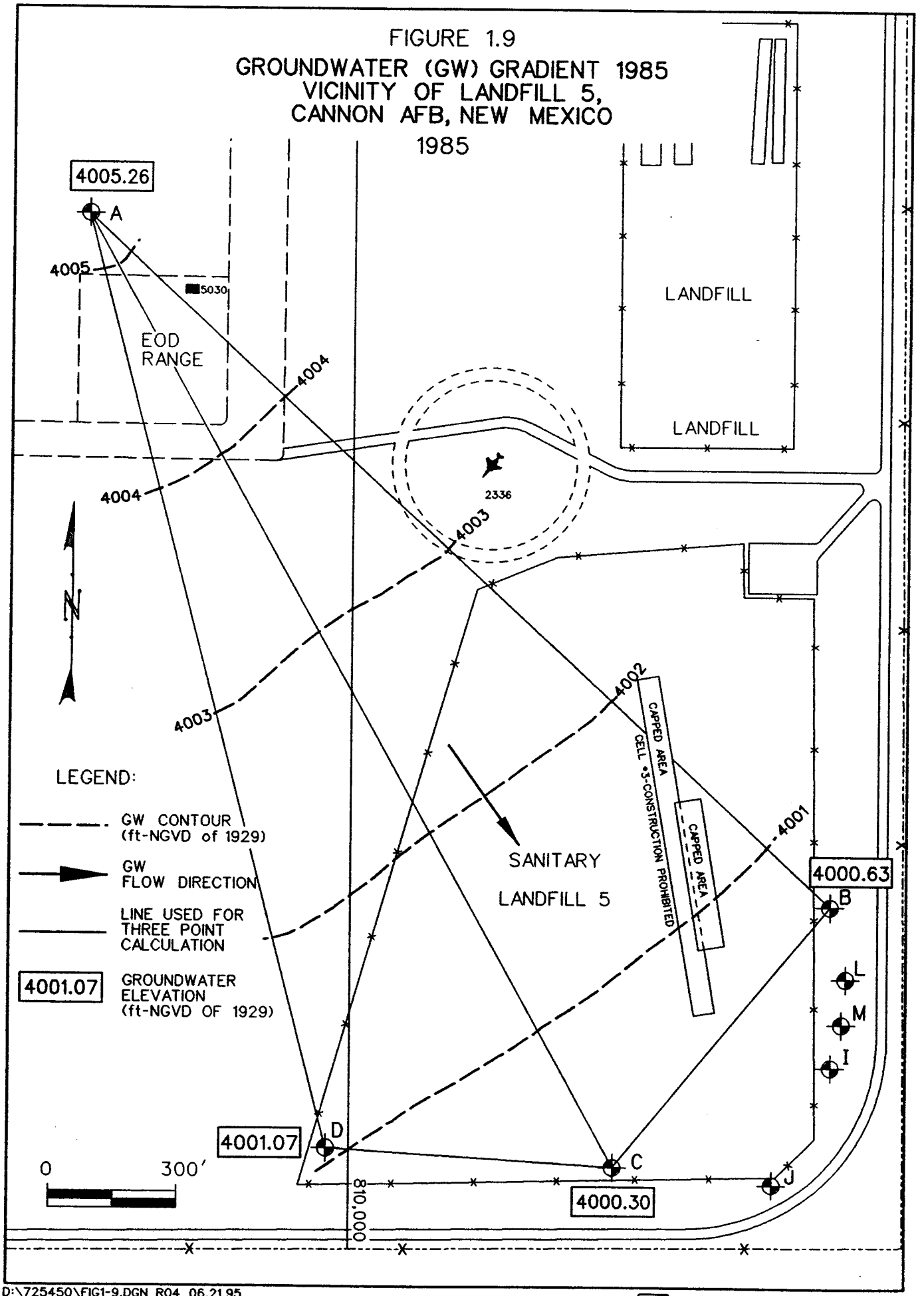
TABLE 1.1
Water Level Data for Landfill 5, 1985-1993
Cannon AFB, New Mexico

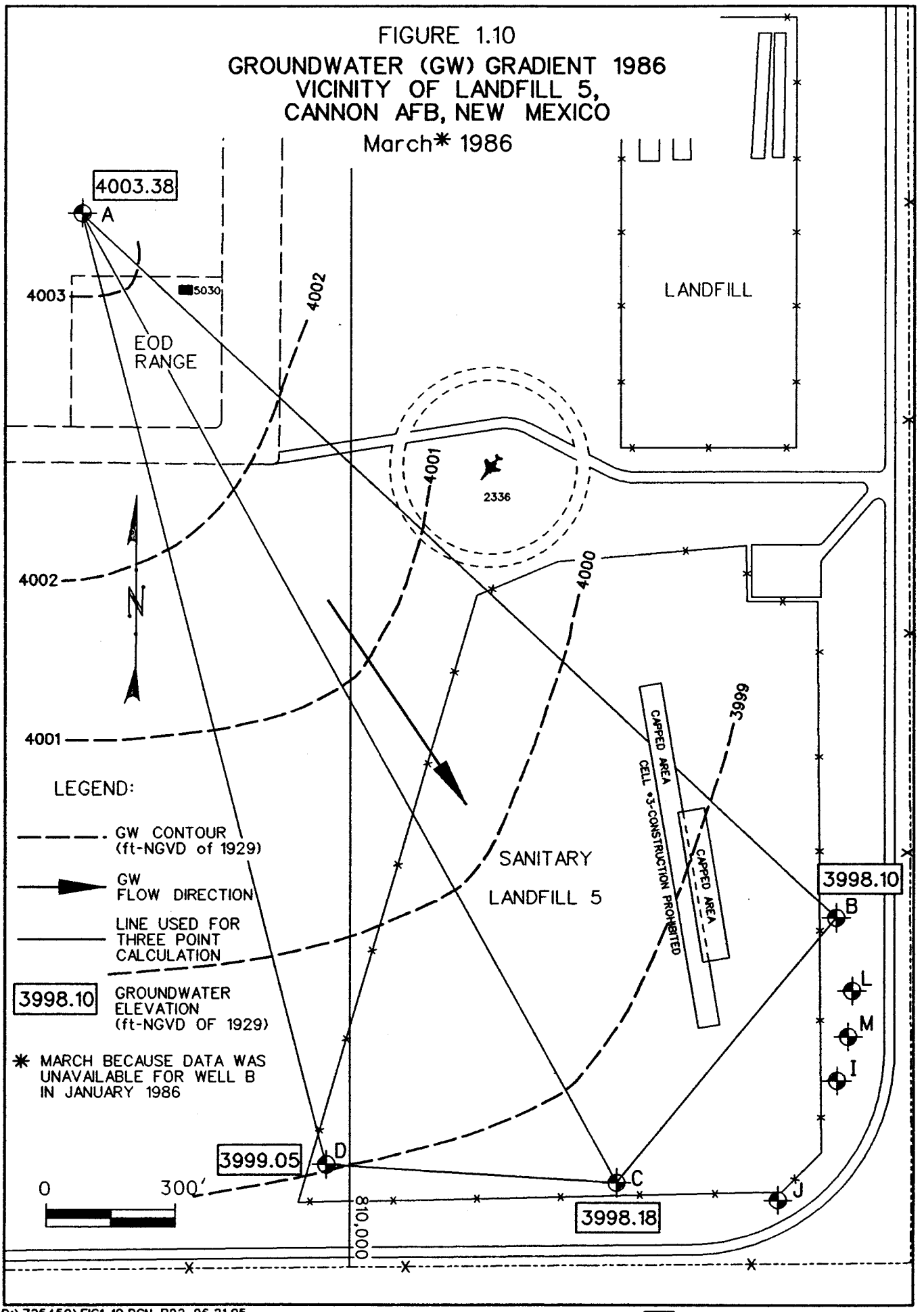
	Well A		Well B		Well C		Well D		Well I		Well L	Well M
Date Measured	Depth to Water (ft)	Water Elevation (ft NGVD)	Depth to Water (ft)	Water Elevation (ft NGVD)	Depth to Water (ft)	Water Elevation (ft NGVD)	Depth to Water (ft)	Water Elevation (ft NGVD)	Depth to Water (ft)	Water Elevation (ft NGVD)	Water Elevation (ft NGVD)	Water Elevation (ft NGVD)
25-Jan-85	262.20	4005.26	265.41	4000.63	267.60	4000.30	264.83	4001.07				
22-Apr-85	262.50	4004.96	265.15	4000.89	267.32	4000.58	264.40	4001.50				
6-Aug-85	262.72	4004.74	265.72	4000.32	367.87	4000.03	265.16	4000.74				
25-Sep-85	264.08	4003.38	267.53	3998.51	271.83	3996.07	264.81	4001.09				
8-Nov-85	263.04	4004.42	267.85	3998.19	269.78	3998.12	266.50	3999.40				
3-Dec-85	263.52	4003.94	267.60	3998.44	269.61	3998.29	266.63	3999.27				
11-Dec-85	263.69	4003.77	267.85	3998.19	269.78	3998.12	266.72	3999.18				
15-Jan-86	263.92	4003.54			269.92	3997.98	266.82	3999.08				
4-Mar-86	264.08	4003.38	267.94	3998.10	269.72	3998.18	266.85	3999.05				
8-Jul-86	263.54	4003.92	267.43	3998.61	269.35	3998.55	266.28	3999.62				
26-Jan-87	263.54	4004.42	266.93	3999.11	269.01	3998.89	266.09	3999.81				
21-Jul-87	263.04	4004.03	267.62	3998.42	270.05	3997.85	266.44	3999.46				
24-Jan-88	263.43	4004.31	266.58	3999.46	268.83	3999.07	265.25	4000.65	Constructed in 8/88			
31-Aug-88									266.50	3995.86		
25-Oct-88	263.15	4003.45	267.96	3998.08								
6-Dec-89	269.66	4003.02	267.71	3998.33	269.35	3998.55	266.13	3999.77	265.31	3997.15		
30-Jan-90	264.44	4003.61	266.83	3999.21	268.71	3999.19	265.92	3999.98	265.21	3998.00		
31-Jul-90	263.98	4003.48	269.04	3997.00	271.40	3996.50	268.02	3997.88	266.05	3996.31		
Jun-92		4000.71								3995.42	3994.4	3994.88
Sep-92		4000.45								3994.96	3993.93	3994.52
Feb-93		4000.01								3994.17	3993.72	3994.48
Apr-93		4001.39								3996.52	3995.14	3995.42

CAFBPOST



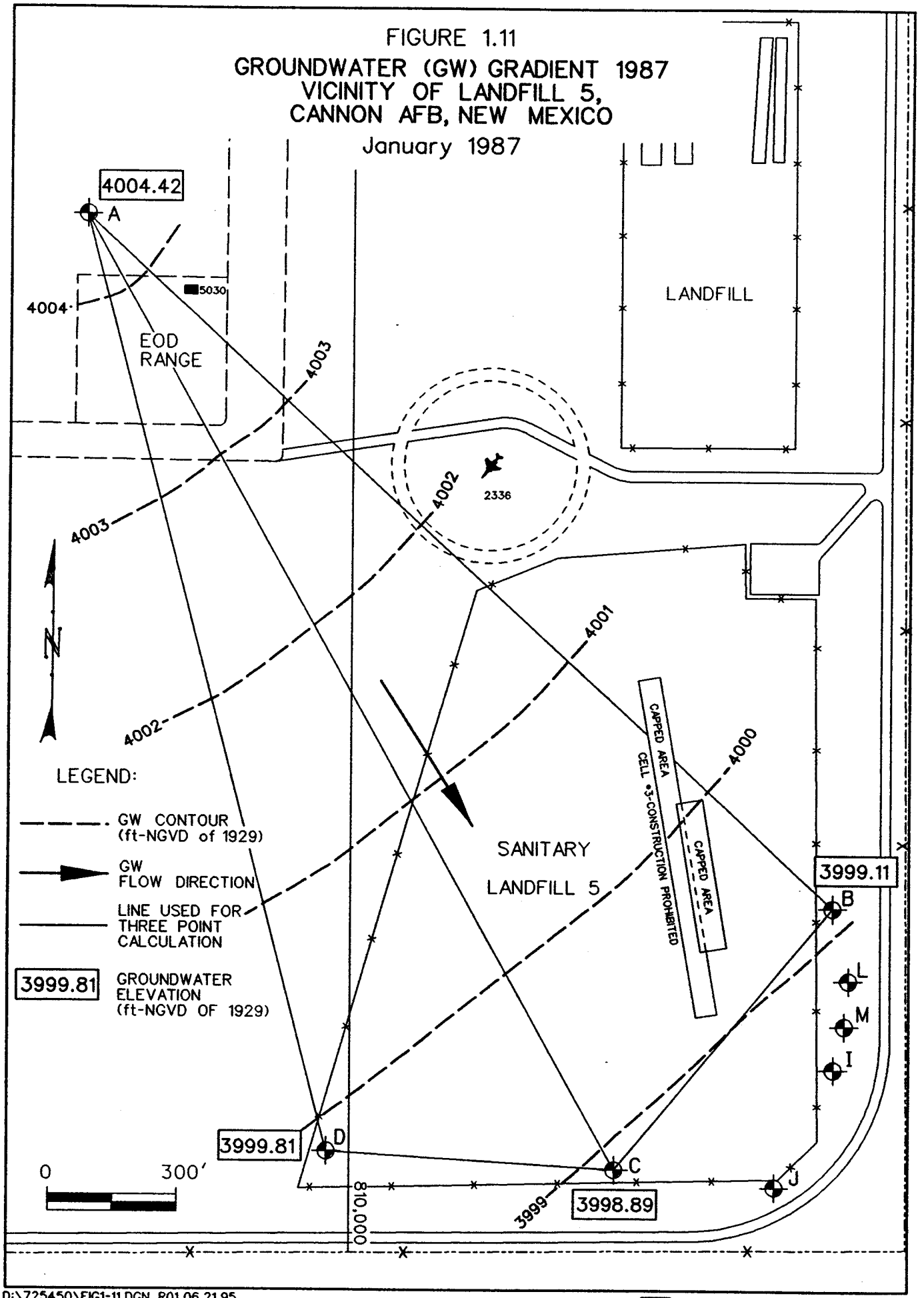
D:\725450\FIG1-9.DGN R04 06.21.95

PARSONS ENGINEERING SCIENCE, INC.



D:\725450\FIG1-10.DGN R02 06.21.95

PARSONS ENGINEERING SCIENCE, INC.



D:\725450\FIG1-11.DGN R01 06.21.95

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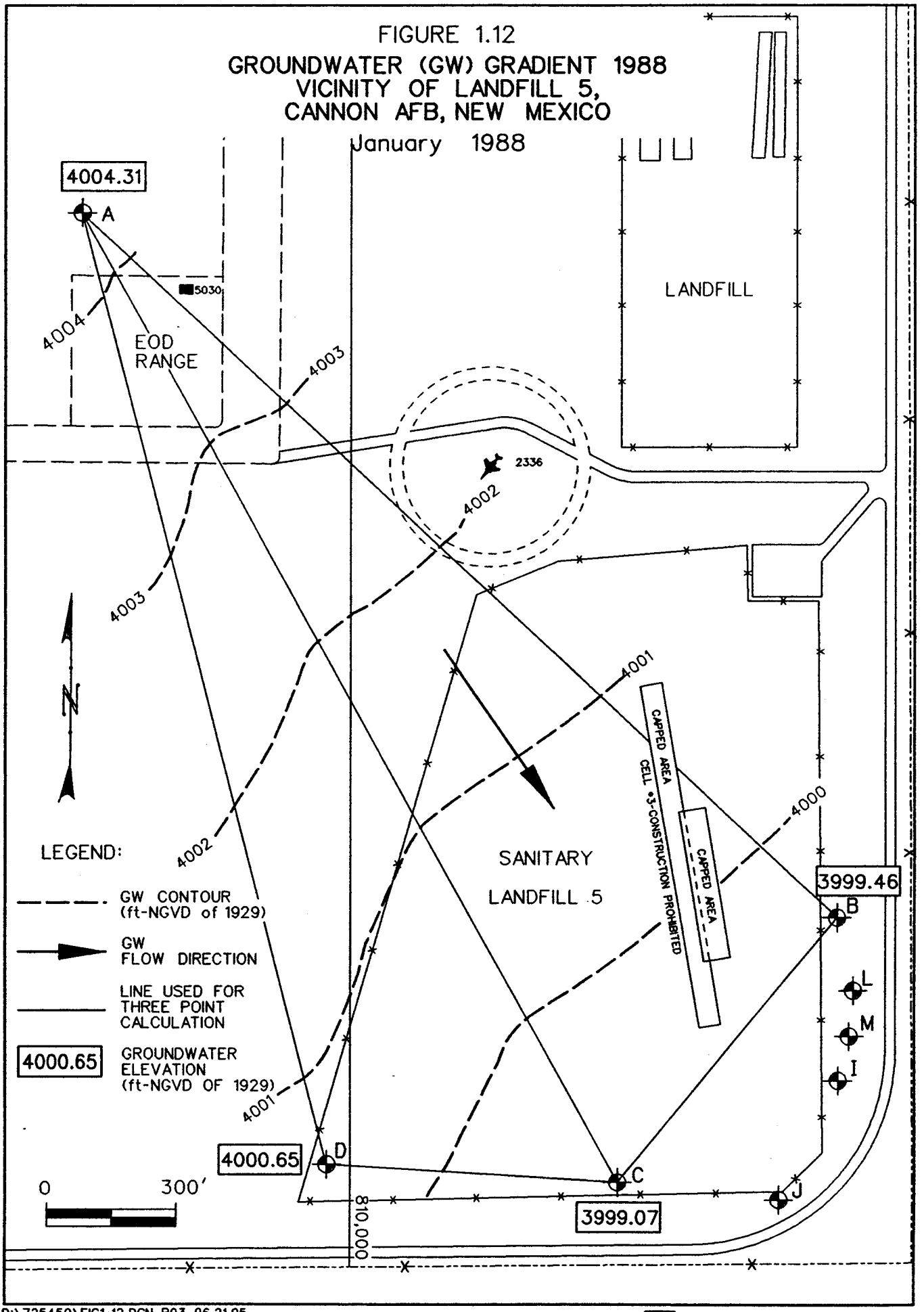
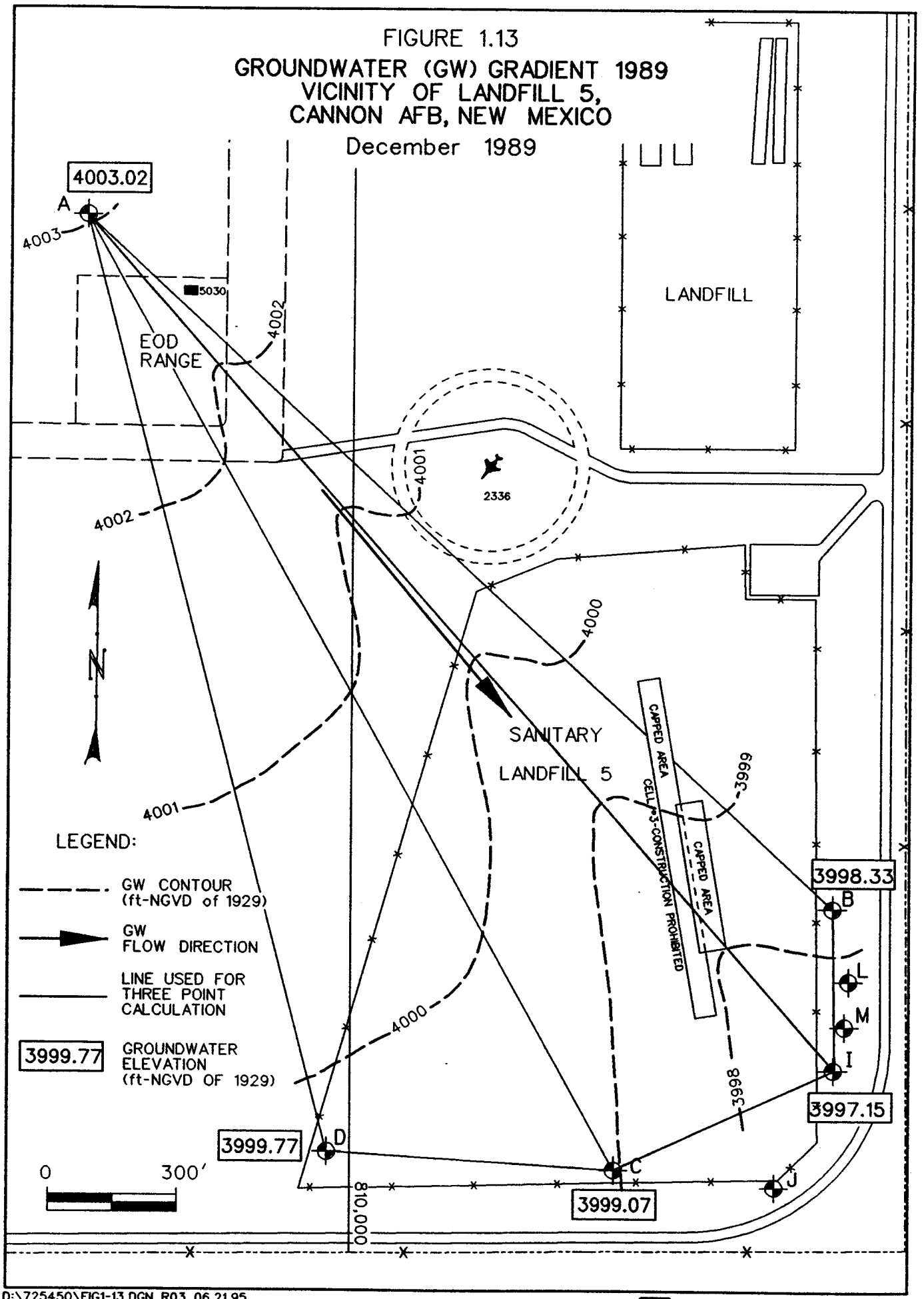


D:\725450\FIG1-12.DGN R03 06.21.95

PARSONS ENGINEERING SCIENCE, INC.



D:\725450\FIG1-13.DGN R03 06.21.95

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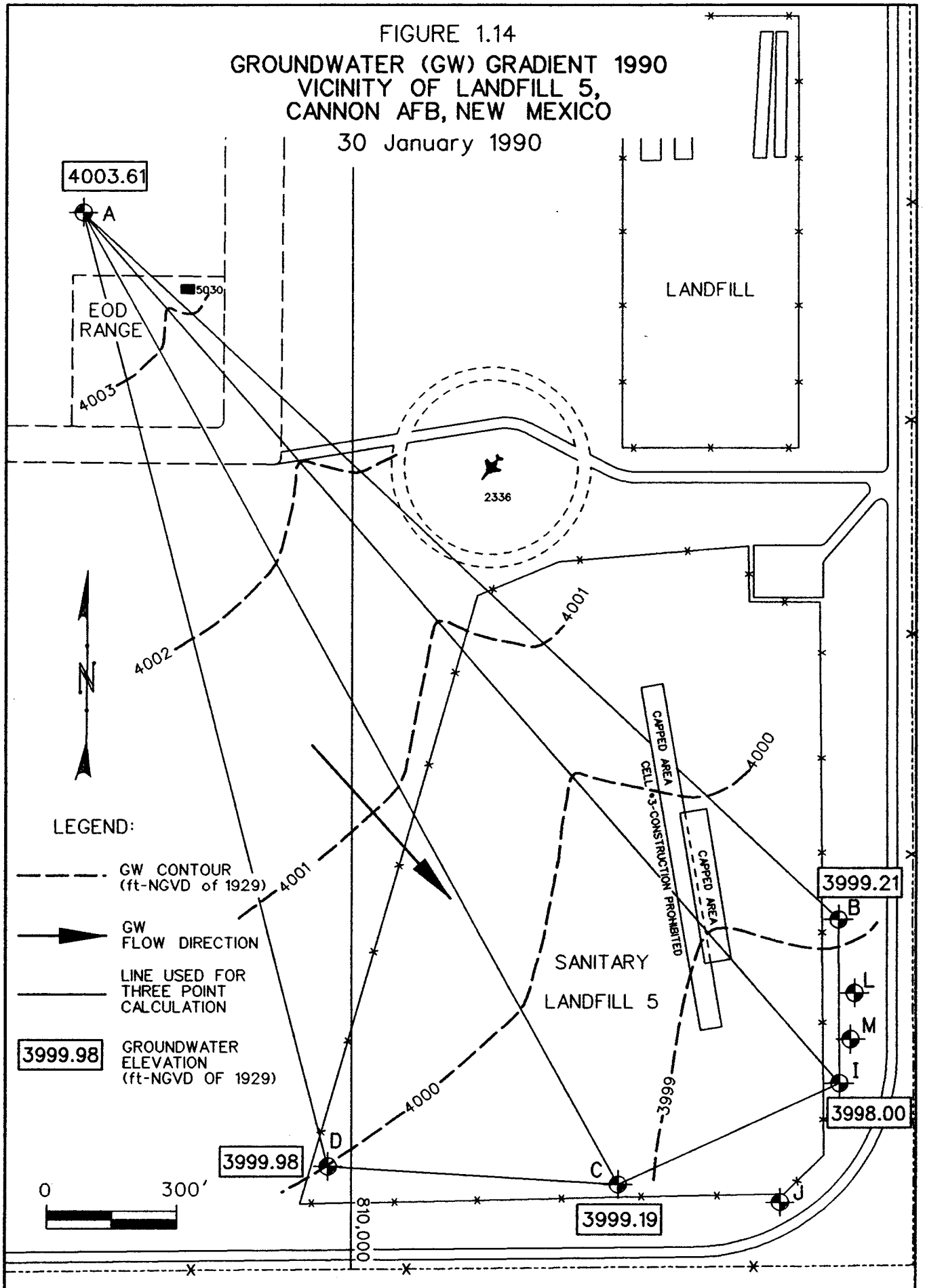

D:\725450\FIG1-14.DGN R03 06.21.95

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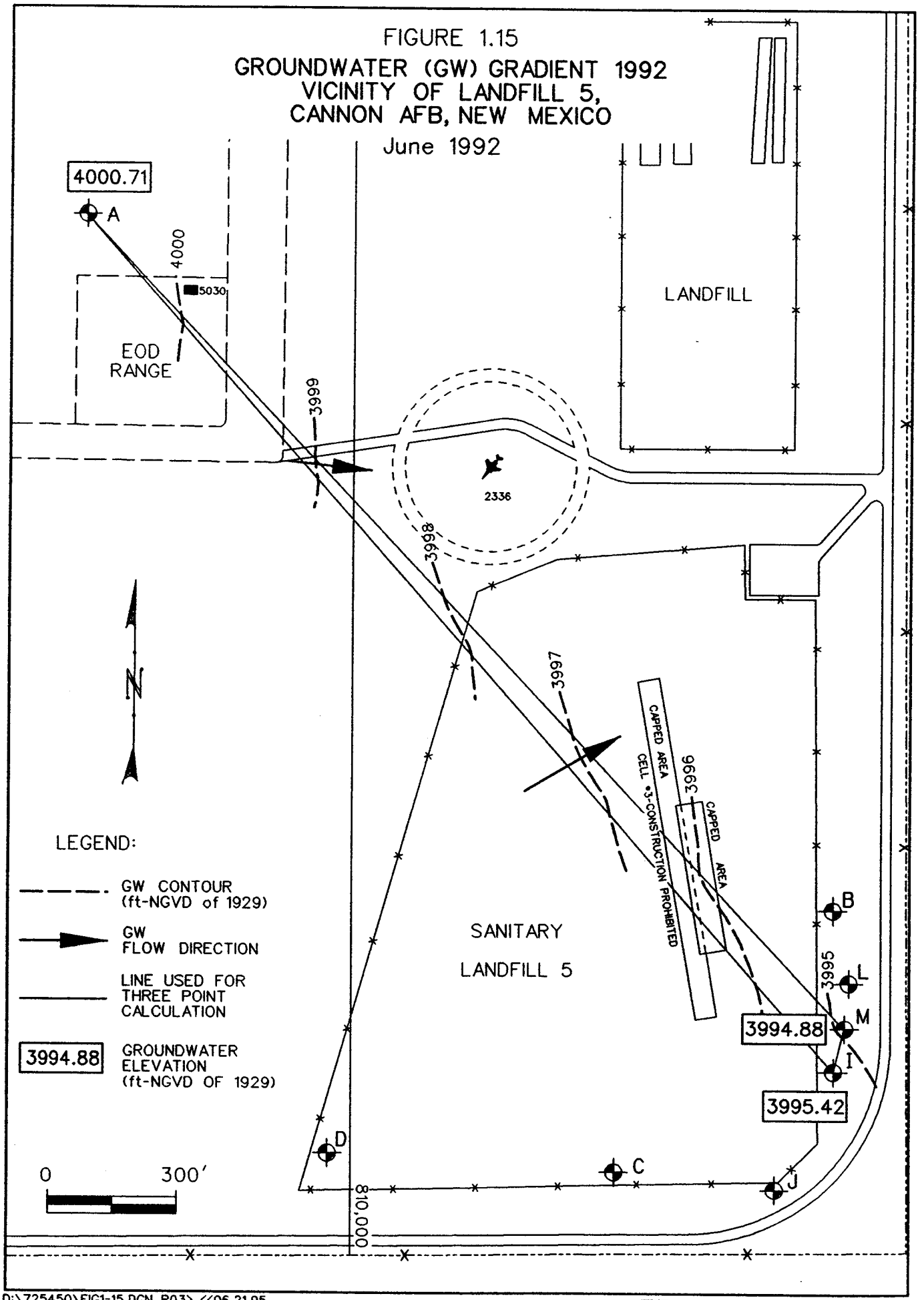

D:\725450\FIG1-15.DGN R03> <<06.21.95

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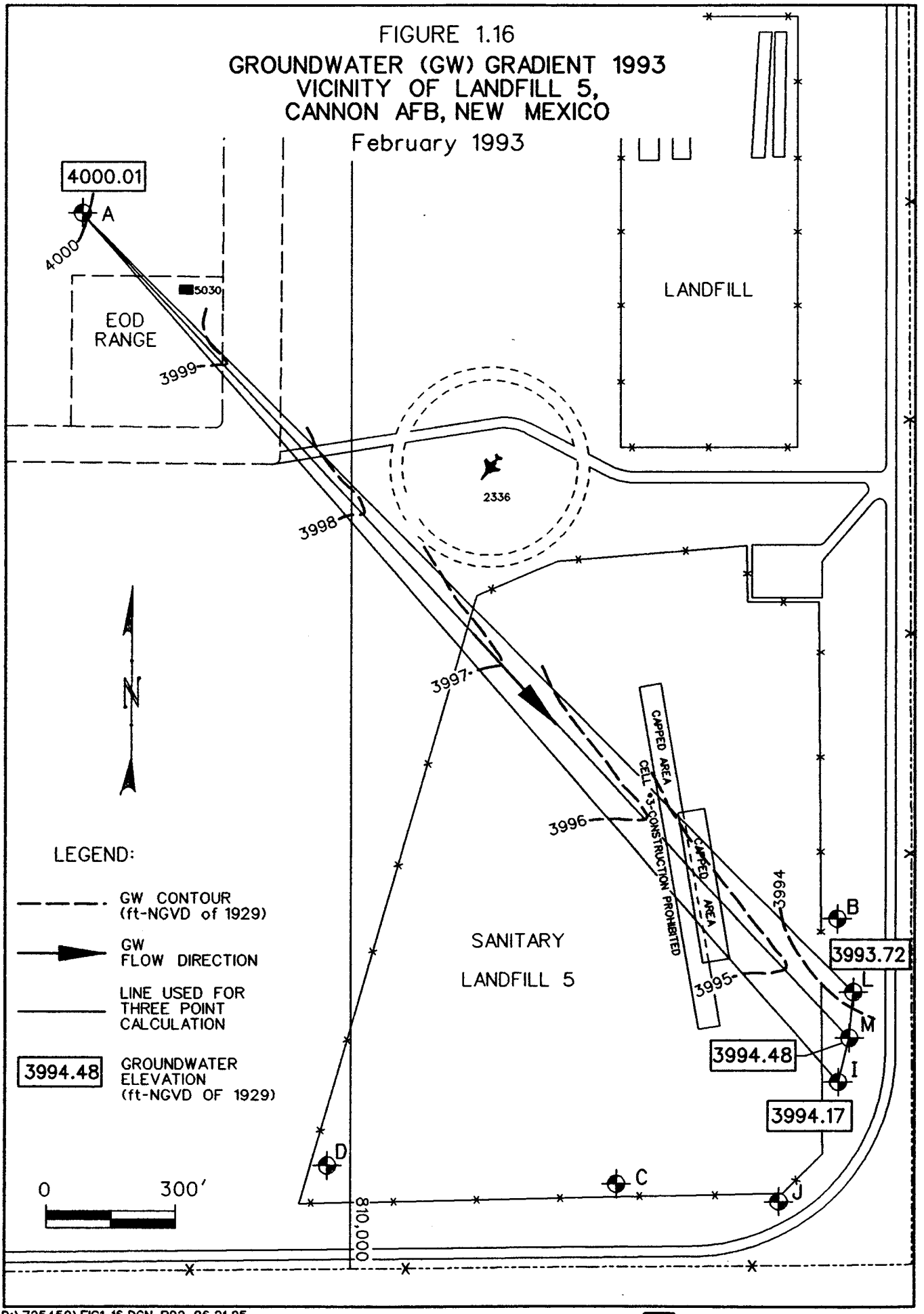

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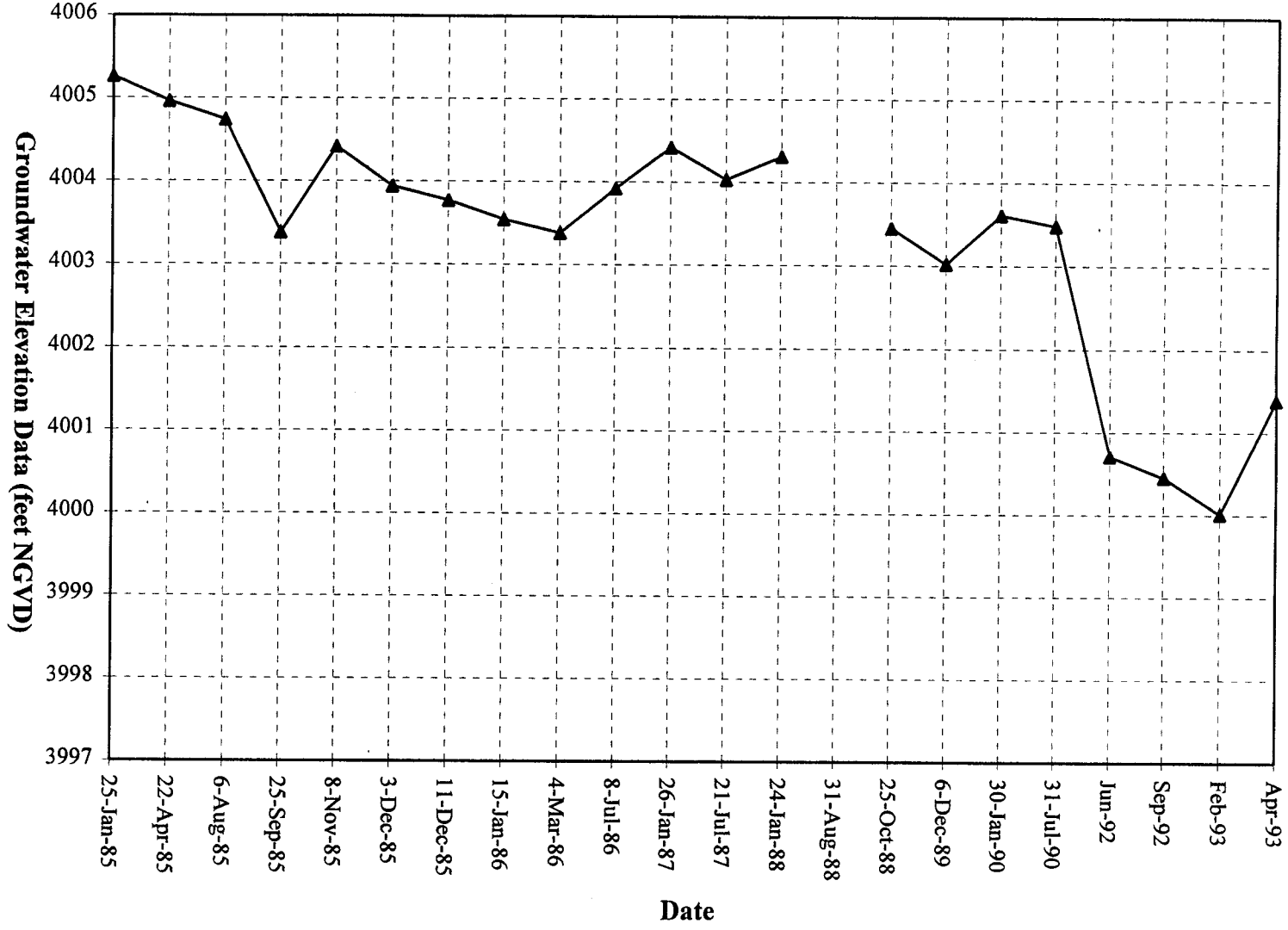
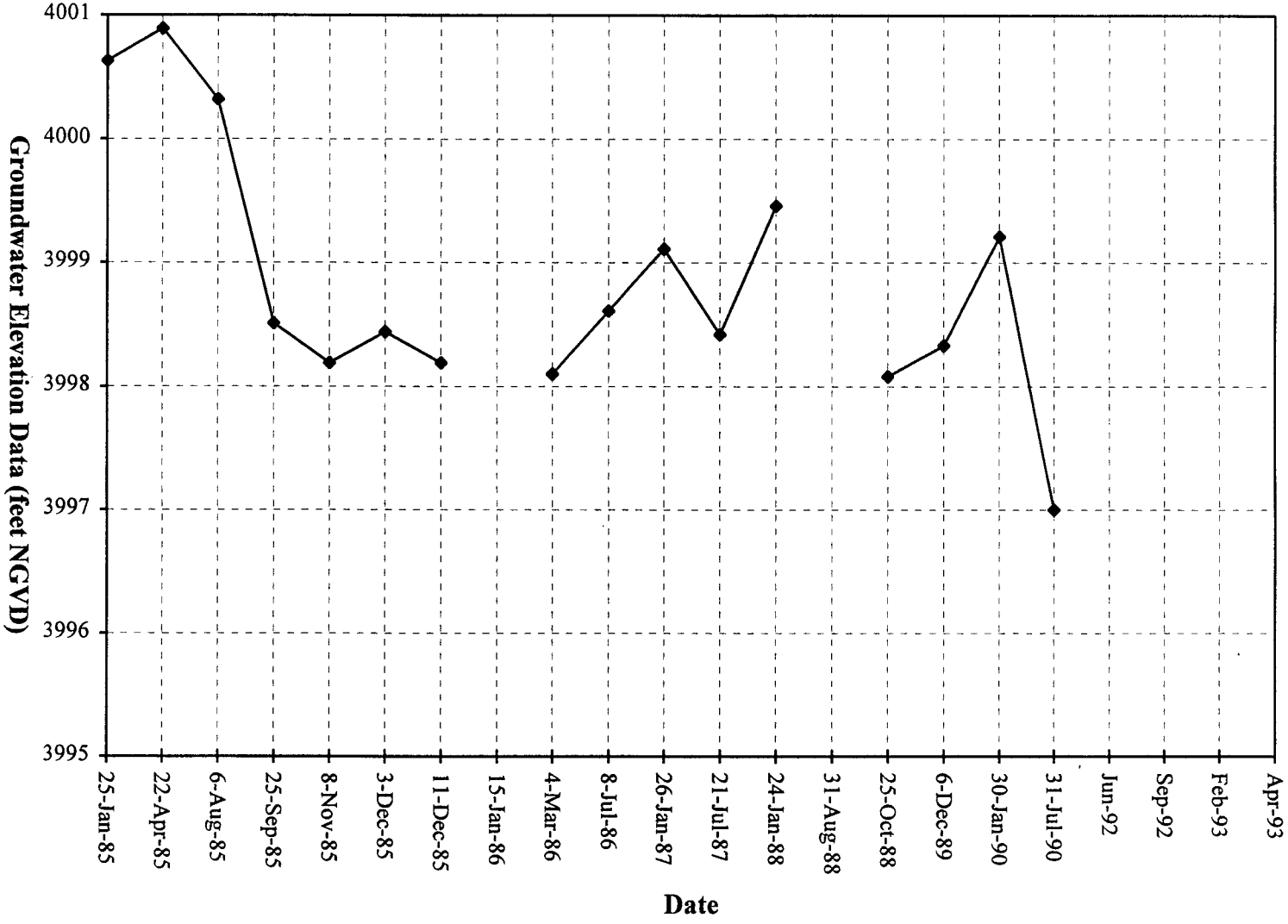
FIGURE 1.17 Well A - Water Level Data for Landfill 5, 1985 - 1993
Cannon AFB



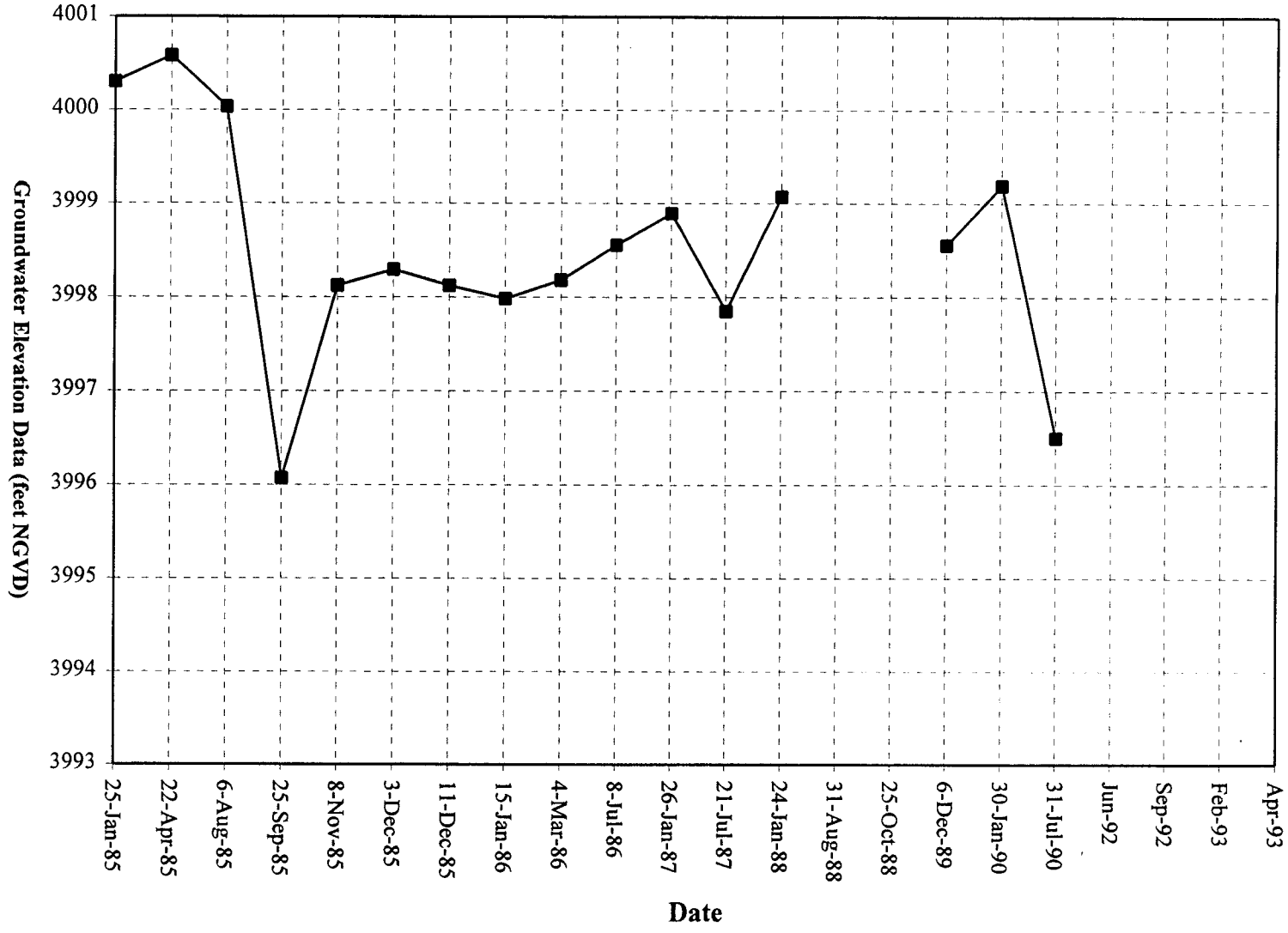
File: GraphA.XLS

FIGURE 1.18 Well B - Water Level Data for Landfill 5, 1985 - 1993
Cannon AFB



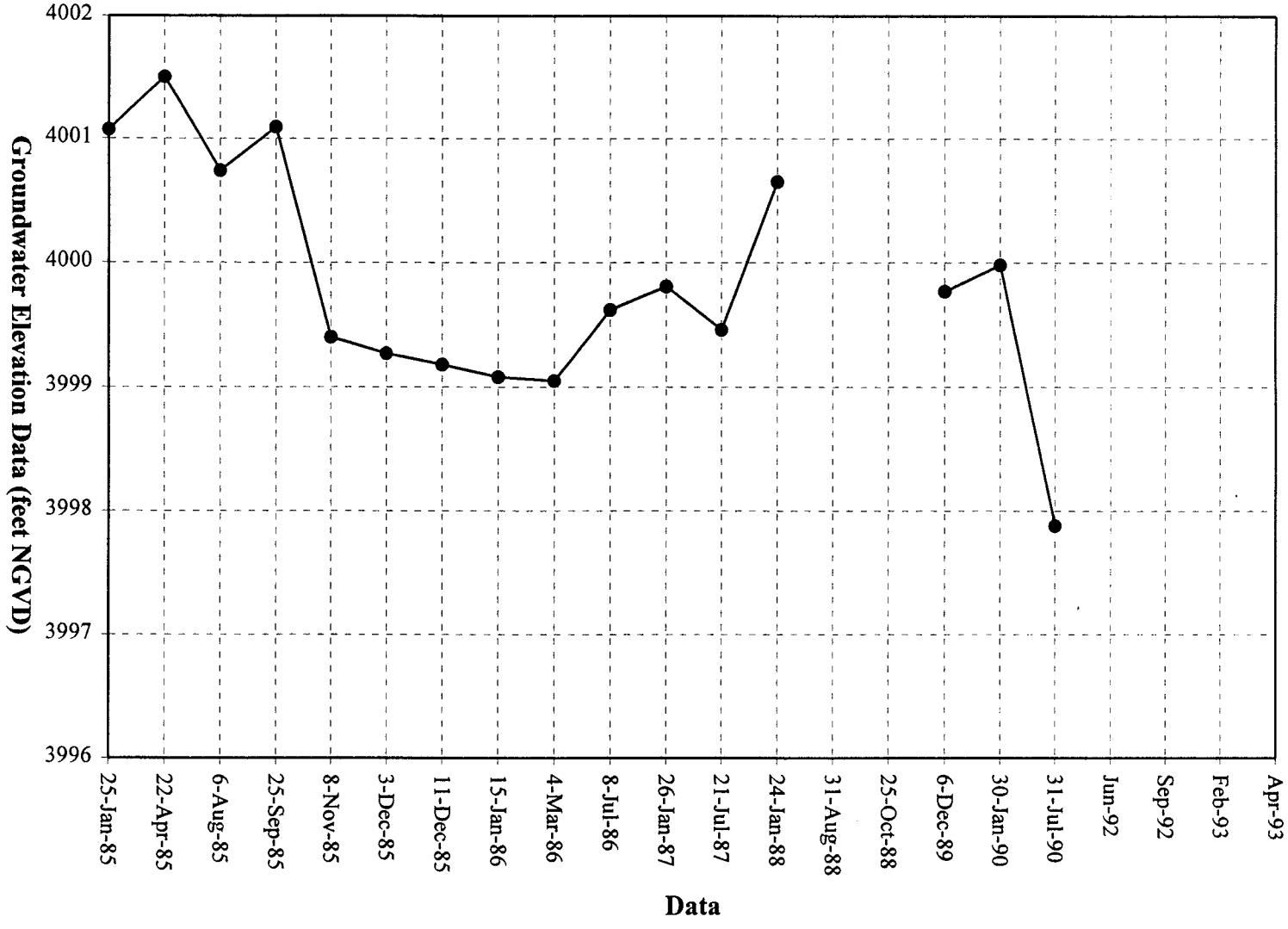
File: GraphB.XLS

FIGURE 1.19 - Well C - Water Level Data for Landfill 5, 1985 - 1993
Cannon AFB



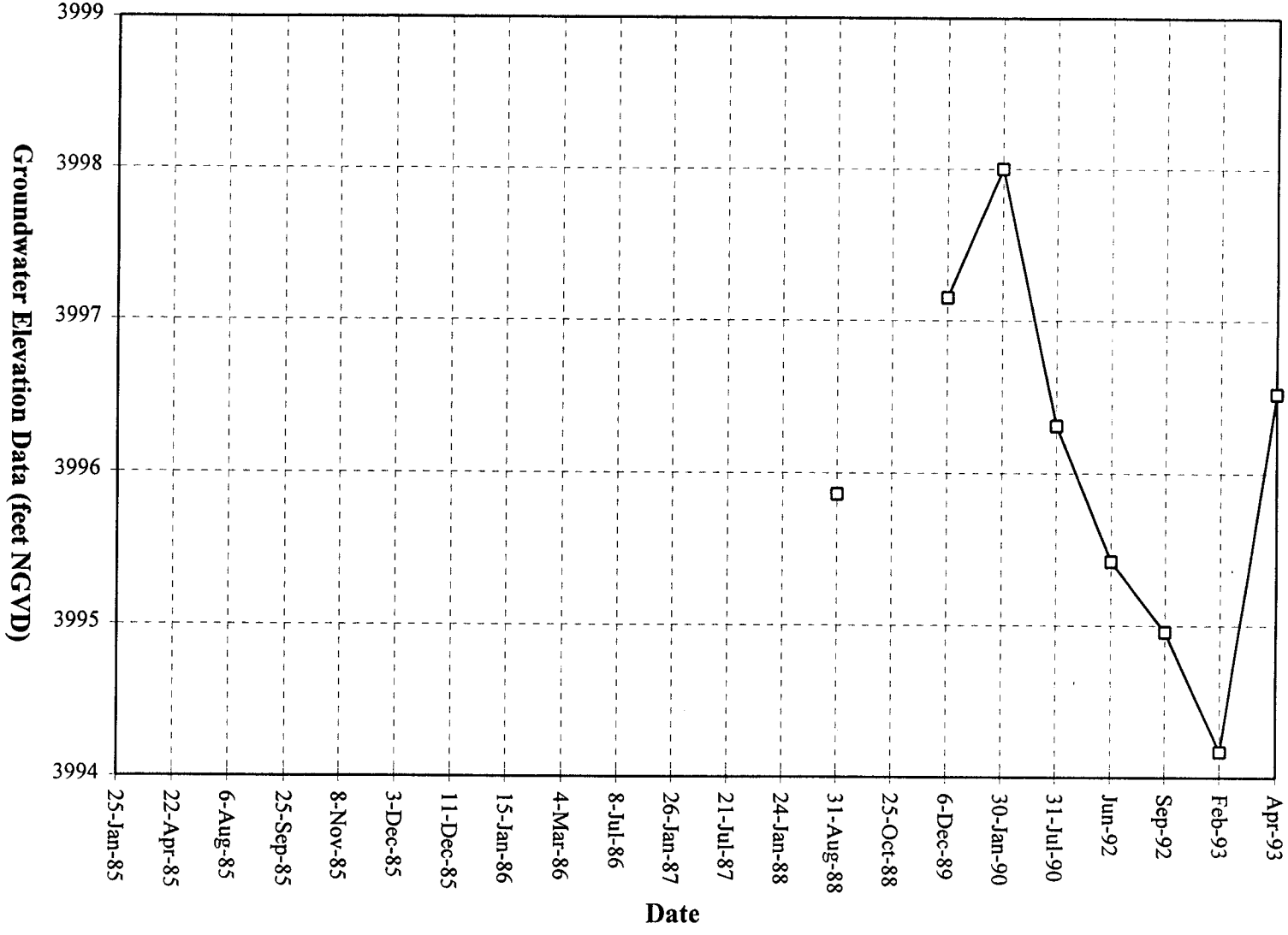
File: GraphC.XLS

FIGURE 1.20 Well D - Water Level Data for Landfill 5, 1985 - 1993



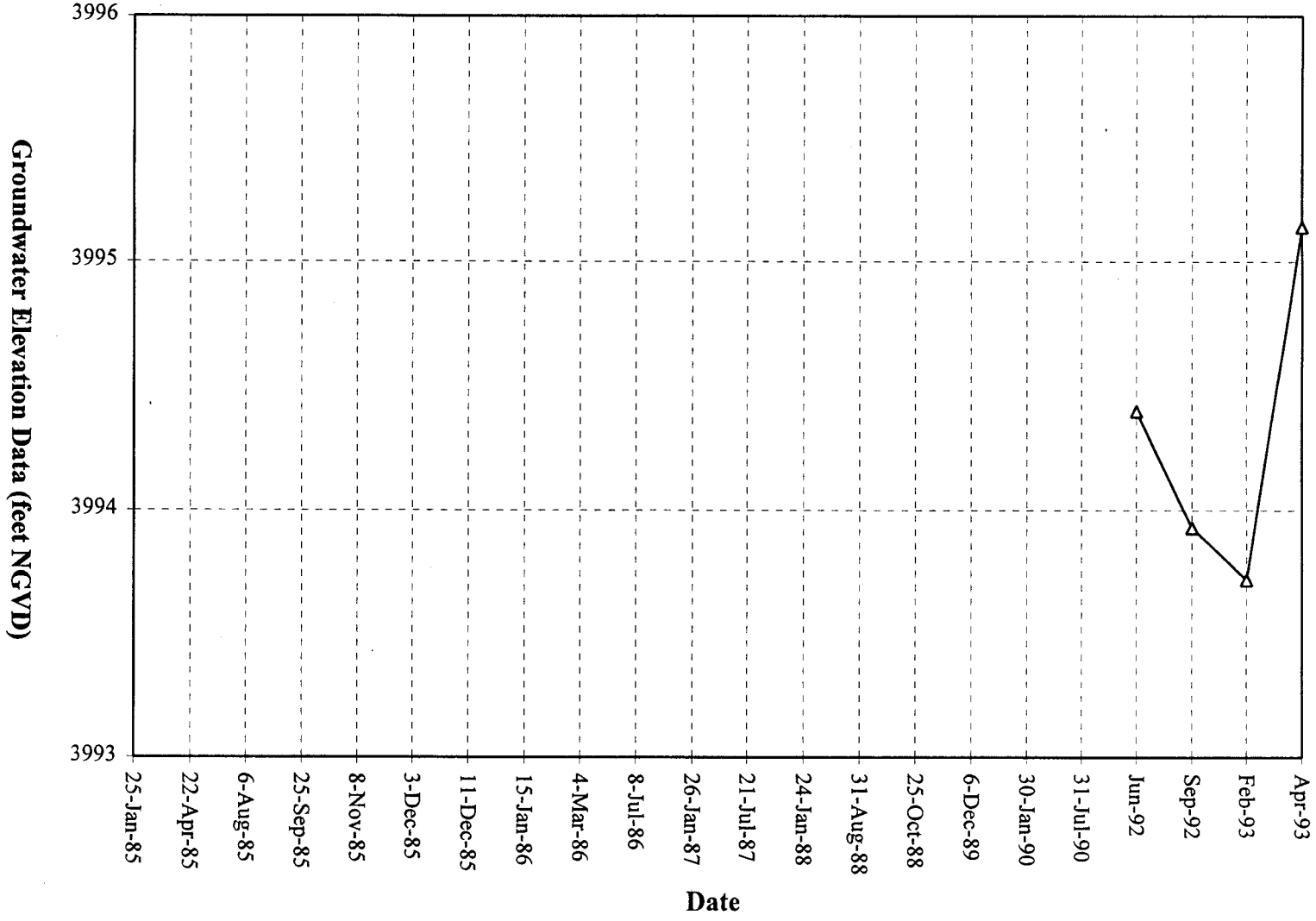
File: GraphD.XLS

FIGURE 1.21 Well I - Data for Landfill 5, 1988 - 1993
Cannon AFB



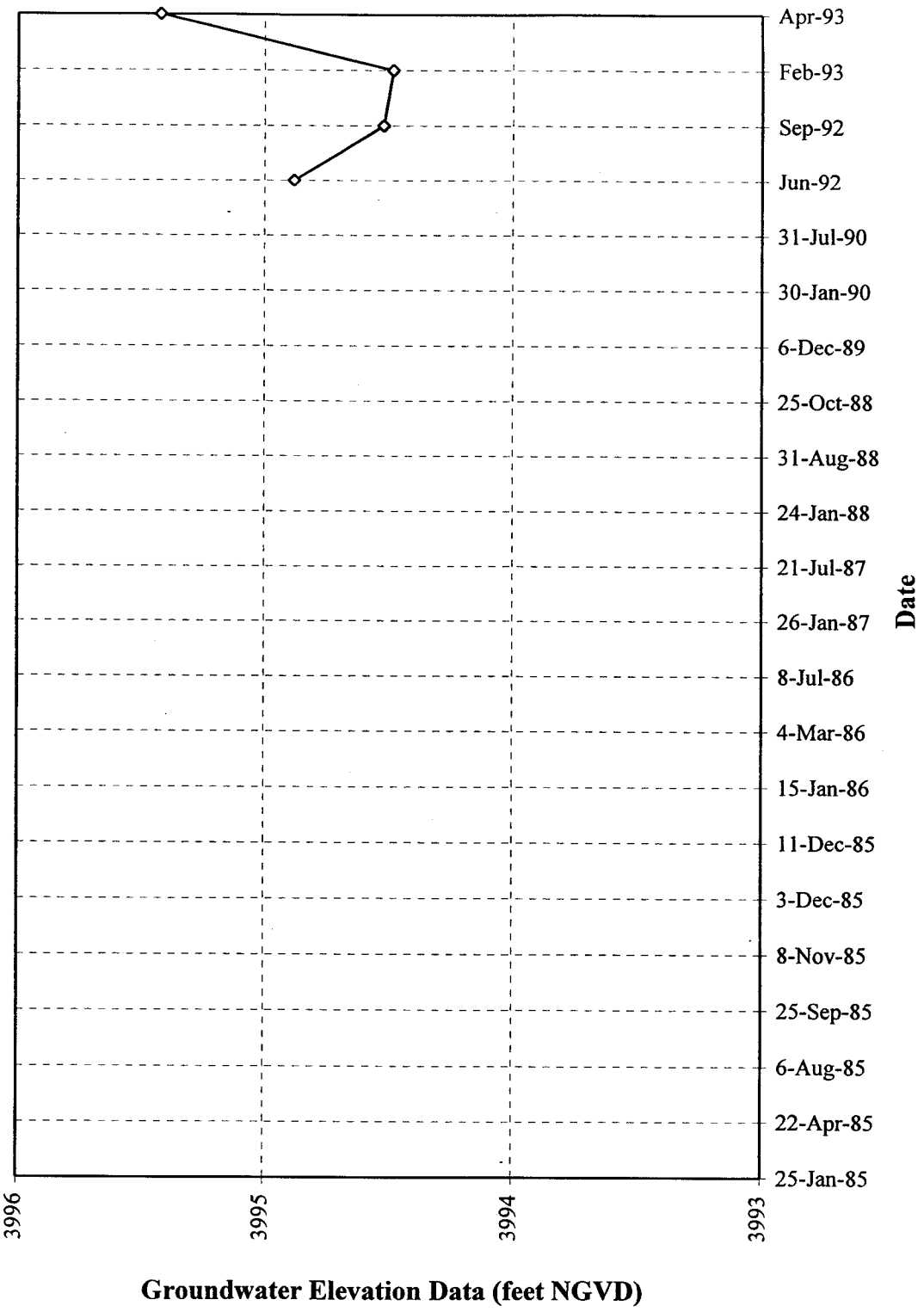
File: graphi.XLS

FIGURE 1.22 Well L - Water Level Data for Landfill 5, 1992 - 1993
Cannon AFB



File: GraphL.XLC

FIGURE 1.23 Well M - Water Level Data for Landfill 5, 1992 - 1993
Cannon AFB



File: GraphM.XLC

SECTION 2
OBJECTIVES AND PERFORMANCE STANDARDS

2.1 General

Final closure of Cell 3 of Landfill 5 was accomplished by covering it with a geocomposite soil cap consisting of a sodium bentonite clay liner, a high density polyethylene (HDPE) liner, and a 24-inch minimum layer of compacted soil material with a vegetative cover. This combination will restrict the percolation of infiltrating precipitation through the cell contents and reduce the potential of leaching or mobilization of hazardous waste constituents from the cell. The security equipment and groundwater monitoring plan were designed to ensure the protection of human health and the environment.

This section describes objectives and performance standards for the various structures associated with closure of Cell 3, including the geocomposite soil cap and vegetative cover, gas venting system, survey control points, security equipment, and groundwater monitoring equipment. Post-closure inspection and maintenance programs, described in Sections 3 and 4, will ensure the integrity of these structures throughout the post-closure care period.

2.2 Structures Associated with Closure of Cell 3

2.2.1 Geocomposite Soil Cap and Vegetative Cover

The objective of the soil cap is to prevent percolation of surface water through the cell contents, thereby minimizing the potential for leachate generation and to prevent any waste in the cell from protruding and coming in contact with the surface environment. The final soil cap design was chosen with the following performance standards in mind:

To provide long-term minimization of downward migration of liquids through the closed landfill cell by having the clay and HDPE intact;

To function with minimum maintenance by promoting surface drainage and taking advantage of the cover's tendency to resist erosion by water or wind;

To accommodate settling and differential subsidence in order to maintain the integrity of the cover; and

To have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

General Design of the Geocomposite Soil Cap and Vegetative Cover

The geocomposite soil cap and vegetative cover system for Cell 3 of Landfill 5 consists of the following layers (from bottom to top):

- Buffer Layer (placed directly on top of the cell as it existed)
- Bedding Layer
- Sand Gas Vent Layer
- Geotextile Filter

- Bentonite Layer
- HDPE Liner
- Compacted Soil Layer with Vegetative Cover

A typical cross section of the geocomposite soil cap and vegetative cover appears in Figure 2.1. Descriptions of the components are presented below.

The buffer layer is a 2-foot thick soil layer immediately above the actual waste. This layer serves to protect the geocomposite soil cap from penetration by objects protruding from the landfill by accommodating any effects of settling on the geocomposite soil cap. The construction of the buffer layer was completed approximately 12 years ago. Due to the relatively small volume of waste in the cell and its shallow depth of approximately 25 feet, it is anticipated that little additional settling will occur in the future and that the buffer layer is adequate. A layer of bedding material was graded and compacted above the buffer layer.

A 6-inch layer of filter sand is directly above the bedding soil. The filter sand serves to allow gases to properly vent. A 4-inch diameter perforated polyvinyl chloride (PVC) horizontal vent pipe oriented along the length of the centerline of Cell 3 is installed at the bottom of the filter sand layer to collect and remove gases permeating through the sand. Three 4-inch diameter PVC vertical vent pipes (with vent caps) 200 feet apart from each other extend up from the horizontal vent pipe through the filter sand, penetrate the HDPE liner and vegetative cover, and finally vent to the atmosphere 12 inches above crown cover. A leak-proof seal between the vent pipes and HDPE liner ensures continuity in liner protection and integrity.

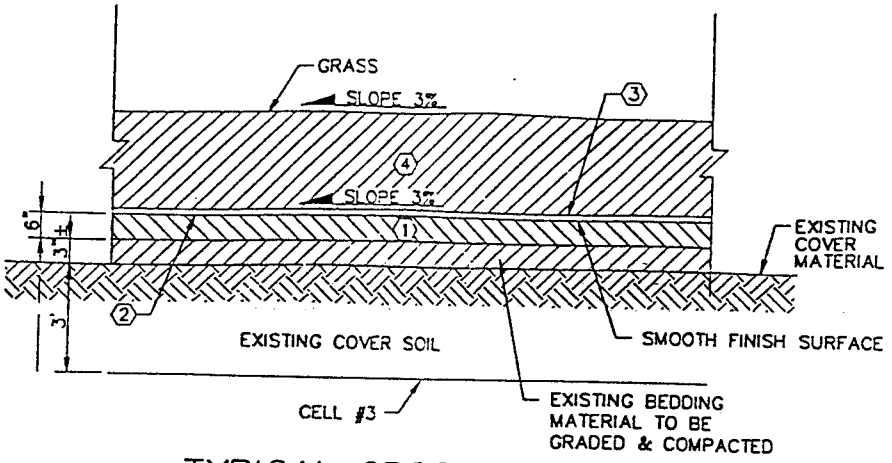
A non-woven geotextile filter fabric covers the compacted sand gas vent layer to prevent mixing of the one-eighth inch thick sodium bentonite clay liner above it with the filter sand. The geotextile filter has the capacity to vent any gases that may be generated in Cell 3.

Installed above the sodium bentonite clay liner is a 40 mil HDPE liner of low permeability (10^{-12} centimeter per second (cm/sec)). The liner extends 7 feet past the edge of the cell so that any percolation reaching the HDPE liner surface from above will be shed beyond the perimeter of the cell.

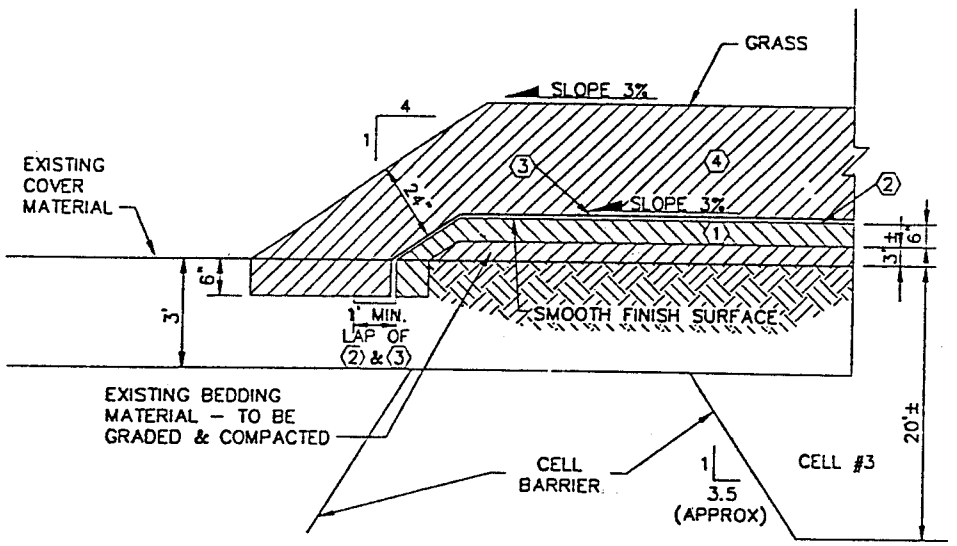
A 24-inch minimum layer of compacted soil is installed on top of the HDPE liner to act as a protective cover. The 3% slope of the protective cover surface is of a suitable gradient to allow diversion of rainwater and surface runoff away from Cell 3 in a reasonable manner toward the perimeter 4:1 side slopes. The protective soil serves to preserve the integrity of the HDPE liner by preventing direct exposure of the liner to ultraviolet solar radiation and deters liner wear due to weather and direct physical contact.

The vegetative cover consists of a mixture of native grasses that thrive in the local climate and require little maintenance. The use of native grasses acts as a net to collect and deposit wind blown soils onto the cap, thus tending to reverse any the soil erosion due to rainfall. The condition of the vegetative cover will be monitored to ensure adequate vegetation and roots to prevent erosion, stabilize the soil, and maximize evapotranspiration. Based on calculations that appear in Appendix B, anticipated soil loss due to erosion for the 25 percent side slopes is approximately 3.47 cubic feet per year over a surface area of 18,000 square feet. Considering the 24-inch soil covering, complete erosion of the side slopes would occur in 10,375 years. Erosion

FIGURE 2.1
TYPICAL CROSS-SECTION OF GEOCOMPOSITE SOIL CAP
CANNON AFB, NEW MEXICO



TYPICAL CROSS SECTION (A C3|C5)
N.T.S.



TYPICAL EDGE DETAIL (B C3|C5)
N.T.S.

KEYED NOTES:

(1) 6" SAND/GAS VENT LAYER COMPACTED TO 95% MAX. INDEX UNIT DENSITY IN ACCORDANCE WITH ASTM D 4253

(2) NON-WOVEN FILTER FABRIC

(3) 40 MIL HIGH DENSITY POLYETHYLENE SHEET WITH BENTONITE

(4) 24" MIN. COVER MATERIAL (VARIES) COMPACTED TO 90% MODIFIED PROCTOR IN ACCORDANCE WITH ASTM D 1557

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of the 3 percent top slope would take even longer to occur.

2.2.2 Gas Venting System

Cell 3 has received solvents, paint removers, and thinners, which, after closure, could volatilize and release gases. Analyses of Cell 3 core samples detected less than 0.01 parts per million (ppm) of volatile organics and no organic solvents (HMTC, 1992). Complete volatilization may have occurred in the decade before the geocomposite soil cap was installed. However, the general design of the geocomposite soil cap allows for venting of any potential gases through the gas venting system described in Section 2.2.1.

2.2.3 Survey Control Points

Survey control points are located at each corner of Cell 3. Each corner is monumented by 5/8-inch rebar and an aluminum cap stamped "PS, Inc. LS 7255". These points enable the precise location of groundwater monitoring wells and the piezometric surface of the aquifer for groundwater flow characterization. The survey control points can also serve as an early indicator of settlement and differential subsidence.

2.2.4 Security Equipment

The purpose of security equipment is to secure the area of the closed cell and to prevent entry of unauthorized personnel and livestock. Security equipment for Cell 3 consists of a fence, gate, and warning placards. Access to the site is controlled by a lockable entry gate attached to a permanently anchored four-strand barbed-wire fence, surrounding the perimeter of the landfill cell, at a distance of 20 feet from the edge of Cell 3. The gate is kept closed and locked when an operator is not on duty. A placard identifying the landfill cell is permanently attached to the fence. Placards that read "DANGER-UNAUTHORIZED PERSONNEL KEEP OUT" in both English and Spanish are posted at the entrance to the site, as well as at intervals no greater than 100 feet apart on the fence around the closed unit. The warning placards are legible from a distance of at least 25 feet.

2.2.5 Groundwater Monitoring System

The purpose of a groundwater monitoring system is to detect contamination migration from the landfill into the aquifer below. The recommended groundwater monitoring system is described in Section 5 of this document.

SECTION 3
INSPECTION ACTIVITIES AND SCHEDULES

3.1 General

Inspections of the geocomposite soil cap and vegetative cover, gas venting system, survey control points, security equipment, and groundwater monitoring equipment will be performed routinely in order to ensure the protection of human health and the environment. The detection of hazardous waste, hazardous waste constituents, leachate, contaminated runoff, or waste decomposition products to the soil, groundwater, surface water, or atmosphere depends on the proper functioning of the aforementioned devices. General inspection considerations are discussed in the subsections below. Table 3.1 outlines items to be inspected, the frequency of inspections, a description of items to be observed, and correction methods.

3.2 Reporting/Recording Inspections

The inspections will be conducted by CAFB personnel and will be documented through the use of an inspection form. An example observation and inspection checklist, which outlines inspection observations to be made during a formal inspection, is included in Appendix C of this document. The checklist is consistent with the inspection observations included in Table 3.1. A corrective action form will be prepared for any deficiencies noted during the inspection. An example form is included in Appendix D. Inspection personnel will fill out the inspection checklist. Copies of both checklists will be maintained in the CEV office.

3.3 Frequency of Inspections

The site is designed to require minimum post-closure maintenance. Except where designated otherwise on Table 3.1, quarterly inspections are sufficient to observe any possible damage or inconsistencies with the post-closure plan.

3.4 Structures to be Inspected

3.4.1 Geocomposite Soil Cap and Vegetative Cover

Inspecting the geocomposite soil cap and vegetative cover over Cell 3 is an integral part of minimizing the potential for a release of contaminants into the groundwater. The integrity of the cap will be inspected quarterly and after heavy precipitation events and/or prolonged drought. The cap will be visually inspected for any signs of erosion, cracking, differential subsidence, lack of vegetation, accumulation of water, and rodent damage.

3.4.2 Gas Venting System

The three PVC vent stacks along the centerline of Cell 3 will be inspected for damage or obstruction. Corrective action will be taken as soon as possible to repair any damage to the vent stacks.

3.4.3 Survey Control Points

Survey control points located at each of the corners of Cell 3 will be visually inspected for damage or movement. Survey control points will also be inspected for evidence of settlement or

TABLE 3.1 Inspection Observations

Item Inspected	Frequency	Description of Items to be Observed	Correction Method
1. Condition of Geocomposite Site Cap and Vegetative Cover	Quarterly, and also after precipitation events of high intensity or prolonged drought		
a) Signs of Sloughing or Sliding at the Outslopes	" " "	Check for bulging along or at the base of the slopes. Check for vertical displacement and cracking. Special care should be taken in areas of heavy vegetation to avoid overlooking such failures.	Repair slide area by replacement with suitable material. Grade and revegitate. Use straw bales as necessary to control erosion.
b) Signs of Differential Subsidence	" " "	Check for subsidence of soft foundation material (evidenced by bowl-shaped depressions, and possibly impounding water). Care should be exercised in areas of heavy vegetation to avoid overlooking such areas. Inspect areas adjacent to gas vent pipes and survey control points.	Clear vegetation in the area. Repair low spots by filling to grade with off-site borrow material. Fertilize, seed, and mulch as necessary to reestablish vegetation. Use straw bales as necessary to control erosion.
c) Evidence of Sheet Erosion	" " "	Check areas that lack ground cover. Sheet erosion is evidenced by surficial loss of soil in a somewhat uniform pattern over wide areas.	Regrade as necessary. Fertilize, seed, and mulch to establish vegetation. Use straw bales to control erosion if necessary.

TABLE 3.1 (continued)

Item Inspected	Frequency	Description of Items to be Observed	Correction Method
d) Evidence of Gully	" " "	Check areas that lack ground cover. Gully erosion is due to the effects of the concentration of overland flow and results in the creation of narrow and deep channels.	Replace eroded material with suitable off-site borrow. Regrade as necessary. Fertilize, seed, and mulch to establish vegetation. Use straw bales as necessary to further check erosion.
e) Evidence of Boggy Areas	" " "	Check for the presence of wet or boggy areas (evidenced by areas where vegetation may be thriving due to moist conditions or ponded water may be present).	Clear vegetation in the area. Repair low spot by filling to with off-site borrow. Fertilize, seed, and mulch. Use bales as necessary.
f) Extent, Condition, and Changes in Vegetative Cover	" " "	All areas that were seeded shall have a vegetative cover that is similar to background conditions on similar soils and slope. Irregularities such as difference in color, density, rate of growth, type of growth, or a difference in the character of the vegetation will be noted.	Sample soils to determine nutrient deficiencies. Apply fertilizer amounts as specified by soil analysis, followed by seed and mulch application.

TABLE 3.1 (continued)

Item Inspected	Frequency	Description of Items to be Observed	Correction Method
g) Evidence of Rodent Damage	" " "	Check for the presence of animal burrows or insect mounds.	Apply pesticide or rodenticide, backfill and regrade areas involved. Apply fertilizer, seed, and mulch.
h) Evidence of Undesirable Weeds	" " "	Check for undesirable weeds.	Pull undesirable weeds at each inspection.
2. Condition of Gas Venting System	Quarterly	Check that the PVC vent stacks are not cracked or damaged and that the pipe is not obstructed.	Repair or replace pipe if damaged. Remove any obstruction in pipe.
3. Condition of Survey Control Points	Quarterly	Check that survey control points are still in existence. Check for damage or movement. Inspect for evidence of settlement or differential subsidence of the soil cap.	Replace/re-establish as necessary. Provide protective case if necessary. If settlement or subsidence is detected, low spots will be filled in and regraded as necessary. Remove dirt or debris covering survey control point.

TABLE 3.1 (continued)

Item Inspected	Frequency	Description of Items to be Observed	Correction Method
4. Condition of Security Equipment	Quarterly		
a) Fence/Gate	" " "	Check for severe rusting, corrosion, or breakage of the barbed wire fence and gate. Check for failure of any fence supports. Gate should be securely locked.	Repair or replace damaged fencing/gate as appropriate. Straighten and pour concrete around affected support. Install new lock if necessary.
b) Warning Placards	" " "	Check that warning placards are still in existence and legible.	Repair damaged, illegible placards or replace if necessary.
5. Condition of Groundwater Monitoring Equipment	" " "		
a) Pumps	Coincident with semi-annual sampling events	Check that pumps are in good working condition.	Repair/replace pumps as necessary.
b) Sampling Equipment (non dedicated)	One month prior to sampling event	Check that equipment is in good condition. Check that adequate supply of appropriate sampling containers are on hand.	Deteriorated/malfunctioning equipment must be repaired or replaced prior to next sampling event.

TABLE 3.1 (continued)

Item Inspected	Frequency	Description of Items to be Observed	Correction Method
c) Monitoring Wells	Coincident with sampling event - quarterly for 1 year following replacement of MW-A, and semi-annually thereafter.	Check for visual evidence of physical damage to the well casing. Check for damage to the cement apron and assure that the annulus is properly sealed. Check for tampering of the lock and MW cap. Insure that wells are accessible and visible to all appropriate personnel.	Damaged wells will be replaced if they cannot be repaired and if the integrity of samples is at risk. Patch cracks in cement apron. Repair/replace annulus if improperly sealed. Repair/replace lock or MW cap if damaged or malfunctioning. Clear away any debris blocking access to well.

differential subsidence of the geocomposite soil cap. Dirt or debris covering the survey control points will be removed during each inspection.

3.4.4 Security Equipment

Inspecting the security equipment is necessary in order to ensure that access to the landfill is limited to authorized personnel only. Security equipment will be inspected quarterly for signs of damage or breakage to the fence, gate, or lock, and to ensure the warning signs are legible and intact.

3.4.5 Groundwater Monitoring Equipment

Groundwater monitoring equipment includes pumps, sampling equipment (equipment not physically associated with the well itself, e.g., sampling bottles), and the monitoring wells. The Inspection and Maintenance Program for this equipment is described in Sections 7.12 and Table 3.1 of this document.

SECTION 4
MAINTENANCE ACTIVITIES AND SCHEDULES

4.1 General

This section provides a description of activities necessary to maintain the integrity of the geocomposite soil cap and vegetative cover, and the proper functioning of the gas venting system, security equipment, and groundwater monitoring equipment for both the short and long term. Maintenance on any of the aforementioned components will be performed as necessary based on inspection results. Any deficiency will be corrected as quickly as possible. Materials and procedures used for repairs will conform with the original design specifications.

4.2 Timetable for Maintenance Activities

All maintenance/corrective activities will be completed as soon as possible. The above is subject to weather constraints.

4.3 Reporting

Completion of repairs will be documented through the use of corrective action forms. An example form is included in Appendix D. Repairs will be performed by personnel designated by CAFB personnel.

4.4 Structures Requiring Maintenance

4.4.1 Geocomposite Soil Cap and Vegetative Cover

The geocomposite soil cap and vegetative cover was designed to reduce the erosion potential and minimize post-closure maintenance as discussed below. Any repairs will be part of regular post-closure care.

1. Mowing Schedule - The vegetative mix selected for this site consists of native grasses that do not require mowing.
2. Reseeding and Mulching Schedule - If damage to the vegetative cover is observed, reseeding will be required. Reseeding will be accomplished as needed and will be based on the findings of regular inspections. A straw mulch may be applied to help retain moisture, prevent erosion, and protect the vegetation until it matures.
3. Soil Replacement/Erosion Control - Due to the relatively flat surface slopes on the completed site, no severe erosion is expected. The only potential locations that may be affected by severe erosion are the 4:1 slope faces of the site. The activities for erosive damage include replacement of the construction cover material per the specification. Soil will be replaced as required, based on needs determined from regular inspections. If regrading is necessary, then a backhoe will secure the necessary common borrow for the cover from an existing pile outside the cell fence. All repair work on the cover will be completed by hand compaction, using a vibrating plate. Heavy machinery will not be allowed to travel on the cover. The repair of all surface subsidence, soil erosion problems, or slope damage will be completed as soon as possible.

4. Fertilizing Schedule - Fertilizer will be applied as necessary.
5. Weeding Schedule - Weeding will be conducted at every inspection to control undesirable weeds which may take root.
6. Sprinkling Schedule - Sprinkling is not expected to be required after vegetation cover is established. Sprinkling may be required on newly seeded areas for establishment. A temporary watering system will be installed if the precipitation is inadequate to establish a vegetative cover.
7. Rodent and Insect Control Programs - During the routine inspections, the soil cap and vegetative cover will be checked for animal burrows or insect mounds. If any are observed, rodenticide or pesticide will be applied. The burrows or mounds shall be carefully backfilled/graded after application of pesticide or rodenticide and the areas involved revegetated as soon as possible afterwards. Following initial restoration of the site, the area shall be inspected monthly for a minimum of three consecutive months in order to evaluate the success of the extermination/revegetation. If the rodents and/or insects reappear, the above procedure shall be repeated.

4.4.2 Gas Venting System

Maintenance of the gas venting system may involve repairing or replacing cracked or damaged vent pipes and removing obstructions from the vent pipe.

4.4.3 Survey Control Points

Maintenance of the survey control points may involve resurveying locations in order to replace/reestablish monuments that have been moved or damaged. Protective cases may be installed to prevent movement and damage. If settlement or differential subsidence is detected with respect to the survey control points, low spots will be filled and regraded per specifications.

4.4.4 Security Equipment

Based on routine site inspections, maintenance of the security equipment may be necessary to ensure it remains reliably functional throughout the post-closure care period. The perimeter fence is designed to withstand the stress of high winds and should require only minimal maintenance. However, maintenance of the fence and gate may involve periodic replacement of sections as a result of normal wear, severe weather conditions, and vandalism. Similarly, the gate lock and warning placards may require periodic replacement.

4.4.5 Groundwater Monitoring Equipment Maintenance

An Inspection and Maintenance Program for groundwater monitoring equipment is described in Section 7.12 of this document.

4.5 Point of Contact

The Inspection and Maintenance Program will continue for 30 years following the receipt of the final closure certification for Cell 3 of Landfill 5. The CEV office is responsible for the post-closure care of the cell. The point of contact in the CEV office is Sandy Mukherjee. The CEV office is located at 114 North Perimeter Road on CAFB and the phone number is 505-784-4639.

SECTION 5

PROPOSED GROUNDWATER MONITORING SYSTEM

5.1 TECHNICAL APPROACH

The recommended groundwater monitoring system will consist of one upgradient (MW-A) and three downgradient (MW-I, MW-L, and MW-M) wells. The purpose of the monitoring program is to detect potential releases to groundwater from Cell 3 of Landfill 5 and to identify baseline conditions. The locations of the monitoring wells are shown in Figure 5.1. Design and construction details are presented in Appendix A.

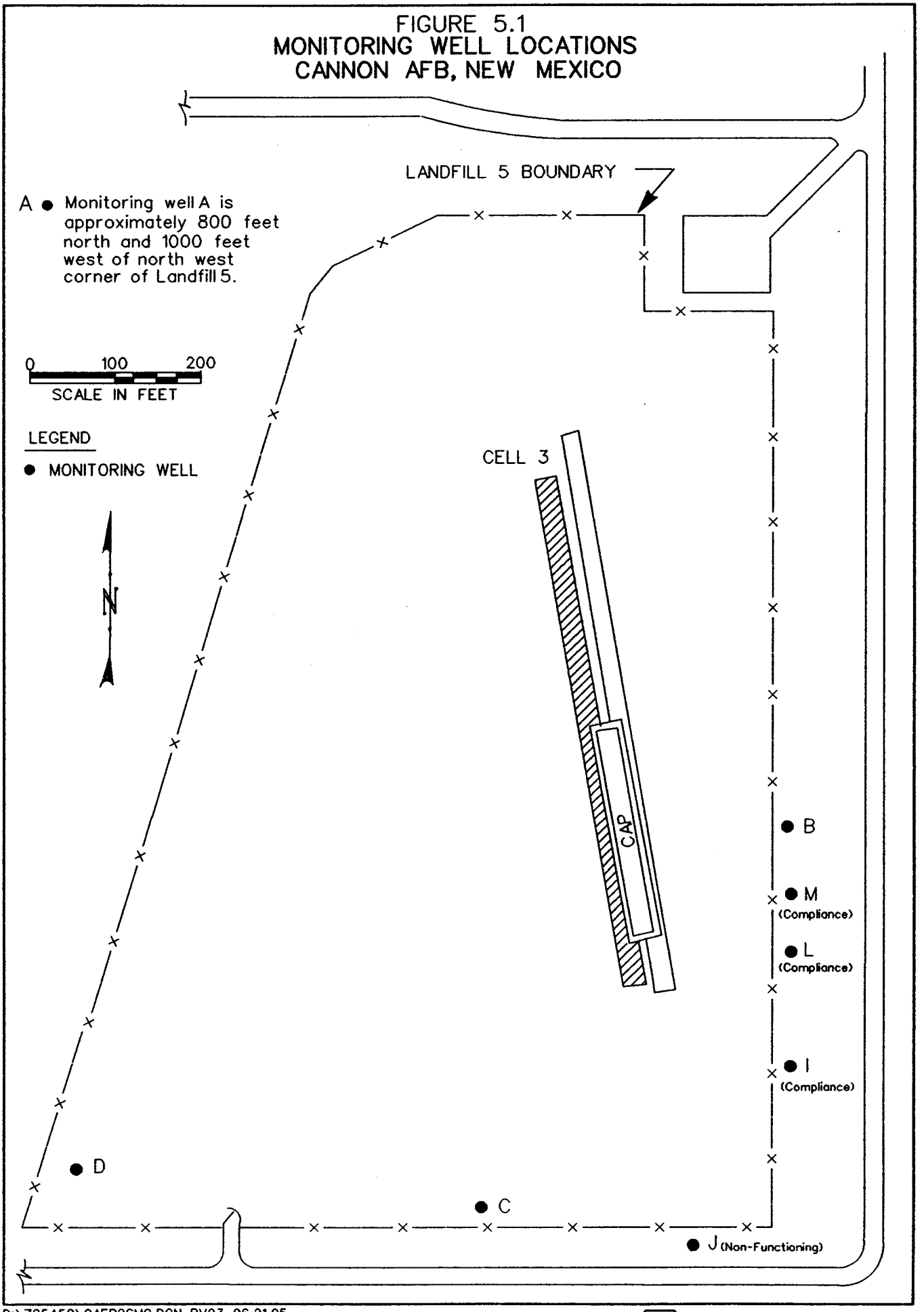
5.2 BACKGROUND MONITORING WELL

MW-A will be used as the interim background well for the detection program. The Detection Monitoring Program is discussed in Section 6. The well is located upgradient of Landfill 5 approximately 800 feet north and 1000 feet west of the northwest corner of the landfill (Figure 5.1). The purpose of this well will be to monitor groundwater quality as it enters the site and to establish background conditions for downgradient comparisons.

MW-A is screened at a depth of 343 to 328 feet. The screened interval is approximately 50 feet below the top of the water table as measured in January 1992. This screened interval differs from the downgradient wells which are screened at the top of the water table. The NMED agreed in the 1990 Compliance Agreement that CAFB could use this well as a background well. However, to allow for a more direct water quality comparison between the background and downgradient wells, CAFB is planning to request funding from Air Combat Command to install a replacement well for MW-A.

The intent of a replacement well for MW-A is to install a screen across the unsaturated/saturated interface in order to be compatible with downgradient monitoring well construction. The new well will be located in the vicinity of the existing MW-A, where local constraints include a nearby SWMU and the airfield clear zone. Design and construction of the new well will take place on the following schedule:

March 1995 - January 1996	Program additional well/baseline monitoring and obtain funds.
January 1996 - May 1996	Design/workplan preparation, review, and approval.
May 1996 - June 1996	Well construction/development.
June 1996 - May 1997	Baseline monitoring
June 1997	Analysis and draft report preparation
July 1997	NMED and EPA reviews of draft report.
August 1997	Final report.



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5.3 DOWNGRADIENT MONITORING WELLS

MW-I, MW-L, and MW-M, will be used as the downgradient monitoring wells in the detection program. These wells are located along the eastern edge of Landfill 5 (Figure 5.1). The four other existing wells, MW-B, MW-C, MW-D, and MW-J, will not be used in the detection program. MW-B, MW-C, and MW-D have screens set at approximately 40 feet below the top of the water table and MW-J has the bottom broken out. These wells will only be used for determining water elevations around the landfill.

The downgradient monitoring wells to be used in the monitoring program are screened in the uppermost portion of the High Plains aquifer at a depth of approximately 260 to 280 feet. Each well is constructed with a 20-foot screened interval. The screened interval in MW-L and MW-M intersects the top of the water table.

The top of the screened interval in MW-I is approximately nine feet below the top of the water table as measured in January 1991. This is not expected to impact the water quality comparisons with the other wells. Water quality from the uppermost part of the aquifer will be sampled. The purging process, prior to sampling, will likely lower the water level in the well by several feet. Thus, the groundwater will be drawn down into the well during purging.

SECTION 6

GROUNDWATER MONITORING PROGRAM

6.1 CURRENT MONITORING PROGRAM

CAFB is going to request funding to install a replacement well for MW-A. Until the replacement well is authorized, CAFB proposes to continue with the current monitoring program as outlined in the 25 August 1993 letter to Ms. Barbara Hoditschek of the NMED. A copy of this letter is included in Appendix E.

Once the replacement well is installed, CAFB will initiate a detection monitoring program in accordance with 40 CFR 264.98. The parameters to be monitored in the Detection Monitoring Program will be selected in stages starting with a comprehensive list and gradually focusing to include only those parameters that are found in the baseline groundwater sampling period. The list of parameters that will be monitored in the Detection Monitoring Program is presented in Table 2 of Appendix G. This list of parameters will be modified as the program progresses. Methods and rationale for modifying the list of parameters are presented in the following sections.

6.2 DETECTION MONITORING PROGRAM

The major phases of the Detection Monitoring Program are presented in the flow diagram in Figure 6.1. These phases include baseline monitoring and detection monitoring. Each phase is discussed in detail below.

6.2.1 Baseline Monitoring

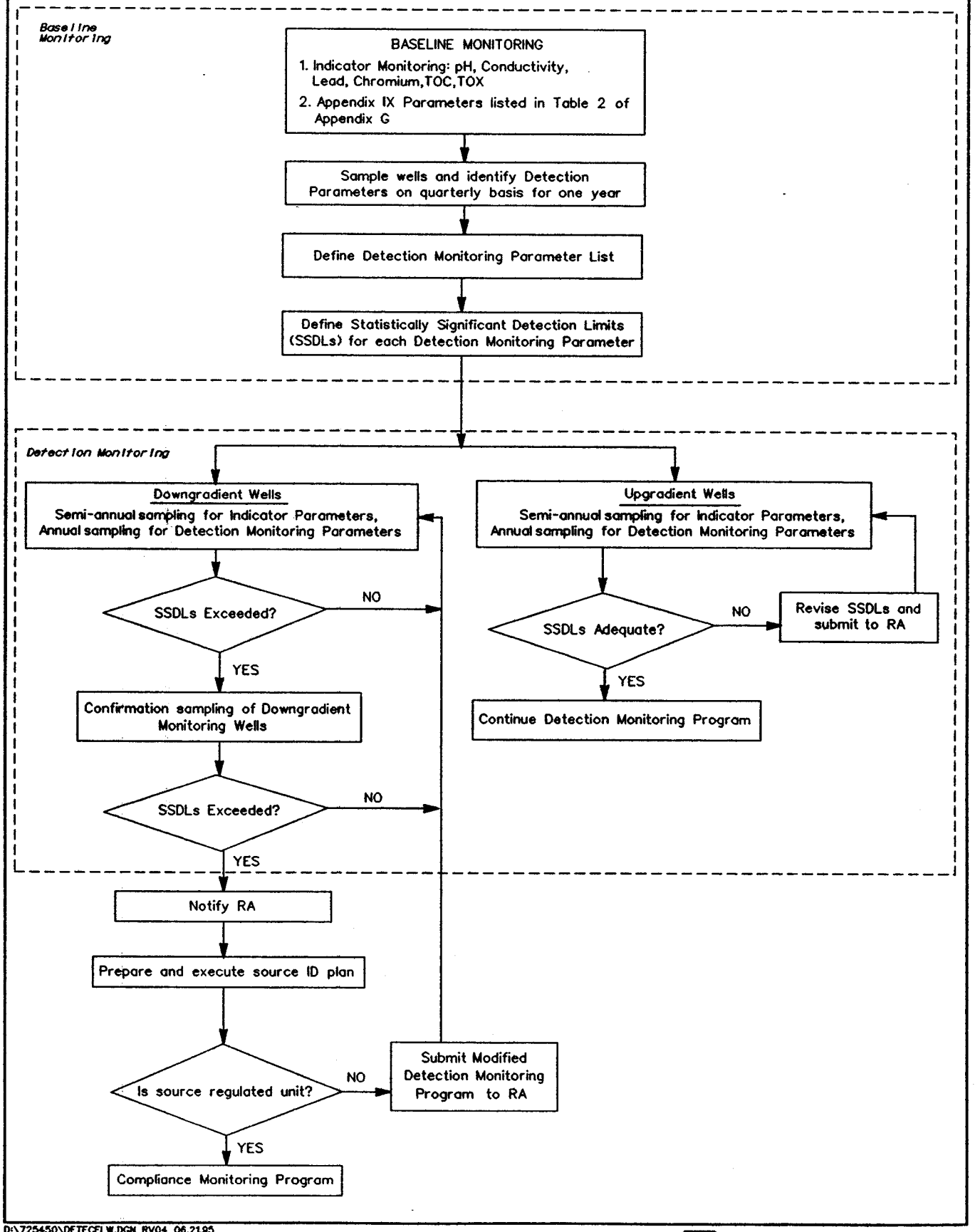
Baseline monitoring will commence once the replacement for MW-A is installed and developed. The purpose of baseline monitoring will be to establish existing levels of contamination against which subsequent results will be assessed. The baseline monitoring program will be conducted for a one-year period. During this period, both the upgradient and downgradient monitoring wells will be sampled on a quarterly basis for the following indicator parameters:

- pH, conductivity, lead, chromium, total organic carbon (TOC), and total organic halogen (TOX).

During one of the quarterly sampling events, the monitoring wells will also be sampled for 40 CFR 264 Appendix IX compounds.

Once the analytical results from the one-year baseline monitoring are complete, they will be analyzed and statistically significant detection limits (SSDLs) will be developed for each parameter. Based on the results, the detection monitoring parameters will be defined and the first year analytical data from downgradient wells will be analyzed to determine if SSDLs were

FIGURE 6.1
DETECTION MONITORING PROGRAM
CANNON AFB, NEW MEXICO



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exceeded. This list of parameters will include the indicator parameters (pH, conductivity, lead, chromium, TOC, and TOX) and possibly a combination of volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), pesticides, herbicides, polychlorinated biphenyls (PCBs), and/or selected inorganic analytes, depending on the results of the baseline monitoring. The need to include dioxin on the list will be reevaluated based upon completion of the ongoing RFI work at Landfill 5 and baseline monitoring sampling results.

SSDLs will be developed using the methods described in Section 6.4. The determined SSDLs will be used in the detection monitoring program to determine whether differences in detection monitoring parameters are statistically different than the baseline concentrations.

6.2.2 Detection Monitoring

Detection monitoring will begin following the completion of the baseline monitoring program. Detection monitoring will be conducted throughout the post-closure care period of 30 years. Detection monitoring will consist of the following steps:

1. Submit proposed SSDLs, from baseline monitoring program, to regional administrator (RA).
2. Sample the upgradient and downgradient wells for the detection monitoring parameters developed in the baseline monitoring program. Wells will be sampled on a semi-annual basis for the indicator parameters listed in Section 6.2.1 and on an annual basis for the list developed in the baseline monitoring program .
3. Evaluate SSDLs based on upgradient well concentrations. Submit revised SSDLs if appropriate.
4. Evaluate the analytical results from the sampling of downgradient wells.
5. If the evaluation of the analytical data indicates that no statistically significant change in the detection parameters is found, then continue the detection monitoring program.
6. If the results indicate a statistically significant increase over the established baseline concentration for any of the detection monitoring parameters, a confirmation sampling round will be initiated. If the results are confirmed, the appropriate regulatory agency will be notified.
7. If the results are confirmed, a source identification plan will be prepared to evaluate potential sources of the parameters exceeding SSDLs.
8. If the source is identified to be other than the regulated unit, then the Detection Monitoring Program will be modified to account for the source.
9. If the source is not identified to be other than the regulated unit, then the Compliance Monitoring Program, in accordance with 40 CFR Section 264.99, will be implemented.

6.3 COMPLIANCE MONITORING PROGRAM

The Compliance Monitoring Program will commence once the Detection Monitoring Program has determined that compounds have been detected above the SSDLs and are determined to be related to the regulated unit. The groundwater protection standards at the

compliance points will be the State of New Mexico standards that are in place at such time that compliance monitoring may be required.

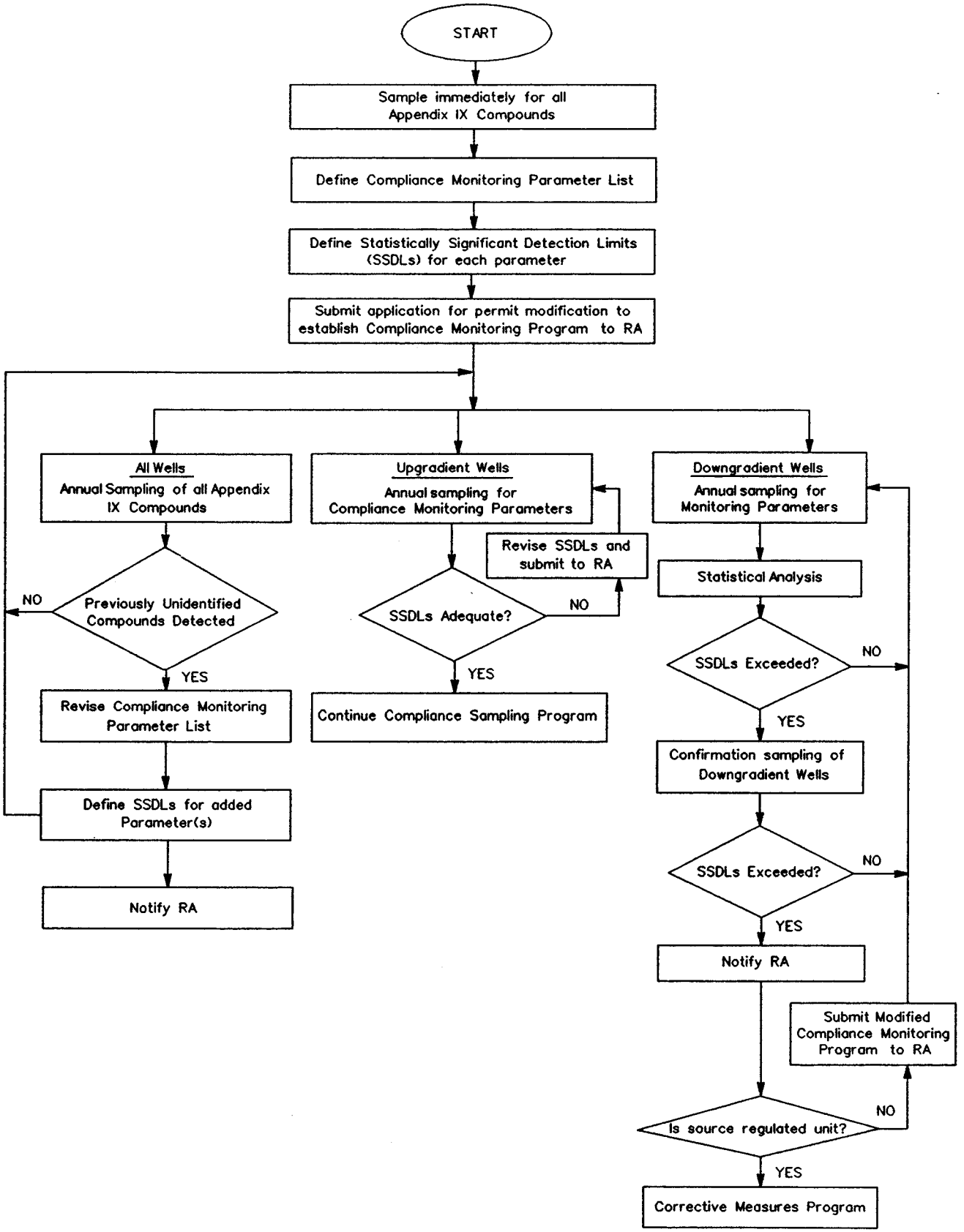
The duration of the compliance period is the number of years equal to the active life of the cell, including any waste management activity prior to permitting and the closure period. If CAFB is engaged in a corrective action program at the end of the compliance period specified above, the compliance period will be extended until CAFB can demonstrate that the groundwater protection standards have not been exceeded for a period of three consecutive years.

A flow diagram of the Compliance Monitoring Program is presented in Figure 6.2. The Compliance Monitoring Program will consist of the following steps:

1. Sample all wells in the groundwater monitoring system for 40 CFR 264 Appendix IX compounds immediately.
2. Determine Compliance Monitoring Parameters based on analytical results of groundwater samples.
3. Based on the statistical procedures developed in Section 6.4, SSDLs levels will be established for each parameter and submitted to the RA.
4. Sample the upgradient and downgradient wells for the Compliance Monitoring Parameters. Wells will be sampled on an annual basis.
5. Evaluate SSDLs based on baseline well concentrations. Submit revised SSDLs to RA.
6. Evaluate the analytical results from the sampling of downgradient wells.
7. If the evaluation of the analytical data indicates no statistically significant change in the Compliance Monitoring Parameters is found, then continue Compliance Monitoring Program.
8. If the results indicate a statistically significant increase over the established SSDLs for any of the Compliance Monitoring Parameters, a confirmation sampling round will be initiated. If the results are confirmed, the appropriate regulatory agency will be notified.
9. If the results are confirmed, a source identification plan will be prepared to evaluate potential sources of the parameters exceeding SSDLs.
10. If the source is identified to be other than the regulated unit, then the Compliance Monitoring Program will be modified to account for the source.
11. If the source is not identified to be other than the regulated unit, then a Corrective Action Plan will be submitted to the RA.

The Corrective Action Plan will include a permit modification which must include plume assessment, corrective measures study and design, and implementation of corrective action.

FIGURE 6.2
COMPLIANCE MONITORING PROGRAM
CANNON AFB, NEW MEXICO



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6.4 DATA EVALUATION AND STATISTICAL PROCEDURES

Groundwater sampling is performed to evaluate whether a release of hazardous constituents has occurred from a regulated unit that may pose a threat to human health and the environment. Regulations in 40 CFR 264 require the use of statistical procedures to determine whether baseline values or concentration limits have been exceeded in any of the monitoring wells during a sampling event. The EPA has developed guidelines for using statistical methods for analysis of groundwater monitoring data at RCRA Facilities (EPA, 1992). These guidelines will be used to evaluate groundwater data collected during the monitoring program.

The major considerations in developing a statistical procedure for Cell 3 of Landfill 5 are:

1. A large number of factors may contribute to the apparent variability of the results for a particular sample during detection monitoring. These include a) natural variability, b) sampling procedures, c) laboratory error, and d) human error. These factors are likely present in both the upgradient and downgradient samples, although their relative contribution to each type of sample may differ.
2. The data from each downgradient well represent only a single measurement of a single sampling event carried out at a single point of time. Thus, the only valid statistical evaluation that can be made is to determine, with a significant confidence level, that this sample is or is not representative of the sample.

Based on these considerations, the statistical procedure will employ multiple criteria to provide reasonable confidence of the detection of a leakage from the site. The criteria are:

1. **Concentration-based.** The concentration of a detected compound will be compared against a SSDL. The SSDL is both parameter and laboratory specific and takes into consideration various factors contributing to the sample variation. The SSDL is the concentration limit at the upper bound of the prediction interval within which a sample belonging to the sample population may be expected to fall.
2. **Multiple Occurrence.** Each detection will be compared with its recent past sampling events to determine whether there is a persistent occurrence of the same parameter or constituents. The concentration level will be compared to its past levels to determine if there is a statistically significant increase from baseline conditions.

The procedure for establishing SSDL and baseline concentrations are described in the next section.

6.4.1 Statistically Significant Detection Limit and Baseline Concentrations

Baseline monitoring will be used to establish contamination levels resulting from Cell 3 of Landfill 5. The SSDL is both parameter and laboratory specific. It is the concentration that corresponds to the upper bound of the prediction interval of the baseline population at 95 percent confidence level.

Baseline concentrations will be established in the first year of monitoring and continually assessed over time using data from the upgradient and downgradient monitoring wells. The statistical evaluation of the upgradient monitoring well will be designed to detect possible increases in the upgradient concentrations as a result of potential off-site sources.

Downgradient to upgradient monitoring well comparisons will be designed to detect whether compliance samples exhibit statistically significant differences from baseline concentration levels, and if so, where these differences occur.

The statistical test procedures will follow EPA guidelines (EPA, 1992) and include Parametric Analysis of Variance (ANOVA), nonparametric ANOVA, or the Test of Proportions. As explained below, the method to be used will be selected depending on data attributes.

If less than 50 percent of the data samples are non-detects, then the statistical tests will be conducted using ANOVA procedures. Parametric ANOVA will be applied if the data from each well are normal and exhibit equal variances (EPA, 1989, p5-5). Data normality will be tested by the Shapiro-Wilk test (EPA, 1992, p9); variance homogeneity will be assessed using Bartlett's Tests (EPA, 1989, p4). Parametric ANOVA will be applied even when the data are not normal but can be normalized via a suitable transformation (e.g., by taking the logarithms of the actual data values). If the data cannot be normalized and/or exhibit significant variance differences, the tests will be conducted using the non-parametric ANOVA procedure (also known as the Kruskal-Wallis Test)(EPA, 1989,p5-13; EPA, 1992, p41). If the data samples include more than 50 percent non-detects, the statistical analysis will be conducted using the Test of Proportions (EPA, 1989, p8-3). Detailed discussions of the above-mentioned statistical procedures with examples and references are included in Appendix H. These statistical procedures are consistent with recommended EPA methods at RCRA facilities (EPA, 1989 and EPA, 1992).

6.4.2 Procedure for Statistical Evaluation

The statistical evaluation procedure for detection or compliance monitoring is based on the methods described above. The major steps are described below:

1. **Concentration Test**. The concentration of each parameter detected will be compared against its SSDL. If all the parameters detected satisfy the concentration criteria and are normally present in background or baseline samples, then the sample has passed the concentration test and proceeds to Step 2. If its concentration exceeds the SSDL, then the sample has failed to meet the concentration criteria and proceeds to Step 3.
2. **Multiple Occurrence Test**. If any of the parameters not detected in upgradient wells has not been detected in the same monitoring well for the past two sampling events, then the sample has passed the multiple occurrence test and the statistical evaluation of this sample is complete. Otherwise proceed to Step 3.
3. The quality assurance/quality control (QA/QC) procedures applied to this sample will be examined along with trip, field, and laboratory blanks. If the analytical results can invalidate the sample, then there is no significant increase in this sample and the results of the QA/QC investigation will be documented in the annual report.
4. If the QA/QC investigation confirms the validity of the results, then the monitoring well will be resampled immediately and the sample will follow the same statistical evaluation procedure. If the result of subsequent sampling fails either of these tests then a statistically significant increase is confirmed.

SECTION 7

MONITORING WELL SAMPLING PROCEDURES

7.1 INTRODUCTION

The purpose of this plan is to ensure that samples collected during groundwater monitoring are representative of the groundwater in the aquifer and to ensure that the samples are collected, analyzed, and reported in a consistent manner. The procedures specified in the Technical Enforcement Guidance Document (TEGD) will take precedence when questions of correct procedure arise.

7.2 REVISION OF THIS PLAN

This plan will be revised and updated according to the Hazardous Waste Management Regulations, Part 901, Section 270.42 whenever directed by NMED. CAFB may initiate minor modifications if it can be demonstrated to the RA's satisfaction that the new procedure will ensure a more representative sample. This plan will be revised and updated whenever directed by the RA.

7.3 DETECTION OF ORGANIC VAPORS

The wellhead will be checked for the presence of organic vapors with an organic vapor analyzer upon opening. If organic vapors are detected at 1 ppm or more, the wellhead will be allowed to air out for at least one hour before continuing the sampling event. The air in the wellhead will be rechecked before continuing the sampling.

7.4 WATER ELEVATION, TOTAL DEPTH MEASUREMENT, FLOW RATE, AND FLOW DIRECTION

Water elevation and total depth measurements will be made from the visibly marked, surveyed point on the top of the PVC well casing rim. The type of measuring tape (e.g., steel or Teflon®) used for the measurements will be recorded in the equipment log book. Using this data, groundwater flow rate and direction in the uppermost aquifer will be determined at least annually. These measurements will also be used to determine purge time and/or volume for achieving stability.

1. Depth to the bottom of the well will be measured during every sampling event unless the well has a dedicated, permanently installed pump. If the pump prevents the measurement of well depth, these measurements will be taken every five years, or when the pump is pulled, whichever is more frequent. Total depth measurements will be taken and recorded to the nearest 0.25 foot. Total depth will be determined using a steel tape with a weight on the bottom. To measure total depth of the well, a weighted steel tape will be lowered into the well casing until the bottom is felt. The slack in the tape must be taken out while the weighted tape end remains on the bottom of the well. The total depth will

be recorded on the sampling event sheets. The total depth measurements must be adjusted to reflect the length of the weight which is attached to the end of the tape.

2. Water elevations will be taken at the time of each sampling event. All static water level elevations will be measured prior to purging and will be conducted on all wells within a 24-hour time period. The depth to water will be measured to the nearest 0.01 foot. A portable electronic water level probe will be used to determine depth to water.

   Measurements will be taken until three consecutive readings are within one quarter of an inch of each other. The field technician will note which of the three measurements appears to be the correct measurement. This depth will be recorded. Water elevation will be determined by subtracting depth to water from the surveyed elevation of the top of the well casing rim.

   If a plastic or Teflon® measuring tape is used, then this tape must be checked annually against a steel tape to determine if the tape has stretched. This will be recorded in the equipment log. If the synthetic tape has stretched more than 0.01 foot, then the tape must be calibrated with the steel tape.

   It must be noted in the applicable field log book (for the particular well) whether any wells that are being pumped could potentially impact the water elevations measured at the RCRA wells.

3. If the portable probe is used to determine depth to water, it will have to be decontaminated between wells. Decontamination procedures are outlined in Section 7.8. These procedures are also appropriate for the device used to determine total depth of the well.

7.5 FIELD LOG BOOK

A field log book will be maintained for each well. Each log book will have a separate operation and maintenance (O/M) section which will be used to track the O/M of the well and the sampling equipment. These log books will be available for review. The log books will be used to record visits to the wells, any problems with the wells, any maintenance performed, and the occurrence of all sampling events. The well condition will be annotated in these log books to include security of the cap, presence of cracks in or standing water around the concrete pad, condition of protective posts, and condition of the well casing. An example field log book format is shown in Attachment 1 of Appendix F. The log book will be used to record the following information:

- Identification of the well;
- Well depth and measurement technique;
- Depth to water and static water elevation and measurement technique;
- Time needed for recovery after purging;
- Purge volume, purge rate, and time of purge;
- Purge equipment;

- Sample withdrawal equipment;
- Date and time of sample collection and flow rate;
- Parameters to be analyzed, sample container, and preservative;
- Sample identification numbers;
- Field parameter (pH, temperature, specific conductance) data and method of analysis; pH calibration data;
- Name of collector;
- Field observations;
- Climatic conditions, including temperature;
- Method of transportation;
- Type of temperature preservative (Blue Ice, bagged ice);
- Purpose of sampling (detection, assessment, etc.);
- Order in which the samples were collected; and
- Any problems.

7.6 SAMPLE WITHDRAWAL AND COLLECTION

7.6.1 Calibration and Decontamination of Hudac Meter

All field instrumentation used to record water quality parameters (e.g., specific conductance and pH) will be calibrated prior to field use and recalibrated in the field before measuring each sample. Results will be recorded in both the Equipment Log Book and daily field notes.

The pH will be calibrated with a pH 7 and pH 10 buffer if the pH is above 7. If the general pH is not known, then pH paper will be used to determine which buffers to use.

The manufacturer's instructions for calibration procedures will be followed. Batteries will be tested before going out to the field. Spare batteries will be available to use whenever the instrument provides unstable readings.

The instrument's cell or sampling cup must be repeatedly flushed (about three times) with distilled water before and after use and in between wells. The rinse water will be thrown in the purge tank. For the sampling, the cup or cell must be flushed three times with the liquid to be sampled before measurements are made. This liquid will also be thrown in the tank.

Manufacturer's instructions for cleaning and storage will be followed. If the groundwater is visibly contaminated with oil or any other substance, the probe will be cleaned per the manufacturer's instructions and recalibrated.

7.6.2 Purging Techniques and Field Measurements

Wells with rapid water-level recovery (minimal drawdown during purging) will have specific measurements of pH, specific conductance, and temperature taken before, during, and after purging to get an accurate determination of parameter stability to assure that fresh

groundwater is being sampled. Wells with slow water-level recovery should be purged no more than once to dryness. The official field measurements of pH, temperature, and specific conductance, and the groundwater samples must be obtained as soon as the well has recovered enough to yield water for a sample.

Based on the depth to water and the purge rate, the time to purge three saturated well volumes of water will be calculated. The purge rate should not be faster than the rate used to develop the wells during installation. In addition, if the purge rate is so fast as to create an audible noise, it will be lowered. When at least three well volumes have been purged, unofficial field measurements of pH, temperature, and specific conductance will be taken to verify that these parameters have been stabilized. Stability is achieved when two consecutive measurements are +/- 0.05 pH units, 10 umhos, and 1 degree Celsius. A digital direct reading meter will be used to take pH, specific conductance, and temperature readings.

Turbidity measurements will also be taken with the direct reading meter. If turbidity is greater than 5.0 nephelometric turbidity units (NTU), samples will not be collected. The cause of the increased turbidity must be determined and, if necessary, corrected before samples may be collected. If the turbidity problem cannot be resolved within two weeks, then the samples must be collected immediately. A turbidity problem should not delay required sampling events by more than two weeks.

Once two consecutive field measurements indicate that the groundwater has stabilized, samples can be collected. Two more sets of field measurements will have to be taken to obtain the required four replicate measurements. These measurements will be recorded to the nearest 0.01 pH units and 10 umhos.

The purge water will be contained in the tank located next to each well. If analytical results indicate that the groundwater is not contaminated, the purge water may be drained onto the ground. If analytical results indicate that the groundwater is contaminated, the purge water will be treated as a hazardous waste when the appropriate hazardous waste action levels are also exceeded. Disposal of contaminated purge water on the ground could result in soil contamination that requires clean up.

7.6.3 Sampling Equipment

Each well has a dedicated pump for purging and a dedicated positive gas displacement Teflon® bladder pump for sample withdrawal. If a bailer is used, it will be constructed of inert material with a bottom filling - bottom emptying device. The bailer cord must also be of inert material. Precautions in using sampling equipment must be taken to ensure that parts that come in contact with well fluid are constructed of inert material and can be decontaminated or disposed of between uses.

7.6.4 Sample Collection Technique

The sampling pump will be operated at a flow rate of 100 milliliter (ml)/minute for the collection of samples requiring the elimination of headspace. The flow rate may be increased for collection of other samples, but may never exceed 1 gallon per minute (gpm). The pump must be operated to prevent surging or pulsing, if possible. If a bailer is used, it must be handled in such

a way as to minimize agitation and aeration. The contents of the bailer must be transferred to the sample container with minimum agitation and aeration.

Volatile organics will be the first samples collected. Four replicate samples will be prepared for laboratory analysis of the indicator parameters not measured in the field. Sample volumes, container types, preservatives, and holding times are included on Table 1 of Appendix G. The groundwater samples will be double-bagged in recloseable plastic bags, placed in a sealed laboratory cooler, packed on ice, and delivered to the laboratory. CAFB will make every effort to maintain samples at 4 degrees Centigrade from the time the samples have been collected until delivered to the laboratory.

7.7 EQUIPMENT DECONTAMINATION

The only non-dedicated pieces of equipment that will be used are the portable static water level meter (when needed) and the pH/specific conductance meter. The pH/specific conductance meter will be used for all sample locations.

In the event that non-dedicated equipment is be used, the decontamination area will be located in an area unaffected by site activities that may cause contamination of equipment. The following decontamination procedure will be used:

1. Wash in potable water with non-phosphate detergent and scrub with a stiff brush;
2. Rinse with high performance liquid chromatography (HPLC)-grade water;
3. Rinse with methanol;
4. Rinse with HPLC-grade water; and
5. Air dry.

7.8 CHAIN OF CUSTODY (COC) AND SAMPLE REQUEST FORMS

The COC is used to track samples from the point of collection to the laboratory. A sample is considered to be in a person's custody if the sample is:

1. In a person's possession;
2. Maintained in view after possession is accepted and documented;
3. Locked and tagged with Custody Seals so that no one can tamper with it after having been in physical custody; or
4. In a secured area which is restricted to authorized personnel.

The COC lists the field personnel responsible for taking samples, the project name and number, the name of the analytical laboratory to which the samples are sent, and the method of sample shipment. The COC also lists a unique description of every sample bottle in the set. Triplicate copies of the COC must be completed for each sample set collected. If samples are split and sent to different laboratories, a copy of the COC record will be sent with each sample.

The REMARKS space will be used to indicate if the sample is a matrix spike, matrix spike duplicate, or matrix duplicate. Since they are not specific to any one sample point, trip and field blanks will be indicated on separate rows. Once all bottles are properly accounted for on the

form, a sampler will write his or her signature and the date and time on the first RELINQUISHED BY space. The sampler will also write the method of shipment, the shipping cooler identification number, and the shipper airbill number on the top of the COC. Mistakes will be crossed out with a single line and initialed by the author.

One copy of the COC will be retained by sampling personnel and the other two copies will be put into a sealable plastic bag and taped inside the lid of the shipping cooler. After closing the cooler, custody seals provided by the laboratory will be affixed to the latch and across the back and front lids of the cooler, and the person relinquishing the samples will sign their name across the seal. The seal will be taped, and the cooler will be wrapped tightly with clear packaging tape. The cooler will then be relinquished by field personnel to personnel responsible for shipment, typically an overnight carrier. The COC seal must be broken to open the container. Breakage of the seals before receipt at the laboratory may indicate tampering. If tampering is apparent, the laboratory will contact the Project Manager, and the sample will not be analyzed.

The sample request form provides the necessary information to the laboratory. Sample request forms annotate that these are for RCRA purposes and that SW 846 methods are required. Examples of sample request forms may be found at Attachment 3 of Appendix F.

7.9 SAMPLE SHIPMENT

Samples collected during post-closure activities will be classified as environmental samples. In general, environmental samples are collected from streams, ponds, wells, or soil borings, and are not expected to be grossly contaminated with high levels of hazardous materials.

The sample label will be legibly written and completed with an indelible pencil or waterproof ink. The information will also be recorded in a log book. As a minimum, it will include:

1. Project codes, sample station number, and identifying code;
2. Time and date sample was collected;
3. Name of sampler;
4. Type of sample; and
5. Any other pertinent information.

7.9.1 Environmental Samples

Environmental samples being shipped to a laboratory will be packaged and shipped according to the following procedure:

Packaging

1. Place sample container, properly identified and with a sealed lid, in a sealed polyethylene bag.
2. Place sample in a fiberboard container or plastic cooler which has been lined with a large polyethylene bag.

3. Pack with enough non-combustible, absorbent, cushioning material to minimize the possibility of the container breaking.
4. Seal the large bag.
5. Seal or close outside container.

Marking/Labeling

Sample containers must have a completed sample identification label and the outside container must be marked "Environmental Sample." The appropriate side of the container must be marked "This End Up" and arrows should be drawn accordingly. No Department of Transportation (DOT) marking label is required.

Shipping Papers

No DOT shipping papers are required.

Transportation

There are no DOT restrictions on mode of transportation.

7.10 FIELD QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) PROGRAM

Field QA/QC samples will be collected and reported to ensure that the groundwater samples are representative of the groundwater quality and to ensure that cross-contamination has not occurred. Duplicate samples are required as an indication of variability in water quality or the precision of the laboratory analysis. Duplicate samples will be collected as any other sample (see Appendix G, Table 3).

7.10.1 Trip Blanks

The Occupational and Environmental Health Laboratory (OEHL) or a contract laboratory will prepare at least one trip blank for each sampling event. Trip blanks will consist of 40-ml vials of deionized, distilled water. All trip blanks will come from the lab and accompany the volatile samples at all times. One trip blank will be sent to the lab with each volatile analysis group and analyzed using Method 8240.

Trip blank contamination can be attributed to improperly cleaned containers, contaminated deionized, distilled water, or cross-contamination during the trip or at the lab. If contamination is detected in trip blanks, the probable cause must be adequately demonstrated within 60 days of receipt of the lab report. If the contaminant in question is a potential constituent from the site, immediately modify the lab or field procedure to prevent future contamination. Provide documentation to the RA of the modification within 60 days of receipt of the lab report. Trip blank data will not be used to correct sample data.

7.10.2 Equipment Blanks

Equipment blanks will be taken to check the effectiveness of cleaning of non-dedicated sampling devices. Currently, all sampling devices are dedicated to a specific well, therefore equipment blanks will not be taken.

If non-dedicated equipment is used, distilled, deionized water will be poured or pumped through the device and collected. Equipment blanks may be analyzed for Method 8240 (volatiles), Method 8270 (semi-volatiles) and metals (As, Ba, Cd, Cr, Pb, Hg, Se, Ag). At least one equipment blank will be collected per sampling event. These blanks will be handled in a manner identical to the procedures used for the samples.

If contamination is detected in the equipment blanks, it must be adequately demonstrated that the contamination was caused by the lab procedure or equipment decontamination within 30 days of receipt of the lab report or use dedicated sampling equipment for future sampling events. If the above mentioned procedures are proven to cause the contamination, then lab procedures and/or the equipment decontamination will be modified to prevent future contamination by the contaminant in question. Provide documentation of the modification to the RA within 60 days of receipt of the lab report. Equipment blank data will not be used to correct sample data.

7.10.3 Duplicate Samples

At least one set of duplicate samples must be collected from one well per sampling event. Duplicates will be collected immediately after the primary sample is collected. Duplicates will be analyzed for all parameters to be analyzed. Duplicates will be handled the same way any other sample is handled. Analysis will be the same as for the primary sample. Results will be used to measure the precision of the groundwater data.

7.11 GROUNDWATER MONITORING EQUIPMENT INSPECTION AND MAINTENANCE (I/M) PROGRAM

7.11.1 Pump Maintenance

CAFB will designate personnel responsible for inspecting the pumps at the time of sampling. CAFB will maintain a replacement pump on hand to be used in case immediate replacement is necessary. Hose repair kits should be kept for the same purpose. These inspections and any maintenance will be recorded in the field log books maintained for each well. Entries will include date and time of the inspection, name of the person performing the check, any observations made, and the date and nature of any repairs or other remedial action.

7.11.2 Equipment Tracking

CAFB will designate personnel responsible for maintaining an Equipment Log Book. This will be used to track inspection and maintenance of sampling equipment (not to include the equipment physically associated with the well itself, which will be recorded in the Field Log Book for each well).

1. An inventory of sampling equipment will be entered in the Equipment Log Book.
2. One month prior to a sampling event, sampling equipment will be inspected to ensure that it is in good condition. Equipment that is found to be deteriorated or malfunctioning must be repaired before the next sampling event. A check will be made to ensure that there are enough of the appropriate sampling collection containers. Any problems with equipment and corrective action will be annotated. Any shortfalls of collection containers and date they were ordered will be annotated.

7.12 MAINTENANCE OF MONITOR WELLS

Wells must be maintained in good working order. Visual or geochemical evidence of physical degradation of casing material, concrete pad, significant increases in turbidity of samples, changes in the recovery rate, and damage to well casing, etc. will be investigated and recorded in the Field Log Book and repaired. Damaged wells will be replaced if they cannot be repaired and if the integrity of the samples is at risk.

Wells will be analyzed for turbidity with a digital direct reading meter during each sampling event to determine if the well is structurally stable or to determine if the well needs to be redeveloped.

If redevelopment is necessary, it should not employ a discharge rate that exceeds the recovery rate and should include a surge and flow reversal method to dislodge the fine particles from the filter pack. Air must never be used to redevelop wells. Redevelopment should continue until the turbidity is below 5 NTU or until another State-approved standard is achieved. Air jetting must never be used to redevelop the wells.

If redevelopment does not lower the turbidity to acceptable levels, CAFB will determine the reason for the increased turbidity. If the turbidity is caused by damage to the well or incorrect filter pack or screen slot size, then the well must be replaced. If the well evidences high pH that is caused by bentonite or other well construction materials, then the well must be replaced or repaired.

Design plans will be modified to meet state specifications, as necessary, before well drilling and installation activities are initiated. CAFB will provide well design plans to the NMED for approval.

SECTION 8
QUALITY ASSURANCE/QUALITY CONTROL FOR CHEMICAL ANALYSES

8.1 QUALITY ASSURANCE OBJECTIVES

The quality assurance objectives for all measurement data include considerations of precision, accuracy, representativeness, completeness, and comparability. Parts of this section incorporate by reference EPA publication, Test Methods for Evaluating Solid Waste, 3rd Edition (SW-846).

8.2 PRECISION

Precision, as defined in SW-846, is the agreement between a set of replicate measurements without assumption or knowledge of the true value. Precision is assessed by duplicate/replicate sample analysis and is expressed in terms of relative percent difference (RPD). The RPD is as follows:

$$RPD = \frac{V1 - V2}{(V1 + V2)/2} * 100$$

where:

- RPD = relative percent difference;
- V1 = first sample value; and
- V2 = second (replicate) sample value.

The selected laboratory will meet or exceed the precision for the applicable analytical methods, as recommended in SW-846. Acceptable levels of precision may vary according to the sample matrix, the specific analytical method, and the analyte concentration.

8.3 ACCURACY

Accuracy is determined by analyzing a sample and its corresponding matrix spike (MS) sample. Accuracy is expressed as percent recovery (%R)

The %R is calculated as shown below:

$$\%R = \frac{Ss-So}{Sa} * 100$$

where:

- %R = percent recovery;
- So = Background value, value obtained by analyzing the sample;
- Sa = Concentration of the spike added to sample; and
- Ss = Value obtained by analyzing the sample with the spike added.

The laboratory will meet or exceed the accuracy reported for analysis of samples with similar matrix and concentration of contaminants. The expected %R will confirm to the values specified in SW-846 for the recommended analytical methods. The %R is dependent upon the sample matrix, method of analysis, and compound analyzed.

8.4 REPRESENTATIVENESS

Representativeness is the degree to which sampling data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, or an environmental condition. Representativeness is a qualitative parameter which is most concerned with the proper design of the sampling program. Samples must be representative of the environmental media being sampled. Selection of sample locations and sampling procedures incorporate consideration of obtaining the most representative sample possible.

Representativeness will be evaluated through the analysis of field replicate samples which are collected and analyzed as separate, individual samples. In addition, trip blanks will provide a measure of quality control for volatile organic compound analyses, as discussed in Section 7.

8.5 COMPLETENESS

The completeness of the data is the percentage of valid data obtained from the measurement system (field and laboratory) versus the amount of data collected from the system. At the end of each sampling event, an assessment of the completeness of data will be performed and, if any data omissions are apparent, an attempt will be made to re-sample the parameter in question, if feasible. The specific objective for completeness of this project shall be that greater than or equal to 90 percent of the data collected is judged to be valid.

8.6 COMPARABILITY

Comparability expresses the degree of confidence with which one data set can be compared to another. The comparability of all data collected will be ensured by:

- Using consistent documented analytical procedures for samples of similar matrices;
- Ensuring traceability of all analytical standards and/or source materials to EPA or National Institute for Standards and Testing (NIST);
- Reporting results from similar matrices in standard units and formats including the reporting of QC data;
- Following laboratory quality control within the Laboratory Quality Assurance Program.

8.7 CALIBRATION PROCEDURES AND FREQUENCY

Instruments and equipment used to gather, generate, or measure environmental data will be calibrated with sufficient frequency and in such a manner that accuracy and reproducibility of results are consistent with the manufacturer's specifications. Records of calibration, repairs, or replacement will be filed and maintained by the designated laboratory personnel performing quality control activities. These records shall be filed at the location where the work is performed and will be subject to QA audit. For all instruments, the laboratory shall maintain a factory-trained repair staff with in-house spare parts or shall maintain service contracts with vendors.

Calibration of laboratory equipment shall be based on approved written procedures. In all cases, recent EPA or laboratory-specified standard operating procedures (SOPs), performed in accordance with SW-846, take precedence over calibration guidelines discussed below.

Analysis of duplicate samples, spiked blanks, and matrix blanks will be performed where possible to document the effectiveness of calibration procedures. The number, frequency, and type of these samples will be sufficient to verify the success of the calibration program (at least 10 percent of all samples).

8.8 ANALYTICAL PROCEDURES

Analytical procedures will conform to the EPA publication, Test Methods for Evaluating Solid Waste (SW-846), 3rd edition.

8.8.1 Laboratory Analytical Parameters

Analyses of groundwater samples will be conducted annually for the VOCs, SVOCs, PCBs, pesticides, herbicides, and inorganic parameters as discussed in Section 6.

The analytical methods and quality control protocols are contained in Appendix G. Table 1 of this appendix specifies the chemical group (VOC, SVOC, etc.), analytical method, preservation, container type and volume, and holding times. Table 2 lists each analyte, method, method detection limit (MDL), and practical quantitation limit (PQL). Table 3 specifies internal (laboratory) quality control procedures. Table 4 specifies the method-specific quality control limits for the groundwater samples. The MDLs and Practical Quantitation Limits (PQLs) from the selected lab will be consistent with SW-846, Appendix B of 40 CFR 186, and the NMED document "Components of an Adequate Laboratory Quality Assurance/Quality Control Plan."

The MDL for each analyte is specific for the analytical laboratory. The laboratory selected to perform the analyses will furnish MDLs to CAFB for submittal to NMED prior to implementation of the sampling program. The analytical laboratory will also confirm its ability to achieve the specified PQLs or supply alternative PQLs for regulatory approval prior to sample collection and analysis.

8.9 LABORATORY RECORDS, DATA REDUCTION, VALIDATION, AND REPORTING

The procedures used for calculations and data reduction are specified in each analytical method (analytical methods are stated in Table 2 Appendix G). The laboratory will enter raw data in bound laboratory notebooks. A separate book will be maintained for each analytical procedure. The data will be entered such that sufficient space remains to enter all subsequent calculations required to arrive at the final (reported) value for each sample.

Data reduction calculations will include factors such as sample dilution ratios, corrections for blank readings, and titrant normality. Instrument chart recordings and calculator print-outs are labeled and attached to their respective pages, except for voluminous gas chromatograph recordings that are cross-referenced and stored separately.

Data will be reported as micrograms of analyte per liter for aqueous samples. Concentration units will be listed on reports and any special conditions will be noted. Data reports will include the unique sample number given to each sample, COC, and case narrative.

8.9.1 Reporting

Reports of analytical results for this project will contain data sheets and the results of analysis of QC samples. The reports will contain the following items:

- Project identification;
- Field sample number;
- Sample matrix description;
- Date and time of sample collection;
- Analytical method description and reference citation;
- Individual parameter results;
- Date of analysis (extraction, first run, and subsequent runs);
- Detection limits achieved;
- Dilution or concentration factors; and
- Corresponding QC report.

Analytical results for gas chromatograph (GC) analysis shall be reported based on quantitation from the first column unless precluded by interferences.

The QC report will contain Level IV reporting requirements consisting of, but not limited to, results of surrogate spikes, internal standards, matrix spike (MS)/matrix spike duplicate (MSD) samples, laboratory control samples (LCS), method blanks, and initial and continuing instrument calibrations.

Quality control results will be reviewed by the laboratory quality assurance manager to determine the accuracy and precision of the analytical results. The laboratory quality assurance manager or the laboratory director will review all final reports and associated quality control data. Approval will be shown by a signature. Results will be recorded on the QC report forms for the appropriate tests and correlated to the analysis results by the QC report number. The QC results will be used to prepare control charts for each test.

Raw gas chromatograph/mass spectrometer (GC/MS) data will be archived on magnetic tape. Chromatograms and reports from all analyses will be saved in appropriate files.

Data will be reported along with method detection levels and any qualifiers necessary. Commonly used data qualifiers consist of the following flags:

For organic compounds:

U Indicates element was analyzed for but not detected. Reported value is the MDL.

J Indicates an estimated value. Generally applied to values above the MDL and below the PQL.

B This flag is used when the analyte is detected in the blank as well as a sample. It indicates possible/probable blank contamination and warns the data user to take appropriate action.

For inorganic analytes:

U Indicates element was analyzed for but not detected. Reported value is the MDL.

B Indicates value greater than or equal to the MDL but less than the PQL.

E Indicates a value estimated or not reported due to the presence of interference.

N Indicates spike sample recovery is not within control limits.

* Indicates duplicate analysis is not within control limits.

S Indicates value determined by Method of Standard Addition.

+ Indicates the correlation coefficient for Method of Standard Addition is less than 0.995.

8.10 INTERNAL QUALITY CONTROL

QC data are necessary to determine precision and accuracy and to demonstrate the absence of interference and/or contamination of glassware and reagents. Laboratory-based QC will constitute at least 10 percent of each data set generated and will consist of blanks, replicates, standards, MS/MSDs, surrogate spikes, and blanks. Depending upon the particular method used, QC may be more rigorous, but at a minimum, one MS and MSD will be provided at a frequency of one for each round of samples collected from the four groundwater monitoring wells.

EPA recommended matrix spiking solutions will be used for GC/MS parameters. Precision and accuracy data will be based on only these spiking compounds. Surrogates and internal standards will be added to all samples requiring GC/MS analysis. Surrogates will be added to all samples requiring GC analysis. One method blank will be run for every 20 samples or each batch (whichever is more frequent) analyzed. Blank samples will be analyzed in order to assess possible contamination and determine what corrective measures need to be taken. QC limits are specified in Table 3 of Appendix G. Table 3 contains all internal QC to be used and the corrective action necessary for non-compliances.

8.10.1 Analytical Replicate Analyses

Replicate samples are aliquots of a single sample that are split on arrival at the laboratory or upon analysis. Since it is anticipated that the levels of most parameters will be below the laboratory detection limits, precision data on replicate analyses will largely be derived from matrix spike and matrix spike duplicate (or matrix duplicate) data for organic and inorganic analyses. Significant differences between two replicates that are split in a controlled laboratory environment will result in flagging the affected analytical results.

8.10.2 Calibration Standards

A calibration standard is prepared in the laboratory by dissolving a known amount of a pure compound, traceable to NIST, in an appropriate matrix. The final concentration calculated from the known quantities is the true value of the standard. The results obtained from these standards will be used to generate a standard curve and thereby quantify the level of compound in the environmental sample.

8.10.3 Surrogate Spike Analyses

A surrogate spike analysis is used to determine the efficiency of recovery of analytes in the sample preparation and analysis. Calculated percentage recovery (%R) of the surrogate spike is used as a measure of the accuracy of the total analytical method. A surrogate spike is prepared by adding (to a sample before extraction) a known amount of pure compound which is similar chemically to the compounds to be assayed in the sample, but yields a unique detection signal. Surrogate compounds will be added to all samples, method blanks, duplicate samples, and matrix spikes as specified in the methods. If the %R does not fall within the limits prescribed by the methods, the corrective actions described in the method will be implemented. (See Table 3 Appendix G).

8.10.4 Matrix Spike/Duplicate Spike Analyses

The effect of matrix interferences on analyses will be determined through the use of matrix spikes. Aliquots of the same sample will be prepared in the laboratory and each aliquot will be treated in an identical manner throughout the analysis. Spikes will be added at concentrations specified in the method. The percent difference between the values of the spiked duplicates will be noted as a measure of the precision of the analytical method.

Selected samples will be spiked to find accuracy as a percentage of the analyte from the sample matrix. These matrix spikes will be prepared using reagent grade salts, pure compounds, or certified stock solutions. Concentrated solutions will be used to minimize differences in the sample matrix resulting from dilution. The final concentration after spiking should be within the same range as the samples being analyzed to avoid the need for dilution, attenuation of instrument outputs, or other required alterations in the procedure that might affect the instrument response and determination of accuracy.

A matrix spike duplicate sample is prepared in the same manner as the matrix spike sample. The matrix spiking compounds and recommended QC limits for percentage recovery and relative percentage differences for water samples are listed in Table 4 of Appendix G.

The results of the analyses will be reviewed by the laboratory supervisor. Deviations from the established QC criteria will be noted and reanalyzed or other corrective action will be implemented as necessary, as outlined in Table 3 of Appendix G.

8.11 PERFORMANCE AND SYSTEM AUDITS

8.11.1 System Audits

System audits, performed by CAFB's quality assurance manager or a designated representative, will encompass evaluation of QA components to ascertain their appropriate selection and application. In addition, field and laboratory QC procedures and associated documentation will be system audited. These audits will be performed periodically during the monitoring period; however, if conditions adverse to quality are detected, or if the Project Manager requests the Quality Assurance Manager to perform unscheduled audits, these activities will be instituted.

8.11.2 Performance Audits

Performance audits will be conducted periodically throughout the monitoring period to determine the accuracy and implementation of the Quality Assurance Program. As in system audits, the Quality Assurance Manager or assigned alternate will exercise planned and scheduled performance audits with the understanding that unplanned audits may be implemented if requested. Performance audits may be performed once annually.

In addition to in-house performance audits, the laboratory also participates in inter-laboratory performance evaluation studies. The laboratory selected will supply a list of performance evaluation programs in which it is a participant and any certifications it holds resulting from such performance evaluation programs.

8.12 PREVENTATIVE MAINTENANCE OF LABORATORY INSTRUMENTS

All analytical instruments will be serviced at intervals recommended by the manufacturer. Service contracts for regular maintenance and emergency service will be maintained for major instruments. An Instrument Repair Maintenance Log Book will be kept for each instrument. Entries will include the date of service, type of problem encountered, corrective action taken, and initials and affiliation of the person providing the service.

Any degradation of instrument performance, such as changes in the response factors or sensitivity, will be used as an indication of potential problems. These will be brought to the attention of the Laboratory Supervisor and preventative maintenance or service will be scheduled to minimize downtime. Back-up instrumentation and an inventory of critical spare parts will be maintained to minimize delays in completion of analyses.

8.13 DATA ASSESSMENT PROCEDURES

The precision, accuracy, and completeness of measurement data generated during the monitoring will be assessed. The assessment procedures are described in Sections 8.2 through 8.6. The analytical procedures require quality control checks such as calibration verifications, method blanks, internal standards, and interference blanks. These checks are made possible by the inclusion of QC samples into the sample data collection process. Table 3 of Appendix G specifies the type and number of QC samples that will be analyzed. The data generated will be used during the data validation process.

8.14 CORRECTIVE ACTION

The following procedures have been established to assure that conditions adverse to quality, such as malfunctions, deficiencies, deviations, and errors, are promptly investigated, evaluated, and corrected.

When a significant condition adverse to quality is noted in the field or the laboratory, the cause of the condition will be determined and corrective action taken to preclude repetition. Condition identification, cause, reference documents, and corrective action planned to be taken will be documented and reported to the CAFB Quality Assurance Manager and involved laboratory management, if necessary, as a minimum. Implementation of correction action is verified by follow-up action. All project personnel have the responsibility, as part of the normal work duties, to promptly identify, correct, and report conditions adverse to quality.

Corrective actions may be initiated as a minimum:

- When predetermined acceptance standards are not attained (objectives for precision, accuracy and completeness);
- When procedures or data compiled are determined to be faulty;
- When equipment or instrumentation is found faulty;
- When samples and test results are questionably traceable;
- When designated approvals have been circumvented;
- As a result of system and performance audits;
- As a result of a management assessment; or
- As a result of laboratory/inter-laboratory comparison studies.

The field investigation team, quality assurance auditors, document and sample control personnel, and laboratory groups, will monitor on-going work performance in the normal course of daily responsibilities. Work at the site will be monitored by the Field Team Leader.

8.15 QUALITY ASSURANCE REPORTS

A QA report will be prepared that includes the following:

- QA/QC activities over the reporting period;
- Any problems/comments associated with the analytical and sampling effort; and
- Any corrective actions taken in the field, results of any audits, and any modifications to laboratory protocols will be discussed.

A summary of QA/QC activities and any problems/resolutions associated with the sampling and analytical effort will be included in the annual monitoring report.

SECTION 9
HEALTH AND SAFETY PLAN

9.1 GENERAL HEALTH AND SAFETY REQUIREMENTS

The purpose of this plan is to identify the health and safety policies, practices, and procedures to be followed during groundwater sampling activities conducted during the post-closure care period for CAFB, Landfill 5, Cell 3. In addition, this plan assigns responsibilities, specifies appropriate personal protective equipment and clothing, outlines site monitoring, and provides for contingencies that may arise during environmental monitoring of the CAFB Site. This plan is based on requirements for health and safety plan content established by the Occupational Safety and Health Administration (OSHA) in 29 CFR 1910.120.

The provisions of this plan are equally applicable to CAFB personnel and all others involved in the groundwater sampling activities at the site. A Plan Acceptance Form (Figure 9.1) will be signed by all personnel working on the site. Details concerning site location, history and background can be found in Section 1 of this document.

9.2 SCOPE OF WORK

The post-closure care activities at Cell 3 of Landfill 5 will provide a means of determining whether the low permeability cap is continuing to perform as designed. Field activities that are to be performed involves groundwater sampling.

9.3 PROJECT TEAM ORGANIZATION

The names of CAFB project personnel are as follows:

CAFB Project Manager: Sandy Mukherjee and Wayne McKenzie

CAFB Field Team Leader: John Eckhoff

CAFB Project Health and Safety Officer: Sandy Mukherjee

The above names are subject to change. The team structure may also change if outside sources are contracted to perform the activities.

9.3.1 Responsibilities of Project Personnel

The Project Manager is responsible for:

- preparing and organizing the background review of the site;
- coordinating the preparation and execution of the Work Plan and Health and Safety Plan; and
- preparing and organizing the field team.

FIGURE 9.1

PLAN ACCEPTANCE FORM

PROJECT HEALTH AND SAFETY PLAN

Instructions: This form is to be completed by each person to work on the project work site and returned to the Project Health and Safety Officer.

I have read and agree to abide by the contents of the Health and Safety Plan for the following project:

Landfill 5, Cell 3
Post-Closure Care
Cannon Air Force Base

_____
Name (print)

_____
Signature

_____
Date

RETURN TO:

CAFB Project Health and Safety Officer

The Field Team Leader has the authority to direct operations and site activities and his responsibilities include:

- managing field operations;
- executing the Work Plan and schedule;
- coordinating with the Project Health and Safety Officer in determining the appropriate protection level;
- enforcing site control;
- documenting field activities and sample collection; and
- serving as a liaison.

The responsibilities of the Project Health and Safety Officer include:

- periodically inspecting protective clothing and equipment;
- ensuring that protective clothing and equipment are properly stored and maintained;
- controlling entry and exit on site;
- confirming each team member's suitability for work based on a physician's recommendation;
- monitoring personnel for signs of stress, such as cold exposure, heat stress and fatigue;
- implementing the Project Health and Safety Plan;
- conducting periodic inspections to determine if the Project Health and Safety Plan is being followed;
- enforcing the "buddy" system;
- knowing emergency procedures, evacuation routes, and the telephone numbers of the ambulance, local hospital, poison control center, fire department and police department;
- notifying, when necessary, local public emergency officials;
- coordinating emergency medical care;
- setting up decontamination lines and the decontamination solutions appropriate for the type of potential chemical contaminants on site;
- controlling the decontamination of equipment, personnel, and samples from the potentially contaminated areas;
- assuring proper disposal of contaminated clothing and materials;
- ensuring that required equipment is available;
- advising medical personnel of potential exposures and consequences; and
- notifying emergency response personnel by telephone or radio in the event of an emergency.

Project team members involved in this field investigation are responsible for:

- taking precautions necessary to prevent injury to themselves and other employees;
- complying with the Project Health and Safety Plan and reporting any deviations from this plan to the Field Team Leader;
- maintaining visual contact between partners (buddy system);
- performing only those tasks they believe they can do safely; and
- immediately reporting any accidents and/or unsafe conditions to the Field Team Leader.

9.4 TRAINING REQUIREMENTS AND MEDICAL SURVEILLANCE

9.4.1 Work Site Training.

On-site personnel involved in groundwater sampling associated with post-closure care activities are required to receive 40 hours of initial training in hazardous waste operations prior to participating (29 CFR Part 1910.120[e]). Prior to beginning work at the site, the Project Health and Safety Officer will provide a briefing which covers the following topics:

- Name of personnel responsible for site safety and health;
- Site history;
- Safety, health and other hazards at the site;
- Work practices by which the employee can minimize risk from hazards;
- Acute effects of compounds at the site;
- Evacuation procedures and routes to emergency medical treatment facilities; and
- Decontamination procedures.

9.4.2 Daily Training Sessions

Each morning before work begins, a short 5- to 10-minute training session will be held covering one of the previous work-site training topics and plans for the days activities. The Project Health and Safety Officer will be responsible for this training and will record in his log book the date, time, topics covered, attendees, and location of all training.

9.4.3 Medical Surveillance

Personnel engaged in hazardous waste operations are also required to be enrolled in a medical surveillance program (29 CFR Part 1910.120[f]).

9.5 SITE VISITOR POLICIES

All visitors entering the site must report to the site Field Team Leader/Project Health and Safety Officer, and state their purpose for entering the area. The site Field Team Leader/Project Health and Safety Officer will record the persons name, date and purpose for entering the area in the field log book.

9.5.1 Review of Health and Safety Plan

All persons, including visitors, entering the site during post-closure groundwater sampling activities must read the Project Health and Safety Plan and sign the plan acceptance form (Figure 9.1).

9.5.2 Training Requirements

Visitors entering the site are required to have the same training as on-site project personnel, as stated above. The Field Team Leader/Health and Safety Officer will brief the visitor on site contaminant and physical hazards, required personal protective equipment/clothing, and emergency procedures.

Visitors are required to provide their own personal protective equipment. If a visitor does not have the required personal protective equipment, required training, or does not comply with site health and safety requirements, the Field Team Leader/Project Health and Safety Officer may request they leave the site.

9.6 CHEMICAL HAZARDS

9.6.1 Potential Chemical Hazards

This section contains information regarding potential chemical hazards at Cell 3 of Landfill 5. Included in this section are a hazard analysis and site monitoring requirements. Site location, history and facility description are presented in Section 1 of this document.

Results of previous investigations at Cell 3 of Landfill 5 indicate that there has been no indication of significant groundwater contamination or degradation of groundwater quality in any of the wells that could be attributed to Cell 3 of Landfill 5. During past investigations at the site, volatile organic compounds were not detected at levels which would cause concern regarding the health and safety of personnel involved in this type of investigation. However, due to the nature of the materials suspected to have been stored at the site and to the location of the monitoring well screened interval relative to the water table (see Section 5.3), these data may not reliable. For this reason, although past data indicates that volatile organic compounds are not present at elevated concentrations, efforts will be made to ensure that workers are protected from exposure to volatile organic compounds in the breathing zone.

9.6.2 Hazard Analysis

Concentrations of potential airborne contaminants resulting from activities associated with groundwater sampling are not expected to approach concentrations of health significance during field activities. However, a number of the contaminants which were disposed of in Cell 3 are skin and eye irritants. To protect field personnel from these irritants, impermeable gloves and boots, and eye protection will be worn whenever the potential exists for liquid splashes (e.g., during groundwater sampling). Skin or eye disorders (rashes, conjunctivitis, etc.) should be reported immediately to the Project Health and Safety Officer by all site workers. Good personal hygiene (hand washing and showers), and procedures for use of personal protective clothing must be followed by all site workers.

Based on the foregoing discussion, groundwater sampling activities conducted on-site are anticipated to utilize Level D protection.

9.6.3 Air Monitoring

Since potential exposure via inhalation to volatile compounds is a possibility, site air monitoring must be conducted. Monitoring is repeated whenever the following circumstances arise:

- Whenever a different type of operation is initiated (e.g., groundwater sampling as opposed to drilling);
- When weather conditions change; and
- When work begins on a different portion of the site.

Initial air monitoring of each site will be conducted using Level D protection. A photo ionization detector (PID) will be the primary site monitoring device used during these activities. Colorimetric indicator tubes will also be used on this site if the PID shows readings of 1 ppm above background. The manufacturer's literature will be consulted for use of these tubes. Required personal protection for each site will be established based upon air monitoring results.

9.6.4 Air Monitoring Criteria

During the field activities at this site, the OSHA air monitoring criteria will be used to determine the appropriate level of personnel protection. The Project Health and Safety Officer will be contacted if modification of the level of protection is deemed necessary.

9.7 PHYSICAL HAZARDS

Training, adherence to work rules, and careful housekeeping can prevent many problems or accidents arising from physical hazards. The general rules and preventative measures for this project are discussed below.

9.7.1 Explosion Hazard

No flammable materials will be brought on site.

9.7.2 Slip, Trip, and Fall Hazards

Personnel should be constantly aware of the possibility of slips, trips, and falls due to poor and possibly slippery footing in the work areas. Good housekeeping can prevent some of these hazards.

9.7.3 Heat Stress and Cold Injuries

The two primary physical agents which may threaten on-site personnel are heat and cold. The following sections delineate preventive measures and methods for heat/cold stress monitoring.

9.7.3.1 Heat Stress

Hot weather can cause physical discomfort, loss of efficiency, and personal injury. Heat stress prevention is important because once a person suffers from heat stroke or heat exhaustion, that person may be more likely to have additional heat related illness. Heat stress can occur even when temperatures are moderate. Steps to prevent heat stress include the following:

- Modify work/rest schedules, mandate work slowdowns as needed, and perform work during cooler hours of the day;
- Provide shelter or shaded areas to protect personnel during rest periods; and
- Urge workers to drink water to maintain worker's body fluids at normal levels.

9.7.3.2 Effects of Heat Stress

If the body's physiological processes fail to maintain a normal body temperature because of excessive heat, a number of physical reactions can occur. they can range form mild reactions such as fatigue, irritability, anxiety, and decreased concentration, dexterity, or movement to death.

Heat related problems include:

- Heat rash: Caused by continuous exposure to heat and humid air and aggravated by chafing clothes. Decreases ability to tolerate heat as well as being a nuisance.
- Heat cramps: Caused by profuse perspiration with inadequate fluid intake and chemical replacement, especially salts. Signs include muscle spasm and pain in the extremities and abdomen.
- Heat exhaustion: Caused by increased stress on various organs to meet increased demands to cool the body. Signs include shallow breathing; pale, cool, moist skin; profuse sweating; and dizziness and lassitude.
- Heat stroke: The most severe form of heat stress. Body must be cooled immediately to prevent severe injury and/or death. Signs include red, hot, dry skin; no perspiration; nausea; dizziness and confusion; strong, rapid pulse; and possibly coma. Medical help must be obtained immediately.

9.7.3.3 Cold Related Illness

If work on this project is accomplished during the winter months, thermal injury due to cold exposure becomes a problem for field personnel. Hypothermia and frostbite are the two injuries which can result due to exposure to the cold.

Frostbite is both a general and medical term given to areas of local cold injury. Unlike systemic hypothermia, frostbite rarely occurs unless the ambient temperatures are less than freezing and usually less than 20°F. Areas of the body which have high surface area-to-volume ratios, such as fingers, toes, and ears are the most susceptible to frostbite.

Local injury resulting from cold is included in the generic term frostbite. There are several degrees of damage. Frostbite of the extremities can be categorized into:

- Frost nip or incipient frostbite: Characterized by suddenly blanching or whitening of skin.
- Superficial frostbite: Skin has a waxy or white appearance and is firm to the touch, but tissue beneath is resilient.
- Deep frostbite: Tissues are cold, pale, and solid; extremely serious injury.

Hypothermia is defined as a decrease in the body core temperature below 96°F. The body temperature is normally maintained by a combination of central (brain and spinal cord) and peripheral (skin and muscle) activity. Interferences with any of these mechanisms can result in hypothermia, even in the absence of what normally is considered a "cold" ambient temperature.

The symptoms of systemic hypothermia are usually exhibited in five stages:

1. Shivering;
2. Apathy, listlessness, glassy stare, sleepiness, and (sometimes) rapid cooling of the body to less than 95°F;
3. Unconsciousness, slow pulse, and slow respiratory rate;
4. Freezing of the extremities; and
5. Death.

The following steps should be taken to prevent hypothermia:

- Educate workers to recognize the symptoms of frostbite and hypothermia;
- Ensure the availability of dry changes of clothes;
- Develop a capability for temperature recording at the site; and
- Assure the availability of warm drinks.

Any person developing moderate hypothermia defined as a core temperature of 92°F cannot return to work for 48 hours.

9.8 PERSONAL PROTECTIVE EQUIPMENT

Based on a review of site history, description, and data, it is anticipated that routine activities at this site will require Level D protection. However, Level C is also delineated below in case air monitoring or site conditions require additional protection.

9.8.1 Level D Protection

Specific Level D protective equipment includes:

- safety boots;
- butyl rubber gloves;
- chemical splash goggles for groundwater sampling activities (if splash hazard is present); and
- hard hat when in the vicinity of heavy equipment.

9.8.2 Level C Protection

Specific protective equipment for Level C personal protection includes:

- full-face air purifying respirator with organic vapor and high efficiency particulate air (HEPA) cartridges;
- chemical resistant clothing (e.g., Saranex) with hood;

- inner PVC gloves;
- outer butyl rubber gloves;
- chemically resistant safety boots or safety boots with disposable chemically resistant boot covers (chemical resistant layer is to be of butyl rubber); and
- hard hat when in the vicinity of heavy equipment.

9.8.3 Protective Equipment Requirements

All personal protective equipment used during the course of this field investigation will meet the following applicable OSHA requirements:

Type of Protection	Regulation	Source
Eye and face	29 CFR 1910.133	ANSI Z87.1-1968
Respiratory	29 CFR 1910.134	ANSI Z88.1-1980
Head	29 CFR 1910.135	ANSI Z89.1-1969
Foot	29 CFR 1910.136	ANSI Z41.1-1967

ANSI = American National Standards Institute

If Level C respiratory protection is used, personnel must wear a respirator that has been successfully fitted to the face.

Air purifying respirators cannot be used under the following conditions:

- oxygen deficient environment;
- Immediately Dangerous to Life or Health (IDLH) contaminant concentration in the breathing zone;
- respirator maximum use limit is exceeded based on respirator protection factor; or
- odor threshold of contaminants exceeds the permissible exposure limit (PEL).

The action levels used to determine the required levels of protection for work activities and specific measuring instruments are presented in Section 9.6.

9.9 DECONTAMINATION

To prevent harmful materials from being transferred into clean areas or from exposing unprotected workers, all field personnel exiting an area of potential contamination may undergo decontamination. The extent of decontamination depends on a number of factors, the most important being the type and concentration of the contaminant involved. Personnel decontamination will be required for work done under Level C conditions, but not under Level D conditions.

9.9.1 Personnel decontamination

The decontamination station will include provisions for collecting disposable protective equipment (such as garbage bags); washing boots, gloves Saranex or vinyl rainsuits (if used), and field instruments and tools; and washing hands, face, and other exposed body parts. Refuse form

decontamination will be left at the facility for disposal. At no time shall contaminated or potentially contaminated personnel, clothing, or equipment be placed or transported in personal vehicles, company vehicles, or rental vehicles.

Decontamination equipment will include:

- Plastic buckets and pails;
- Scrub brushes and long-handle brushes;
- Non-phosphate detergent
- Containers of water;
- Paper towels;
- Plastic garbage bags; and
- Distilled water.

Soft-bristled scrub brushes and long handle brushes will be used to remove contaminants from personnel. Washing and rinsing will be done in combination with a sequential doffing of clothing. Buckets of water or garden sprayers will be used for rinsing and metal or plastic cans or drums will be used to store contaminated liquids.

9.9.2 Decontamination During Medical Emergencies

During some medical emergencies, it is possible that decontamination may aggravate or cause more serious health effects. If prompt life-saving first aid and medical treatment is required, decontamination procedures should be omitted. Whenever possible, personnel should accompany injured personnel to the medical facility to advise on matters involving decontamination.

9.9.3 Equipment Decontamination

The decontamination of equipment is described in Section 7.8.

9.10 CONTINGENCY PLAN FOR EMERGENCIES

9.10.1 Emergency Procedures

In the event that an emergency develops on site, the procedures delineated herein are to be immediately followed. Emergency notification information is contained in Section 9.12. Emergency conditions are considered to exist if any member of the field crew is involved in an accident or experiences any adverse effects or symptoms of exposure while on site, or a condition is discovered that suggests the existence of a situation more hazardous than anticipated.

9.10.2 Emergency Equipment

A first aid kit will be maintained on site. Field personnel will have access to a cellular phone.

9.10.3 "Buddy" System

All work on site will be done using the "buddy" system. Prior to beginning work, buddies will be assigned. Buddies are responsible for ensuring the safety of their respective buddies and

should be aware of the potential for exposure to materials found on site, and the symptoms of exposure to these materials, as well as general hazards of the workplace.

9.10.4 Chemical Exposure

If a member of the field crew demonstrates symptoms of chemical exposure, the procedures to be followed are:

- another team member (buddy) should remove the individual from the immediate area of contamination and communicate to the Field Team Leader via two-way radio or hand signals of the chemical exposure;
- the Project Health and Safety Officer should contact the appropriate emergency response agency;
- precautions should be taken to avoid exposure of other individuals to the chemical;
- if the chemical is on the individual's clothing, the chemical should be neutralized or removed; and
- if the chemical has contacted the skin, the skin should be washed with copious amounts of water.

All chemical exposure incidents must be reported in writing to the Office Health and Safety Representative. The Project Health and Safety Officer is responsible for completing an accident report. Copies of this form will be kept on site by the Project Health and Safety Officer.

9.10.5 Personal Injury

In cases of personal injury at the site, the procedures used are:

- the injured team member's buddy will signal the Field Team Leader via two-way radio or hand signals that a injury has occurred;
- a field team member trained in first aid will administer treatment to the injured worker; and
- the victim will then be transported to the nearest hospital or medical center by ambulance if necessary.

The Project Health and Safety Officer is responsible for making certain that an accident report form is completed. This form is to be submitted to the Office Health and Safety Representative. Follow-up action can then be taken to correct the situation that caused the accident.

9.10.6 Evacuation Procedures

The Project Health and Safety Officer will initiate evacuation procedures by advising all site personnel to leave the site. All personnel in the work area will evacuate the area and meet in the designated area for an accounting of personnel. Further instructions will then be given by the Project Health and Safety Officer.

9.11 MONITORING EQUIPMENT CALIBRATION AND MAINTENANCE

Monitoring instruments used for assuring work safety must be calibrated and maintained periodically. It is important that the operator ensures that the instrument responds properly to the substances it was designed to monitor and that the limitations and possible sources of errors in instrument measurements be understood by the operator.

9.11.1 HNu Photo ionization Detector

A PID will be used to monitor the level of volatile organic compounds in the air.

The detector must be calibrated each day prior to field use according to the manufacturer's specifications. A calibration gas will be taken into the field to perform this routine calibration check. The instrument's function may be verified with an organic point source such as a "magic marker" prior to field survey.

9.12 EMERGENCY CONTACTS

In the event of any unplanned occurrence requiring assistance, the appropriate contact(s) should be made from the list below. Field personnel will have access to a cellular phone. Figure 9.2 provides a map indicating the route to the Base Hospital.

This Emergency Contacts list must be posted at the site.

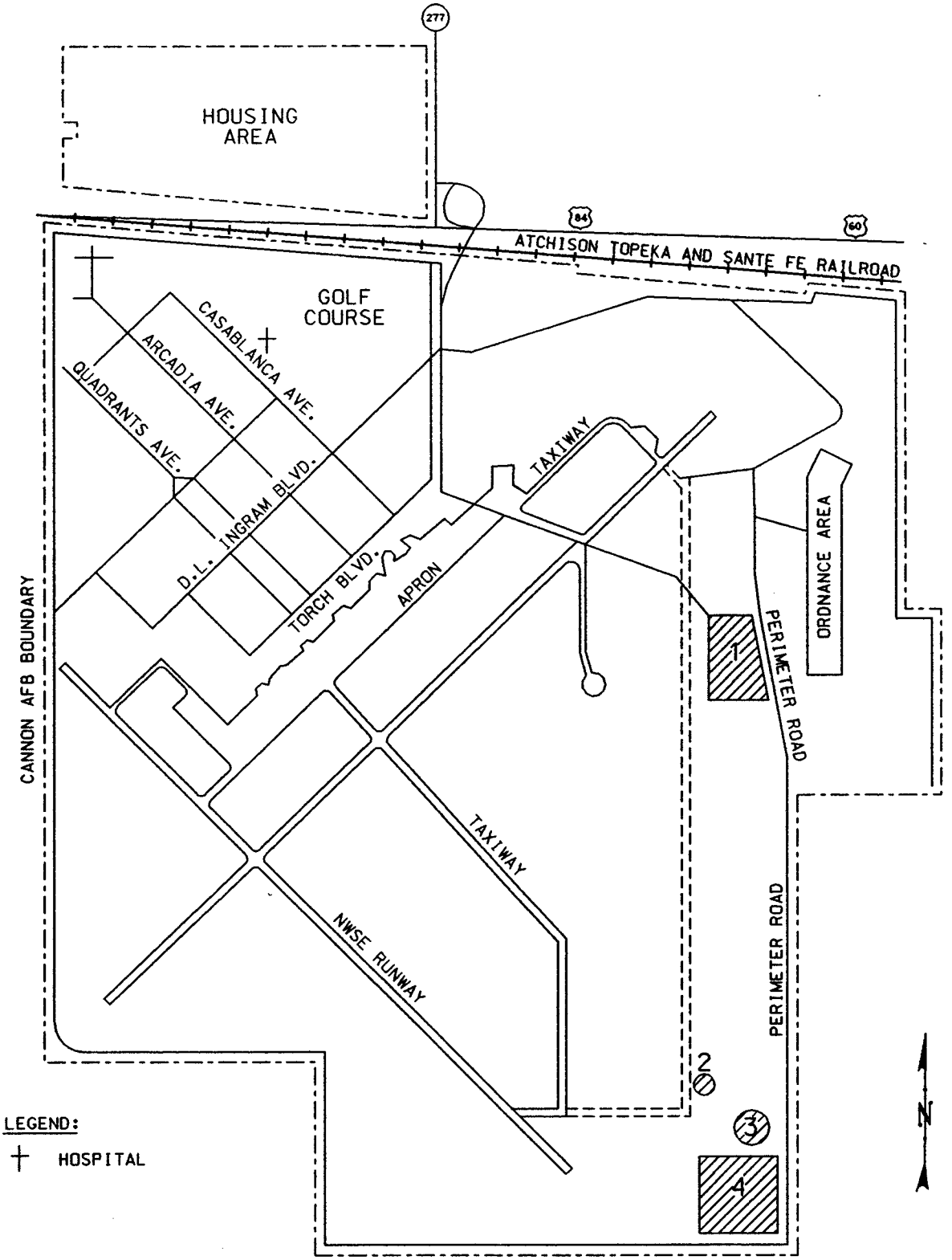
Medical Emergencies

CAFB CEV Emergency Contact Bruce Oshita	505-784-4639/2146/2379/4348
CAFB Hospital 208 West Casablanca	505-784-4059
Ambulance 208 West Casablanca	505-784-4059
Poison Control Center	1-800-962-1253

Other Emergency Phone Numbers

CAFB Chief of Safety 100 South Ingram Boulevard	505-784-2811
Fire Marshall 111 Engineer's Way	505-784-2008
Security Police 112 East Sextant Street	505-774-4498

FIGURE 9.2
LOCATION MAP OF CAFB HOSPITAL
CANNON AFB, NEW MEXICO



LEGEND:

+ HOSPITAL

NOTES:

1. WASTEWATER LAGOONS
2. FIRE DEPARTMENT TRAINING AREA #3
3. FIRE DEPARTMENT TRAINING AREA #4
4. LANDFILL NO. 5

0 1000 2000
SCALE IN FEET

Adapted from Woodward-Clyde

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PARSONS ENGINEERING SCIENCE, INC.

ATTACHMENT 1

DESIGN & CONSTRUCTION DETAILS OF MW-A, MW-I, MW-L, AND MW-M

MONITORING WELL A

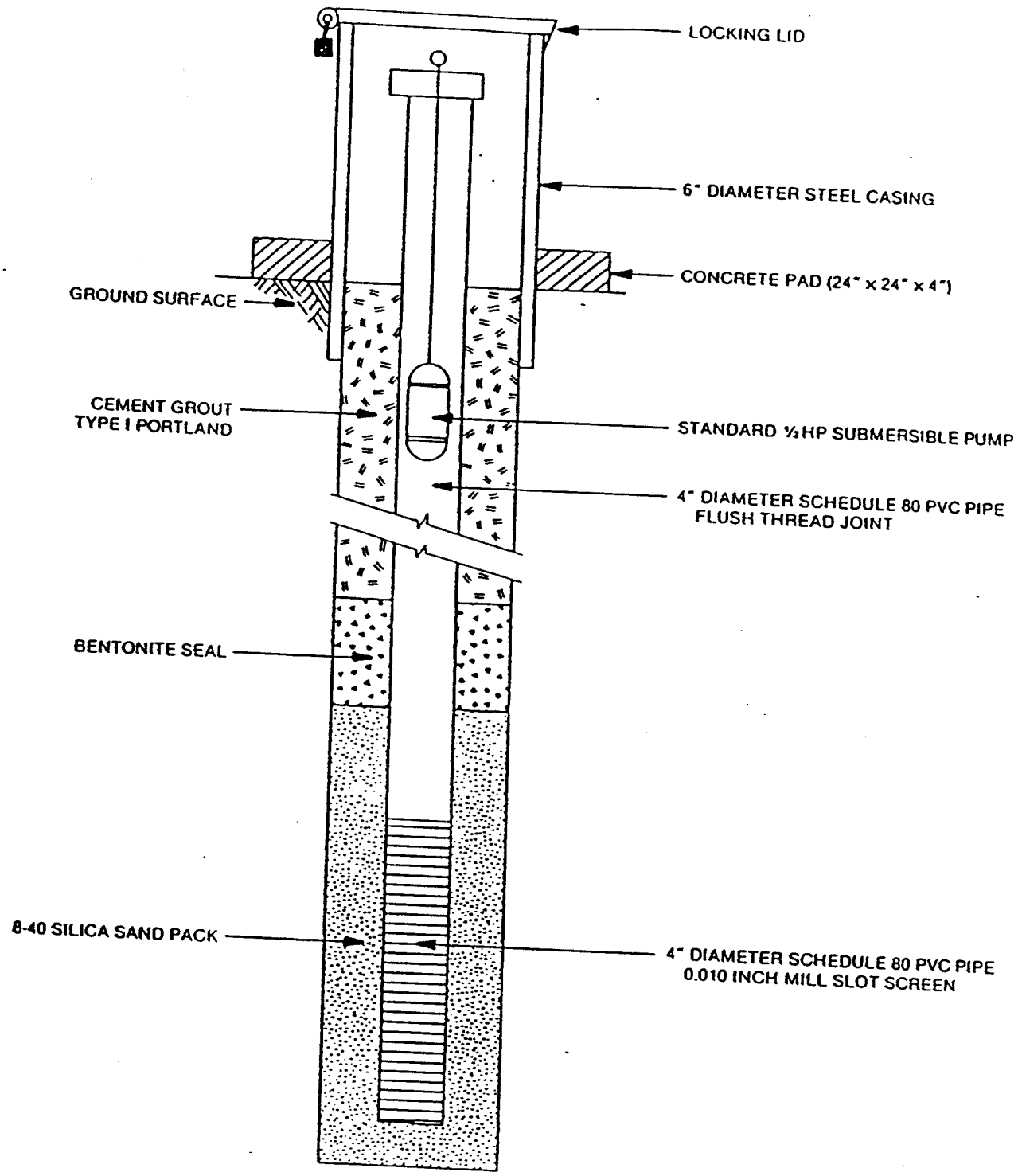


Figure 2. Schematic Diagram of a Ground-Water Monitoring Well, IRP Phase II Stage 1, Site No. 5, Landfill No. 5, Cannon AFB, New Mexico (Radian Corp., 1986)

DRAFT

RADIAN
CORPORATION

Completion Log: Sheet 1 of 2

Well No. Monitor Well A
Location Landfill No. 5

Project Cannon AFB IRP
Log Recorded by T.K. Walters

Construction

Construction Started January 4, 1985
Completed January 7, 1985
Total Depth Drilled (ft) 365
Hole Diameter 8-inch
Drilling Method mud rotary
Problems encountered during drilling/completion hole collapsed back to 343 feet, set casing to 343' 625

Water source for drilling and completion procedures base potable water supply well

Sampling

Number, type and disposition of samples collected water samples, collected after well development

Sample interval (ft-ft) 343', top of Ogallala Aquifer

Storage and/or preservation method(s) 4°C, shipped overnight delivery OEHL/RAS

Materials

Casing type Schedule 80 PVC
Diameter 4 inch
Top of well casing (ft-AGL/BGL) 3'/343'
Elevation (ft-msl) 4267.46
Depth of casing (ft) 343'
Screen type mill slot
Slot size 0.01 inch
Diameter 4 inch (internal)
Screen interval (ft-ft) 343-328

Type(s) of glue used to join casing None - threaded flush joint couplings
Type of gravel/sand pack used Clemtex No. 2 (8-40 mesh)
Amount of gravel pack used 4 bags
Grain size distribution of gravel pack Retained #8 (2.0%), #16 (51.2%), #20 (62.8%)[1]
Lithology of gravel pack Mostly silica (94%)
Source (company and quarry/pit) Clemtex, Inc., Houston, Texas

Interval of gravel pack (ft-ft) 343 - 325
Interval of bentonite seal (ft-ft) 325 - 323
Interval of grouting (ft-ft) 323 - Land surface

Comments

Type of bentonite - Pellets (Volclay)
Type of grout - Portland Type 1 (neat cement)
[1] #30 (78.4%), #40 (91.2%), #50 (98.9%), #100 (100.0%)

Description of Security Measures

N/A

Padlock ID No. N/A
Location of key(s) Cannon AFB

RADIAN CORPORATION

Well Completion Log: Sheet 2 of 2 (Development) Well A (continued)

Development started January 7, 1985 Development ended January 7, 1985

Static level of water before _____ (ft) and after _____ (ft) development.

Measuring point (MP) description top of steel casing

MP Height 2.35 (ft) Elevation 4267.46 (ft)

Quantity of water discharged during development 5 well volumes below static level

Type, size/capacity of pump or bailer used for developmnt air line - lift development

Depth of open hole inside well (below ground level on measuring point)

Before development 343 (ft) After development 343 (ft)

Date/Time	Discharge (GPM/Bail(s)) Note SWL start/End.(1)		Field Measurements Temperature	Conductivity	pH	Remarks
1/25/85	1320 hrs	3 gpm	18.5°	740	7.6	
	1330 hrs		18.5°	750	7.5	
	1410 hrs		18.4°	750	7.4	
	1500 hrs		18.4°	750	7.4	

NOTE: (1) Depth measurements made by Steel Tape (ST); Rope and Bailer (R/B) and Electric Line (EL).
(2) Temperature in degrees celsius.
(3) Conductivity in micromhos/centimeter at field temperature.

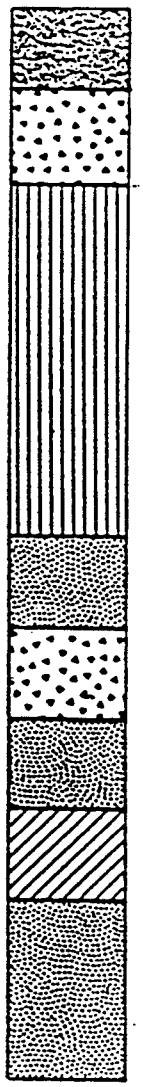
TABLE 3-1. MONITOR WELL CONSTRUCTION SPECIFICATIONS

- Casing: four-inch diameter, flush joint, threaded schedule 80 PVC, plugged at bottom with a permanent plug.
- Screen: four-inch diameter, flush joint, schedule 80 PVC, 0.010-inch mill slot, screen length = 15 feet.
- Sand Pack: 8-40 mesh silica, tremmied from bottom of hole to one foot above top of screen.
- Bentonite Seal: No. 50 Volclay brand bentonite tablets, to two feet above top of sand pack.
- Grout: neat cement (Type I Portland cement) grout tremmied from the top of the bentonite seal to the land surface.
- After each well was installed, it was developed for several hours by air development methods. Water was discharged by this process until the well produced no more fine material when surged and backwashed.
- Cuttings from well drilling activities were contained in 10' x 10' x 8' mud pits and covered. No hazardous or toxic forming materials were disposed of in the mud pits.
- All drill pipe and equipment was steam cleaned (under high pressure) before mobilizing to the next monitor well location.
- Surface Completion: The PVC casing was cut off to provide a two foot stick-up. A protective 5' steel guard pipe 6 inches in diameter with a locking cap was set in a 24" x 24" x 4" concrete pad over the PVC stickup. Each pipe extended about three feet above land surface.
- Guard Posts: Three 3" diameter steel posts 6' in length with a minimum of 2 feet below ground, were emplaced radially 4 feet from the well head, and set in concrete. The guard posts consisted of 2 sections of pipe, fitted together at land surface by keyed-alike locks, for easy removal for well and pump access.
- Pumps: each well was equipped with a submersible pumping apparatus, consisting of a Standard 1/2 HP pump (Model 20X4P 050 - 2.W. Type 20X4P). Each well pump contained a 600-TAX5 motor starter with a P-36-overload and lightning arrestor. Accessory items installed with pumps included a brass check valve, 1" schedule 80 threaded drop pipe, 12 x 2-2 conduction pump wire, 1/8" stainless steel safety cable, 1" stainless steel worm clamps, a three-prong electric plug, 1/4" cable clamps, #10 wire terminals 1 x 3/4" galvanized bushings, and a 3/4" brass hose connector.
- After all wells were in place, each was sampled for the chemical analyses specified in the Scope of Work.

Log of Drilling Operations
Monitor Well #A

Location Cannon AFB, Site 5 Landfill No. 5
Log Recorded by T.K. Walters
Type Drill Rig and Operator Failing 1500
Air/mud rotary - Winnek, Inc.-B Holland

Project Cannon AFB-Phase II Stage I
Beginning 4 Jan. 1985 and end 7 Jan. 1985 of drilling operation
Sampling Interval (Estimated) 5(ft)



Depth (ft)	Graphic Log	Core Sample Interval/ID	Type of Sample Taken	Lithologic Description
0-			G	TOPSOIL; red-brown, fair amount organic matter, caliche contact, 4'.
5-			G	CALICHE; light tan with buff silt.
10-			G	SILT;sandy light brown, with white caliche clasts.
15-			G	SILT; interbedded with caliche, some fine sand 22-25'.
20-			G	SILT; sandy with hard white caliche interbedded.
25-			G	SILT; sandy with hard white caliche interbedded.
30-			G	SAND; silty with caliche buff brown.
35-			G	CALICHE; hard, white, nodular with buff-brown silty sand.
40-			G	SAND; silty, light brown, cemented with calcite, caliche nodules in lower portion.
45-			G	SILT; sandy, unconsolidated, poorly sorted, fine-medium grained with black lithic fragments.
50-			G	SAND; silty, fine-medium grained, unconsolidated, angular, with caliche fragments.
55-			G	SAND; dark brown, poorly cemented, poorly sorted, with clear quartz (angular).
60-				

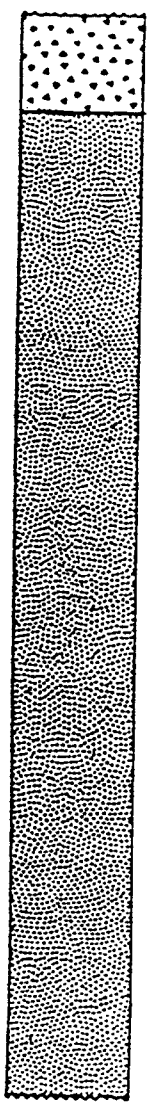
Monitor Well A was grouted from 325 ft to the surface with 8 yds.3 of Portland Type I neat cement.

ST = Shelby tube; SS = split-spoon; G = grab.

Log of Drilling Operations
Monitor Well #A

Location Cannon AFB, Site 5 Landfill No. 5
Log Recorded by T.K. Walters
Type Drill Rig and Operator Failing 1500
Air/mud rotary - Winnek,Inc.-B Holland

Project Cannon AFB-Phase II Stage I
Beginning 4 Jan. 1985 and end
7 Jan 1985 of drilling operation
Sampling Interval (Estimated) 5(ft)

Depth (ft)	Graphic Log	Core Sample Interval/ID	Type of Sample Taken	Lithologic Description
60-			G	CALICHE; buff white and silt, extremely hard, 2' sand, cemented, medium grained.
65-			G	SAND; red-brown, unconsolidated, fine-medium grained, poorly sorted.
70-			G	SAND; light brown, unconsolidated, fine-medium, sorted, coarser than above.
75-			G	SAND; tan-brown, unconsolidated, medium grained, quartzose, coarser than above unit, subrounded grains.
80-			G	SAND; fine-medium grained, poorly sorted, unconsolidated with 6' calcite cemented layer.
85-			G	SAND; fine-medium grained, poorly sorted, increase in calcite cement.
90-			G	SAND; fine-medium grained, poorly sorted, coarser than above, calcite cement about 10%.
95-			G	SAND; medium grained, moderately sorted, quartzose, grains sub-rounded, decrease in calcite.
100-			G	SAND; fine-medium poorly sorted, semi-consolidated, calcite cement 50%, coarser than above.
105-			G	SAND; medium-coarse grained, unconsolidated subangular grains.
110-			G	SAND; same as above.
115			G	SAND; same as above.
120-				

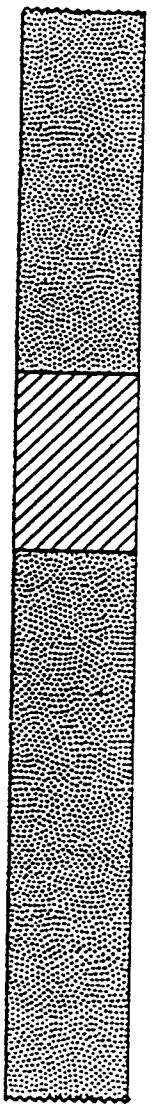
Monitor Well A was grouted from 325 ft to the surface with 8 yds.^{3} of Portland Type I neat cement.

ST = Shelby tube; SS = split-spoon; G = grab.

Log of Drilling Operations
Monitor Well #A

Location Cannon AFB, Site 5 Landfill No. 5
Log Recorded by T.K. Walters
Type Drill Rig and Operator Failing 1500
Air/mud rotary - Winnek,Inc.-B Holland

Project Cannon AFB-Phase II Stage I
Beginning 4 Jan. 1985 and end
7 Jan. 1985 of drilling operation
Sampling Interval (Estimated) 5(ft)

Depth (ft)	Graphic Log	Core Sample Interval/ID	Type of Sample Taken	Lithologic Description
120-			G	SAND; fine-medium grained, unconsolidated, well sorted, subrounded, quartzose.
125-			G	SAND; fine-grained, well sorted, unconsolidated, subrounded, with 5% caliche.
130-			G	SAND; fine-medium grained, well sorted, unconsolidated, subrounded, 5% caliche nodules.
135-			G	SAND; fine grained, very well sorted, unconsolidated, subrounded, 5% lithic fragments.
140-			G	SILT; fine, well sorted, much finer than above unit, unconsolidated.
145-			G	SILT; fine grained, very well sorted, quartzose, with 5% lithic fragments, subrounded.
150-			G	SAND; fine grained, very well sorted, subrounded, quartzose, clear, 5% lithics, drilling slightly slower.
155-			G	SAND; fine grained, silty, with 90% clear quartz, subrounded, 10% lithics.
160-			G	SAND; silty, fine grained, moderately well sorted, subrounded, quartzose.
165-			G	SAND; fine-medium grained, slightly cemented with calcite, caliche nodules 10%.
170-			G	SAND; loosely consolidated, by calcite, fine-medium grained, moderately sorted, caliche 10%.
175-			G	SAND; slightly cemented, by calcite, and caliche nodules (25%), sand is fine-medium, subrounded.
180-				

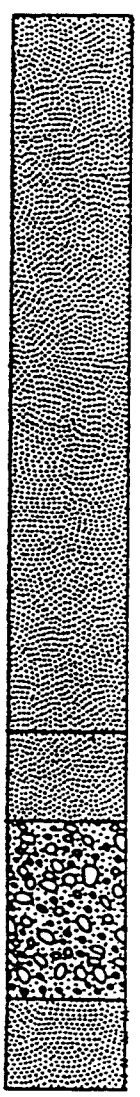
Monitor Well A was grouted from 325 ft to the surface with 8 yds.3 of Portland Type I neat cement.

ST = Shelby tube; SS = split-spoon; G = grab.

Log of Drilling Operations
Monitor Well #A

Location Cannon AFB, Site 5 Landfill No. 5
Log Recorded by T.K. Walters
Type Drill Rig and Operator Failing 1500
Air/mud rotary - Winnek,Inc.-B Holland

Project Cannon AFB-Phase II Stage I
Beginning 4 Jan. 1985 and end
7 Jan. 1985 of drilling operation
Sampling Interval (Estimated) 5(ft)

Depth (ft)	Graphic Log	Core Sample Interval/ID	Type of Sample Taken	Lithologic Description
180-			G	SAND; slightly cemented, fine-medium grained, calcite 50%.
185-			G	SAND; silty, brown, poorly sorted, slightly cemented, fine-medium grained.
190-			G	SAND; unconsolidated, fine-medium grained, subrounded, poorly sorted, 10% lithics.
195-			G	SAND; coarse, and pea gravel, angular, with reworked clay and silt (Cretaceous), unconsolidated, lithics-clay 30%.
200-			G	SAND; tan, fine-medium grained, poorly sorted, angular, with 10% lithic fragments.
205-			G	SAND; tan, fine-medium grained, subangular, with abundant iron staining on quartz grains, lithics 5%, unconsolidated.
210-			G	SAND; tan, medium-coarse, subangular, with reworked shale and silt, poorly sorted, unconsolidated.
215-			G	SAND; olive-brown, 50% green-brown silt and shale, angular quartz, fine-medium grained, poorly sorted.
220-			G	SAND AND SHALE; olive brown, sand medium grained, shale green-brown, with red clay clasts.
225-			G	GRAVEL; unconsolidated, with shale, silt, lithic fragments, unsorted conglomerate.
230-			G	SAND AND GRAVEL; sand cemented, by calcite, gravel angular, loosely consolidated.
235-			G	SAND; with minor gravel, sand fine-medium grained, loosely cemented, poorly sorted.
240-				

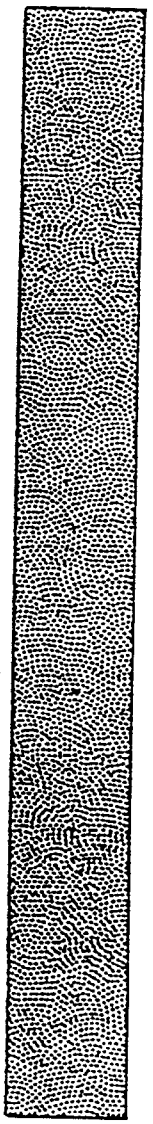
Monitor Well A was grouted from 325 ft to the surface with 8 yds.^{3} of Portland Type I neat cement.

ST = Shelby tube; SS = split-spoon; G = grab.

Log of Drilling Operations
Monitor Well #A

Location Cannon AFB, Site 5 Landfill No. 5
Log Recorded by T.K. Walters
Type Drill Rig and Operator Failing 1500
Air/mud rotary - Winnek,Inc.-B Holland

Project Cannon AFB-Phase II Stage I
Beginning 4 Jan. 1985 and end 7 Jan. 1985 of drilling operation
Sampling Interval (Estimated) 5(ft)

Depth (ft)	Graphic Log	Core Sample Interval/ID	Type of Sample Taken	Lithologic Description
240-				
			G	SAND; tan, medium-coarse grained, with 15% gravel, (may be coming in from gravel zone above).
245-				
			G	SAND; tan, fine-medium grained, poorly sorted, with calcite matrix, slightly silty, 10% lithics.
250-				
			G	SAND; brown, fine-coarse, unconsolidated, angular, with 15% lithics also angular, clay matrix 20%.
255-				
			G	SAND; brown, fine grained, with calcite cement, unconsolidated, poorly sorted with coarse sand-size lithic fragments 10%.
260-				
			G	SAND; brown, fine-medium grained, loosely consolidated with calcite cement, coarse lithics 20%, angular.
265-				
			G	SAND; brown, 95% quartz, fine-medium grained, absence of coarse lithic fragments, "beach sand" texture.
270-				
			G	SAND; brown, 95% quartz, rounded, medium grained, well sorted, lithics also rounded and sorted.
275-				
			G	SAND; brown, medium grained, subrounded, same as above unit with 10% lithics.
280-				
			G	SAND; brown, medium-coarse, subangular, poorly sorted, unconsolidated, lithics 10-15% subangular, out of "clean sand."
285-				
			G	SAND; tan, fine-medium grained, moderately well sorted, subrounded, calcite 10%, lithics 10%.
290-				
			G	SAND; tan, fine-medium, well sorted, subrounded, "clean" with 10% lithics, also fine-medium grained.
295-				
			G	SAND; tan, fine-medium grained, well sorted, rounded with 10% black lithic fragments, no matrix.
300-				

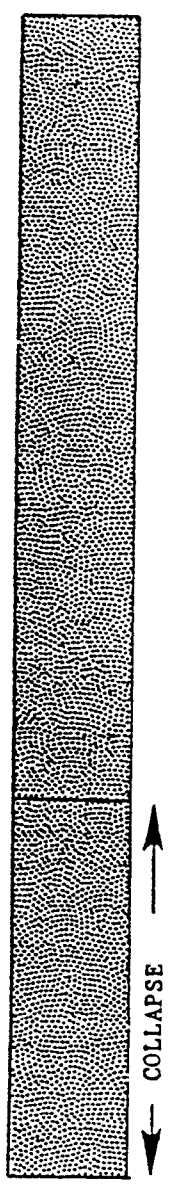
Monitor Well A was grouted from 325 ft to the surface with 8 yds.^{3} of Portland Type I neat cement.

ST = Shelby tube; SS = split-spoon; G = grab.

Log of Drilling Operations
Monitor Well #A

Location Cannon AFB, Site 5 Landfill No. 5
Log Recorded by T.K. Walters
Type Drill Rig and Operator Failing 1500
Air/mud rotary - Winnek,Inc.-B Holland

Project Cannon AFB-Phase II Stage I
Beginning 4 Jan. 1985 and end
7 Jan. 1985 of drilling operation
Sampling Interval (Estimated) 5(ft)

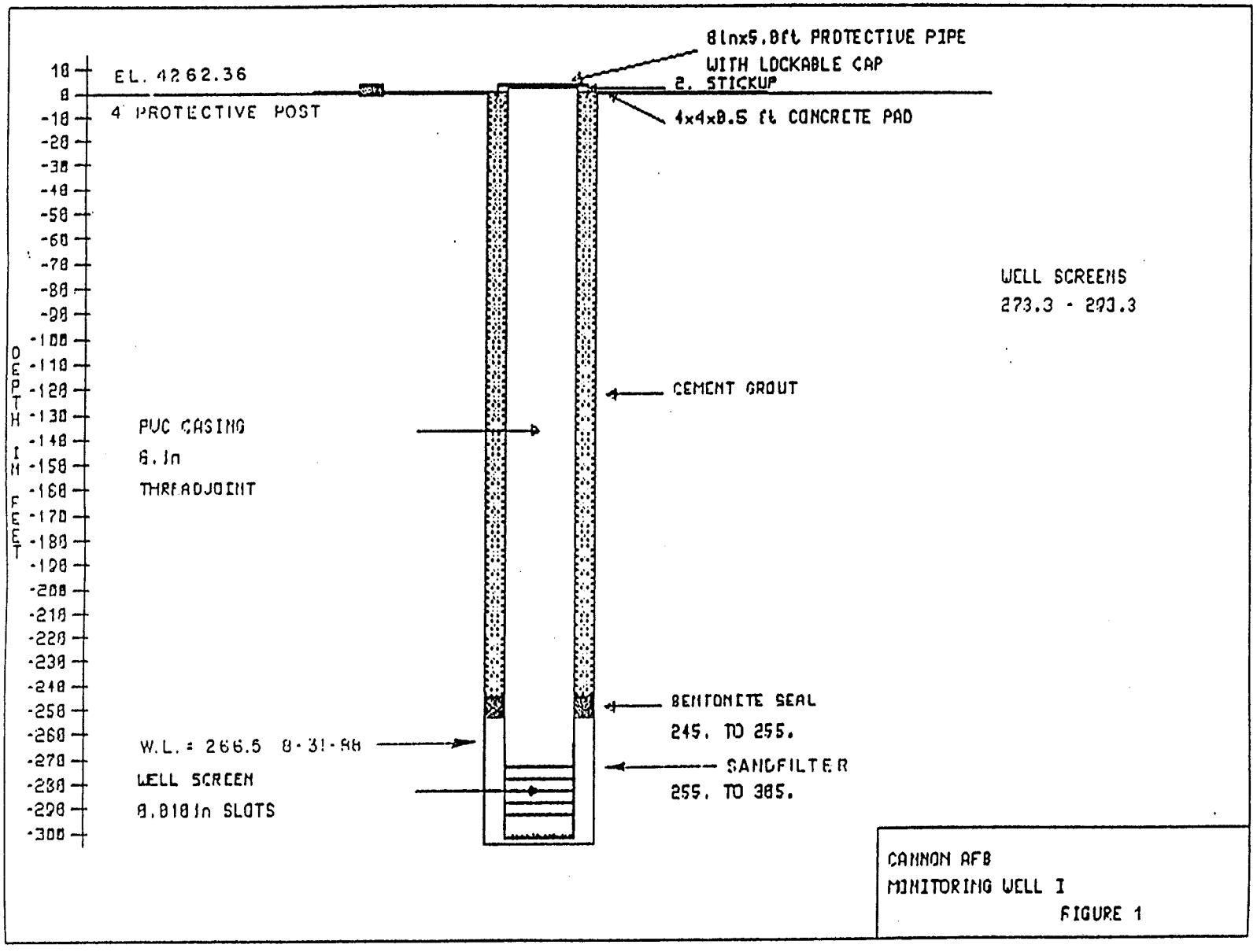
Depth (ft)	Graphic Log	Core Sample Interval/ID	Type of Sample Taken	Lithologic Description
300–				
			G	SAND; tan to brown, fine-medium grained, poorly sorted, with 10% coarse sand fragments, subrounded.
305–				
			G	SAND; brown, fine-coarse, poorly sorted, with 15% lithics, also coarse, subrounded, unconsolidated.
310–				
			G	SAND; with gravel, olive brown, sand is fine-medium grained, poorly sorted, subrounded, gravel coarse.
315–				
			G	SAND; fine-coarse, slightly cemented to larger lithic fragments, sand is subrounded.
320–				
			G	SAND; tan, fine-medium grained, loosely cemented, subrounded, calcite 10%.
325–				
			G	SAND; sand and gravel conglomerate, cemented by calcite, coarse texture, w/grey shale and reworked red silt, well indurated.
330–				
			G	SAND; cemented, with 10% gravel, buff-brown, iron stained, conglomerate, calcite matrix, lithics (red plagioclase, volcanics)
335–				
			G	SAND; medium-coarse, loosely consolidated, lithics 25%, coarse grained, out of confining zone at 339'.
340–				
			G	SAND; fine-coarse, unconsolidated, with sub-angular quartz 342-343' sand and gravel conglomerate; 343-345' sand unconsolidated.
345–				
			G	SAND; loosely consolidated, fine-medium grain, moderately sorted, subrounded lithics 5-15%, water changed to dark brown at 350'.
350–				
			G	SAND; fine-medium grained, poorly sorted, subrounded with 10% lithic clasts.
355–				
			G	SAND; medium grained, loosely consolidated subangular, subrounded with 10% lithic fragments.
360–				
			G	SAND; fine-coarse, poorly sorted, angular, with 30% lithic fragments.
365–				

COLLAPSE

Monitor Well A was grouted from 325 ft to the surface with 8 yds.^{3} of Portland Type I neat cement.

ST = Shelby tube; SS = split-spoon; G = grab.

MONITORING WELL I



CANNON AFB
MONITORING WELL I
FIGURE 1

HOLE NO. 1

DRILLING LOG	DIVISION SOUTHWEST	INSTALLATION CANNON AFB	SHEET 1 OF 2 SHEETS

1. PROJECT LANDFILL 5	10. SIZE AND TYPE OF BIT 9 5/8"
2. LOCATION (Coordinates or Station) 0.00 0.00	11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MSL
3. DRILLING AGENCY ROMAN WELL SERVICE	12. MANUFACTURER'S DESIGNATION OF DRILL FAILING
4. HOLE NO. (As shown on drawing title and file number) 1	13. TOTAL NO OF OVER- DISTURBED UNDISTURBED
5. NAME OF DRILLER JIM ROMAN	14. TOTAL NUMBER CORE BOXES 0
	15. ELEVATION GROUND WATER 3997.9(8/31/88)
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	16. DATE HOLE STARTED 08/10/88 COMPLETED 08/12/88
7. THICKNESS OF OVERBURDEN 0.0	17. ELEVATION TOP OF HOLE 4262.3
8. DEPTH DRILLED INTO ROCK 0.0	18. TOTAL CORE RECOVERY FOR BORING 0.0 %
9. TOTAL DEPTH OF HOLE 305.0	19. SIGNATURE OF INSPECTOR E.N. GILBERT

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4256.3			SAND (SM) (0.0–6.0) SILTY, REDDISH BROWN			USED 9 5/8" ROCKBIT TO 305 FT. SET 273' OF BLANK 6" PVC SCHEDULE 80 FLUSH JOINT CASING WITH 20' OF .020 SLOTTED PVC SCREENS WITH A 10' SEDIMENT TRAP BELOW SCREENS FOR A SUMP.
4250.3			CALICHE (CL) (6.0 – 12.0) SILTY, LIGHT-TAN			
4239.3	20		SAND (SM) (12.0 – 23.0) FINE, TAN			
4229.3			GRAVEL (GC) (23.0 – 33.0) CLAYEY, SANDY			SANDPACK OF SMALL PEA GRAVEL FROM 255' – 305'. BENTONITE SEAL 245'– 255' CONCRETE FROM CLOVIS CONCRETE CO. ABOVE 255' 4' X 4' CONCRETE PAD, COVER PIPE, AND 4 GUARD POSTS INSTALLED.
4214.3	40		SAND (SM) (33.0 – 48.0) FINE			
4207.3			CLAY (CL) (48.0 – 55.0) SANDY			HOLE BAILED AND DEVELOPED ON 8/13/88. PUMP INSTALLED 8/18–19/88. (1 HP 220 VOLT RED JACKET) PUMPED ~500 GAL AT 10 GPM
4199.3	60		CLAY (CL) (55.0 – 63.0) SILTY			
	80		SAND (SM) (63.0 – 125.0) SANDY CLAY ZONES PRESENT			TYPE ROCK BIT ZONE 0.0–305.0
	100				NONE	SAMPLE NONE DEPTH 0.0–305.0
4137.3	120					
	140		SAND (SM) (125.0 – 198.0) LESS CLAY CONTENT			
	160					
	180					
4064.3			CALICHE (CL) (198.0 – 209.0) SANDY, CLAYEY			

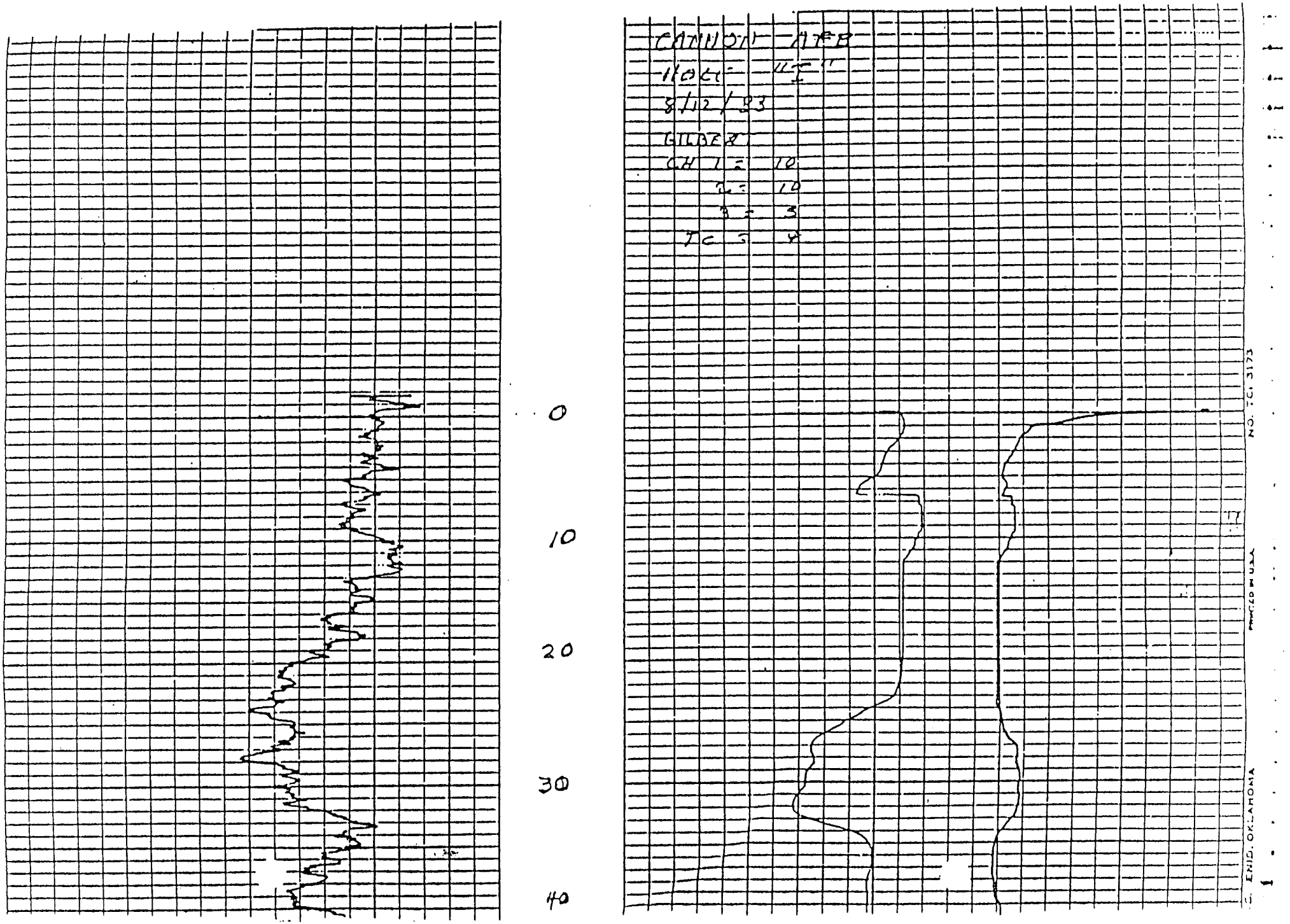
HOLE NO. 1

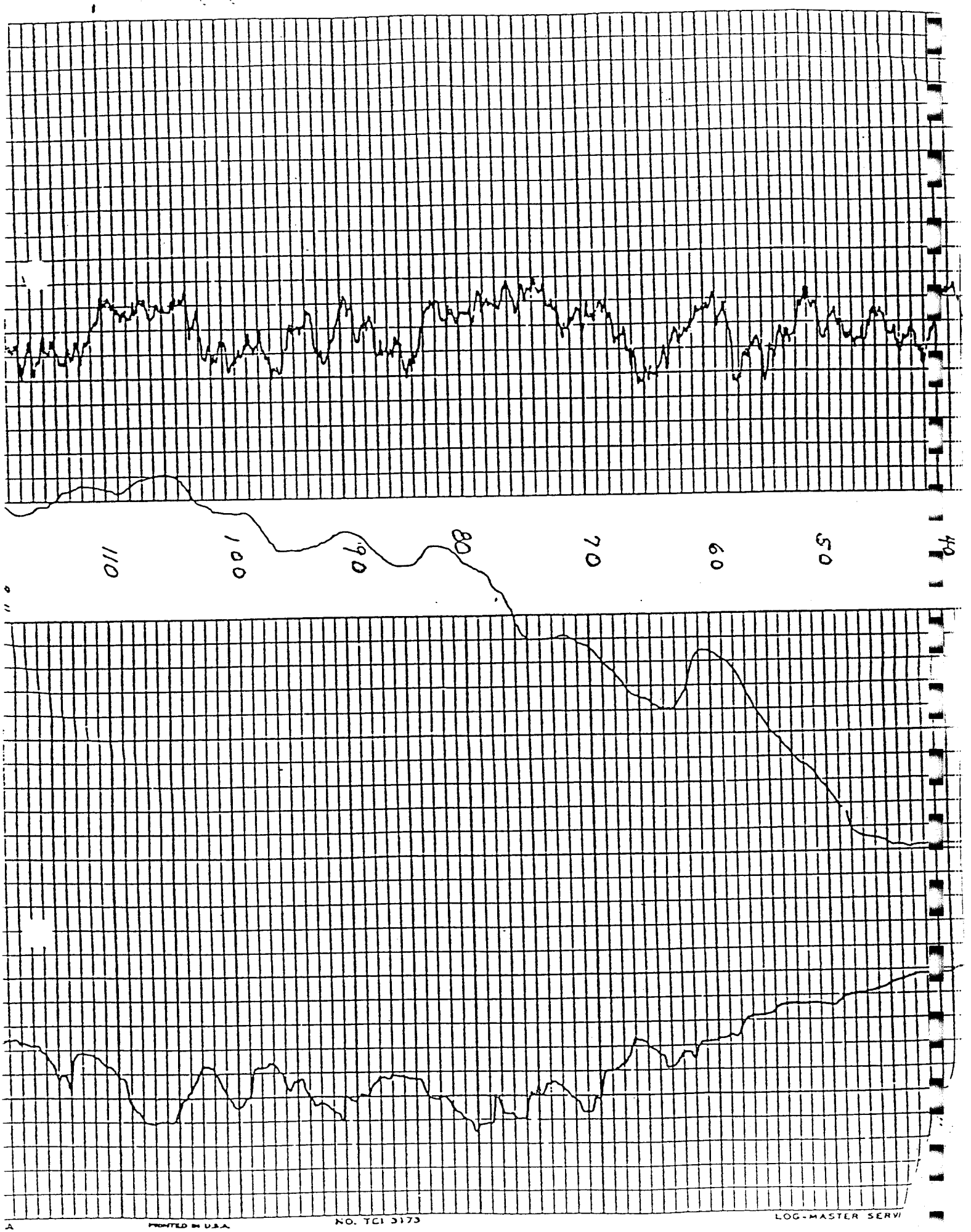
DRILLING LOG	DIVISION SOUTHWEST	INSTALLATION CANNON AFB	SHEET 2 OF 2 SHEETS

1. PROJECT LANDFILL 5	10. SIZE AND TYPE OF BIT 9 5/8"
2. LOCATION (Coordinates or Station) 0.00 0.00	11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MSL
3. DRILLING AGENCY ROMAN WELL SERVICE	12. MANUFACTURER'S DESIGNATION OF DRILL FAILING
4. HOLE NO. (As shown on drawing title and file number) 1	13. TOTAL NO OF OVER- DISTURBED UNDISTURBED
5. NAME OF DRILLER JIM ROMAN	14. TOTAL NUMBER CORE BOXES 0
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER 3997.9(8/31/88)
	16. DATE HOLE STARTED 08/10/88 COMPLETED 08/12/88
7. THICKNESS OF OVERBURDEN 0.0	17. ELEVATION TOP OF HOLE 4262.3
8. DEPTH DRILLED INTO ROCK 0.0	18. TOTAL CORE RECOVERY FOR BORING 0.0 %
9. TOTAL DEPTH OF HOLE 305.0	19. SIGNATURE OF INSPECTOR E.N. GILBERT

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4053.3			CALICHE (CL) (198.0 – 209.0) SANDY, CLAYEY			
4047.3			GRAVEL (GP) (209.0 – 215.0) SLIGHTLY CLAYEY, SANDY			
4037.3	220		GRAVEL (GM) (215.0 – 225.0) CLAYEY, SANDY			
	240		SAND (SM) (225.0 – 300.0) SILTY WITH OCCASIONAL GRAVELS. SATURATED BELOW 265 FT.		NONE	
	260					
	280					
3962.3	300		() (300.0 – 305.0) CUTTINGS BELOW 300 FT NOT LOGGED			
3957.3			BOTTOM OF HOLE 305'			
	320					
	340					
	360					
	380					
	400					

well I


CANNON AFB
HOLE "E"
8/12/83
GILBERT
CH 1 = 10
2 = 10
3 = 3
TC = 4
0
10
20
30
40
NO. TC 3173
PRINTED IN U.S.A.
ENID, OKLAHOMA


110
100
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LOG-MASTER SERVI

LOG-MASTER SERVICES, INC. ENID, OKLAHOMA
NO. TCI 3173
120
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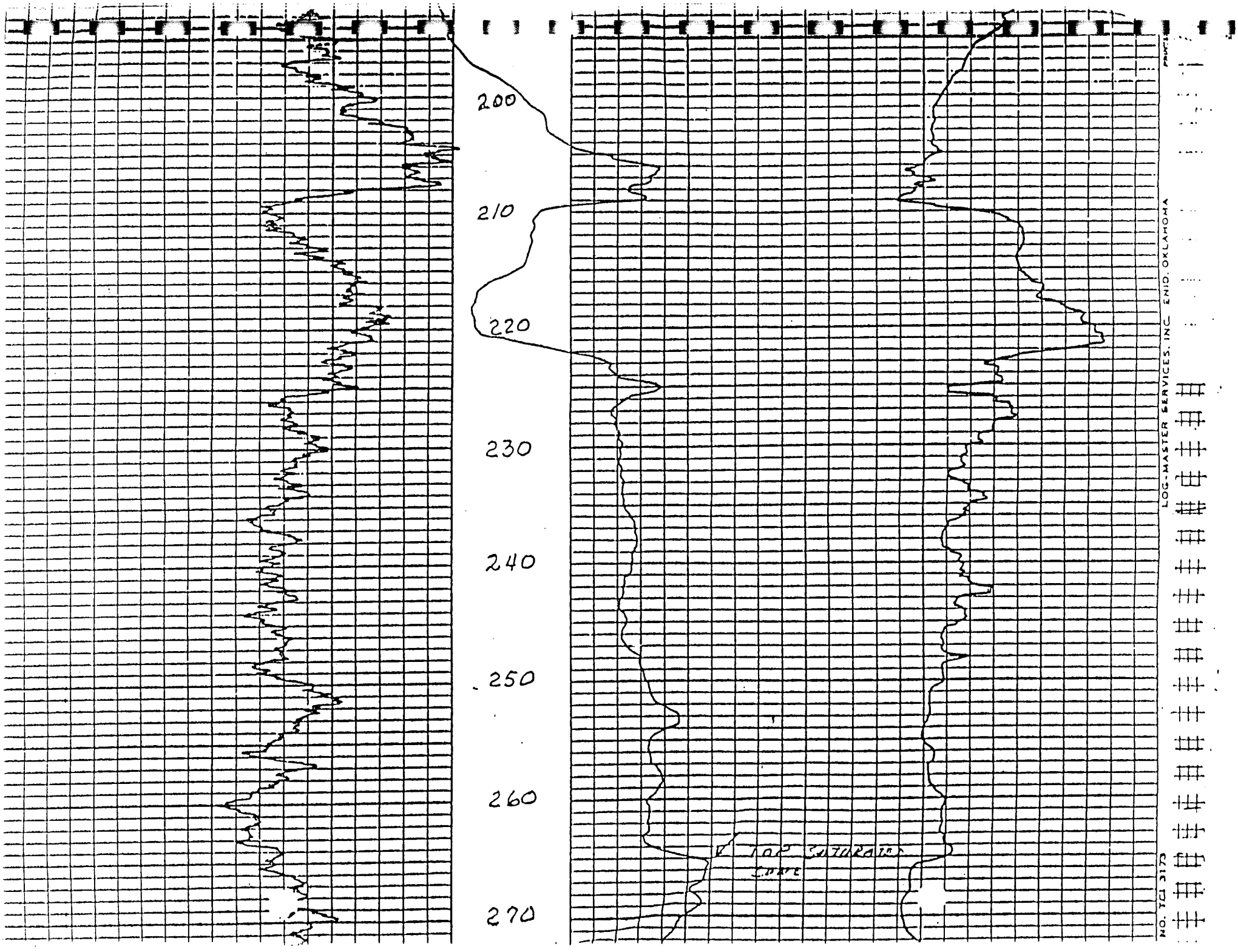
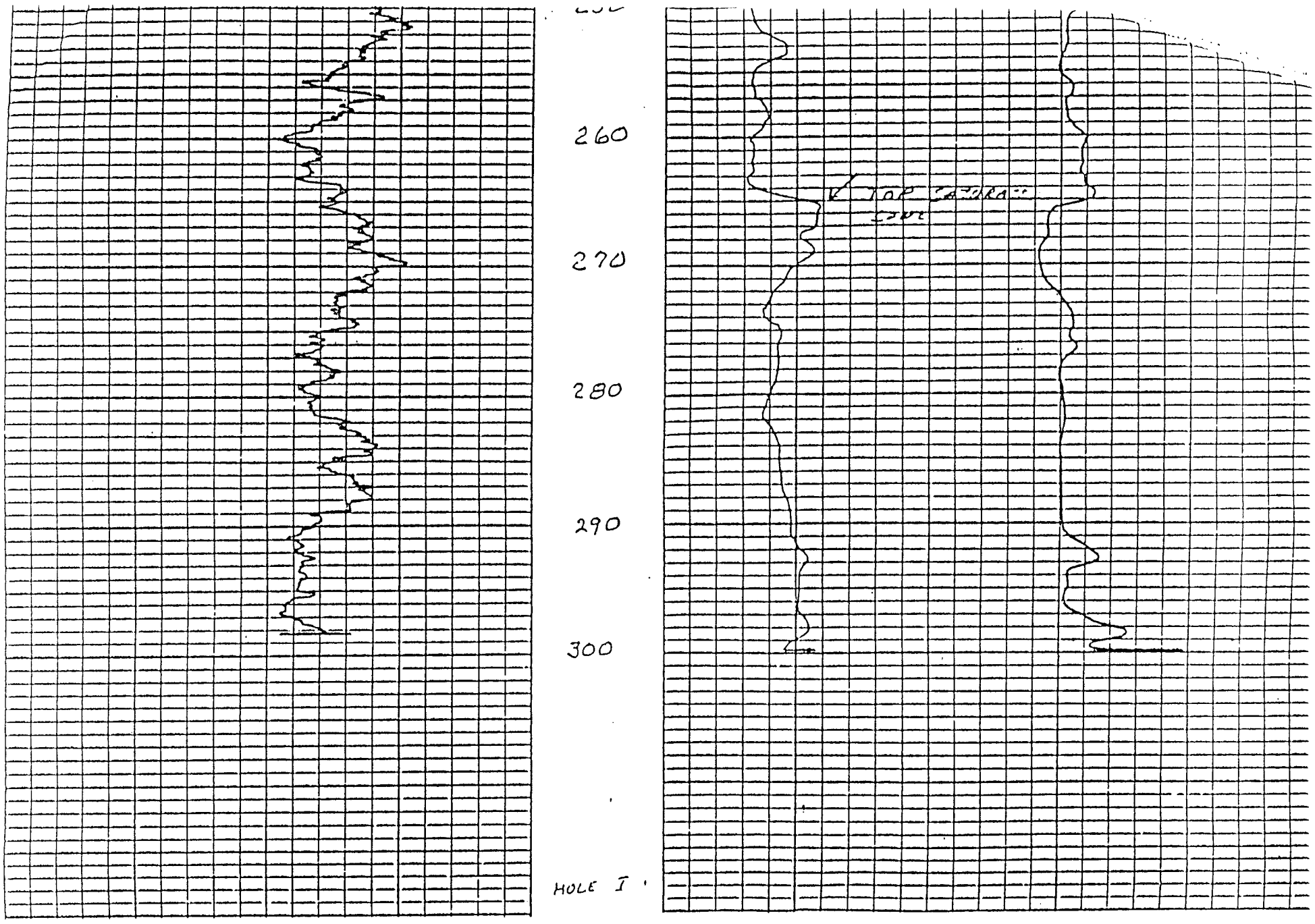

200
210
220
230
240
250
260
270
TOP SATURATED
CORE
LOG-MASTER SERVICES, INC ENID, OKLAHOMA
NO. TCI 3173


260
270
280
290
300
HOLE I
TOP CATORA

MONITORING WELL L

CANNON AIR FORCE BASE - WELL L

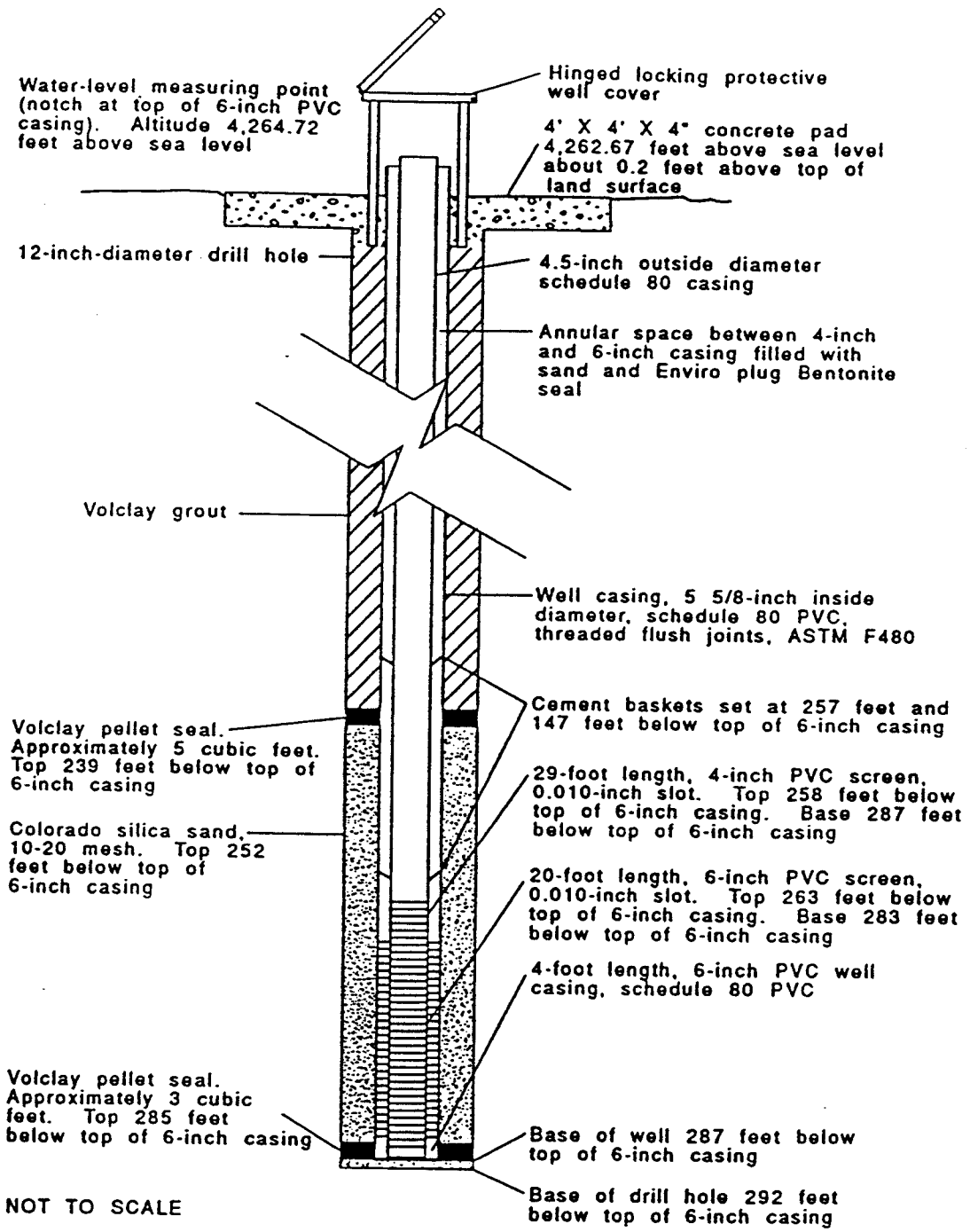


Figure 1.--Well-completion diagram for monitoring well CAFB-L drilled and completed by U.S. Geological Survey, Coal Branch, Denver, Colo. Started on 01-18-92. Completed on 06-02-92. Well drilled using mud-rotary method and Wyoming sodium bentonite drilling fluid.

This figure accurately represents the construction of well L at Cannon Air Force Base.

Peter F. Frenzel Professional Engineer,
Certificate Number 9989

MONITORING WELL IDENTIFICATION REPORT

ENVIRONMENTAL IMPROVEMENT DIVISION
HAZARDOUS WASTE SECTION
1190 ST. FRANCIS DR./HAROLD RUNNELS BLDG.
SANTA FE, NEW MEXICO 87503

FACILITY NAME Cannon Air Force Base

EPA I.D. NUMBER

COUNTY Curry

WELL NUMBER Well L - Landfill 5

WELL LOCATION (LONGITUDE) 103° 1' 8" 00"

WELL LOCATION (LATITUDE) 34° 22' 02"

AQUIFER NAME Ogallala

AQUIFER CONFINED _____ UNCONFINED X

WELL INSTALLATION DATE June 2, 1992

DRILLING METHOD Hydrt (mud rotary)

INNER CASING DIAMETER 4.0 inch inside 5.8 inch

BOREHOLE DIAMETER 12 inch

CASING MATERIAL PVC

METHOD OF DEVELOPMENT BAILD

ELEV BOTTOM OF BOREHOLE 3972.11

ELEV BOTTOM OF WELL CASING 3977.11

ELEV BOTTOM OF SCREENED INT 3973.11

ELEVATION OF SCREENED INT 3973.11 to 3993.11

SURVEYED ELEV OF CASING TOP 4,264.72

DATE OF REPORT August 4, 1992 SIGNATURE Jerry D Larson

NAME (TYPED) Jerry D. Larson

Well L
Core Description

January 20, 1992

15.0	-	15.25	Red silty clay 100% recovery
15.25	-	15.50	White caliche 100% recovery
15.50	-	18.50	Alternating streaks of white caliche and red silty sand 100% recovery
18.5	-	21.0	Alternating streaks of white caliche and red silty sand 100% recovery
21.00	-	22.00	Alternating streaks of white caliche and red silty sand 100% recovery
22.00	-	23.00	Red silty clay and sand mix 100% recovery
23.00	-	24.00	Tan to white caliche - silty sand mix 100% recovery
24.00	-	32.50	Reddish tan silt some caliche layers + sand 100 recovery

January 21, 1992

32.50	-	37.50	Cemented sand & siltstone
37.5	-	42.5	32.5 - 32.75 soft clay/caliche, 32.75 - 34.5 soft reddish orange silt 34.5 - 37.5 caliche - very hard
42.5	-	50.50	Reddish brown silt with hard siltstone lenses 100% recovery 49.5 to 50.5 silty sand
50.5	-	60.5	Mostly red cement siltstone with some sand and layers of uncemented silt 100% recovery
60.5	-	74.5	Becoming sandier mostly highly cemented silty sand red to tan some caliche and softlenses 100% recovery
74.5	-	89.0	74.5-81 soft reddish brown silty sand 81.0-82.5 hard reddish brown sandstone cemented 75% recovery 82.5-88.5 soft reddish brown silty sand 88.5-89 hard sandstone cemented
89.0	-	99	Med-fine sand and sandstone red 40% recovery
99.0	-	103	99-1025 Med-fine sand red 102.5-103 caliche layer 100% recovery
103	-	106	Mostly med-fine sand red with caliche stringers 75% recovery
106	-	109	Mostly med-fine sand red @ 108.5' caliche layer 100% recovery
109	-	114	Mostly med-fine sand, red with large caliche pieces throughout lower part of sample 95% recovery
114	-	120.5	Mostly med-fine sand-red with caliche 115 - 100% recovery
120.5	-	124.0	Med-fine sand reddish brown becoming coarser 136-138 - 100% recovery
124	-	138	Med-fine sand, reddish brown becoming coarser 136-138 - 100% recovery
138	-	153	Med-fine sand becoming finer - reddish brown 66% recovery
153	-	166	Fine sand reddish brown caliche nodules 100% recovery
166	-	179	Fine sand reddish brown caliche nodules 90% recovery
179	-	194	Reddish brown fine silty sand 100% recovery
194	-	208	Reddish brown fine silty sand 90% recovery
208	-	221	Hard caliche and then gravel 0% recovery
221	-	223	Gravel coarse 2+ inch in diameter only caught 6 boulders 10% recovery
223	-	233	Gravel coarse - coarse sands grading to fine sand and clay stringers 20% recovery
233	-	243	Fine tightly packed sand numerous sandstone nodules 100% recovery
243	-	255	Fine tightly packed sand numerous sandstone nodules plus med-fine sand-reddish brown, with few layers of clay 100% recovery
255	-	272	Fine tightly packed sand w/sandstone nodules grading to med-fine reddish brown sand with clay stringers 100% recovery

U.S. GEOLOGICAL SURVEY

COMPANY CANNON AIR FORCE BASE

WELL C.A.F.B.-M

FIELD

COUNTY CURRY STATE NEW MEXICO COUNTRY U.S.A.

LOCATION LAT 342201

LONG 1031800

SECTION 30 TOWNSHIP 02N. RANGE 35E. API NUM 422 A

Permanent Datum T.O.C. ; Elevation 4264.29 Elev.: K.B.

Log Measured From 4262.67 , Above Perm. Datum D.F.

Drilling Meas From 4262.67 G.L. 4262.67

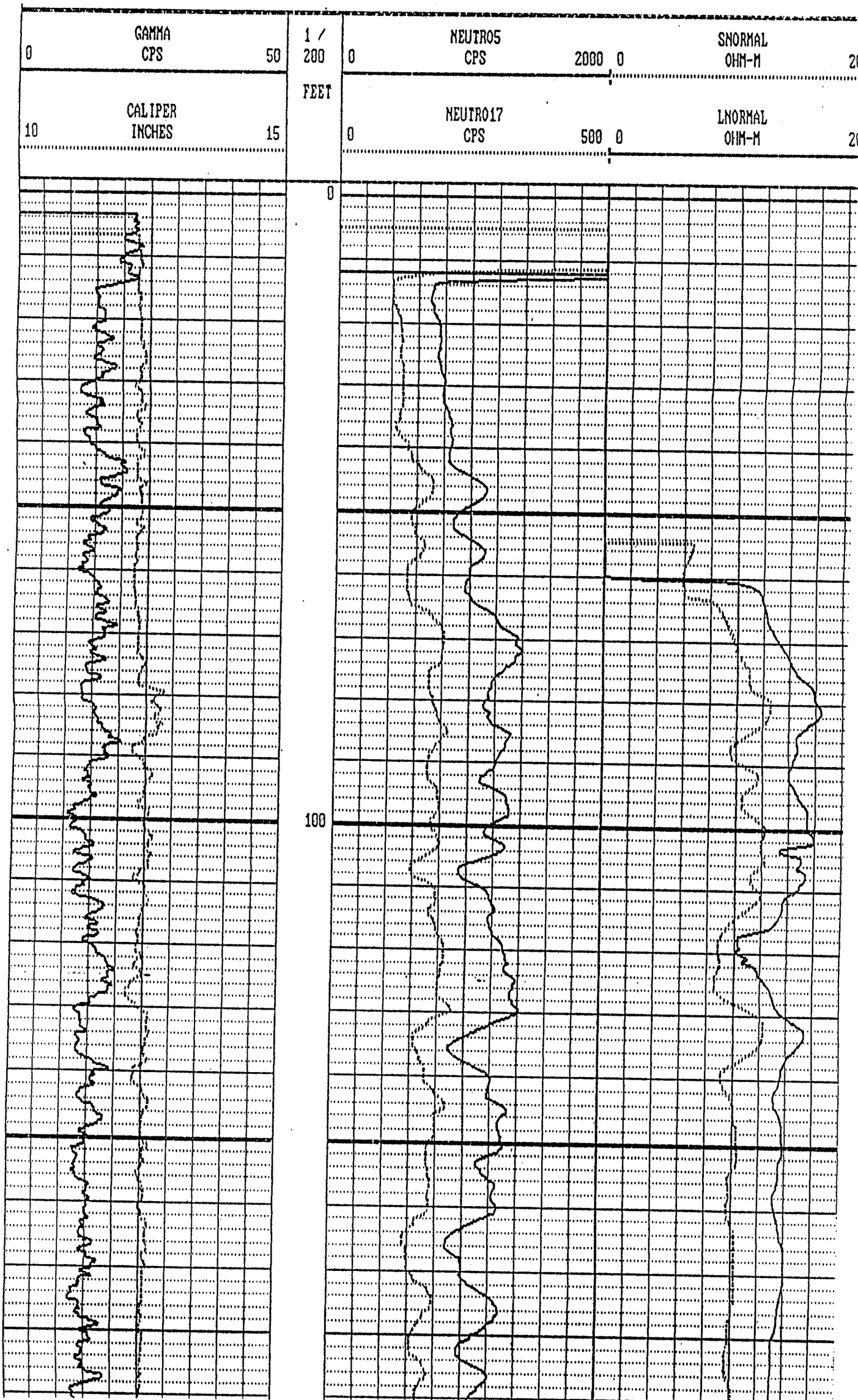
	1	2	3
Date	02/02/1992		
Depth - Driller	287.0		
Depth - Logger	287.0		
Btm Log Interval	287.0		
Top Log Interval	0.0		
Casing - Driller			
Casing - Logger			
Bitsize	12" ROLLER		
Type Fluid in Hole	NATURAL GEL		
Dens. / Visc.	/	/	/
pH / Fluid Loss	/	/	/
Source of Sample			
Rm @ Meas. Temp	@	@	@
Rmf @ Meas. Temp	@	@	@
Rmc @ Meas. Temp	@	@	@
Source: Rmf / Rmc	/	/	/
Rm @ BHT	@	@	@
Max. Rec. Temp.			

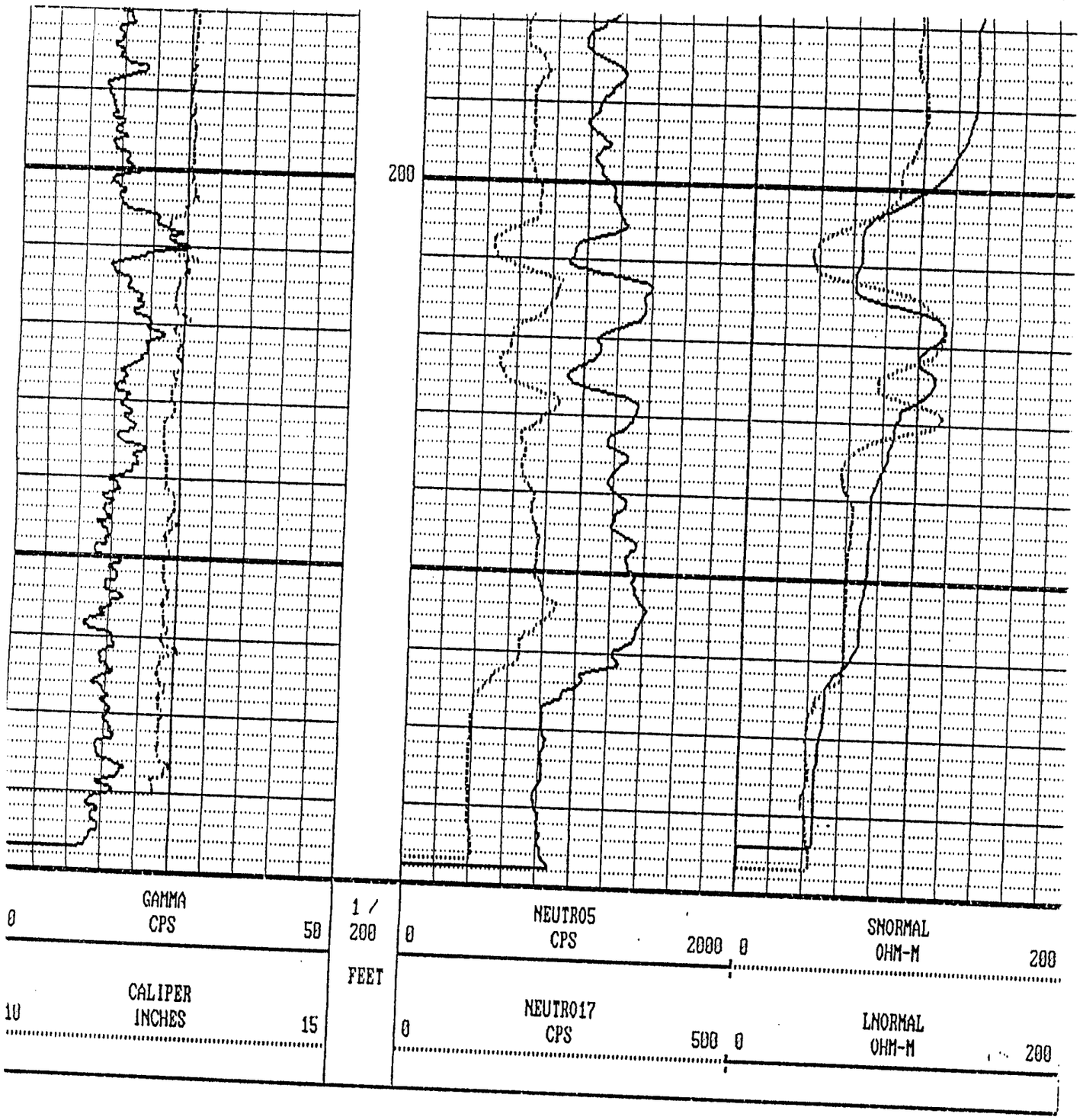
OUTPUT CURVE DEFINITIONS

GAMMA : RADIATION INCREASES RIGHT
CALIPER : 1 INCH/DIV.
NEUTRO5 : POROSITY INCREASES LEFT (5 IN. SPACING)
NEUTRO17 : POROSITY INCREASES LEFT (17 IN. SPACING)
SNORMAL : 20 OHM-M/DIV.
LNORMAL : 20 OHM-M/DIV.

C.A.F.B.-M
14-MAY-92 @ 11:30:51
Depth Axes Curve : DEPTH Units : FT

GAMMA CPS 0 – 50	1 / 200 FEET	NEUTRO5 CPS 0 – 2000	SNORMAL OHM-M 0 – 200
CALIPER		NEUTRO17	LNORMAL


GAMMA
CPS
0
50
CALIPER
INCHES
10
15
1 /
200
FEET
0
100
NEUTRO5
CPS
0
2000
NEUTRO17
CPS
0
500
SNORMAL
OHM-M
0
LNORMAL
OHM-M
0


200
0
GAMMA
CPS
50
1 /
200
FEET
0
NEUTRO5
CPS
2000
0
SNORMAL
OHM-M
200
10
CALIPER
INCHES
15
0
NEUTRO17
CPS
500
0
LNORMAL
OHM-M
200

MONITORING WELL M

CANNON AIR FORCE BASE - WELL M

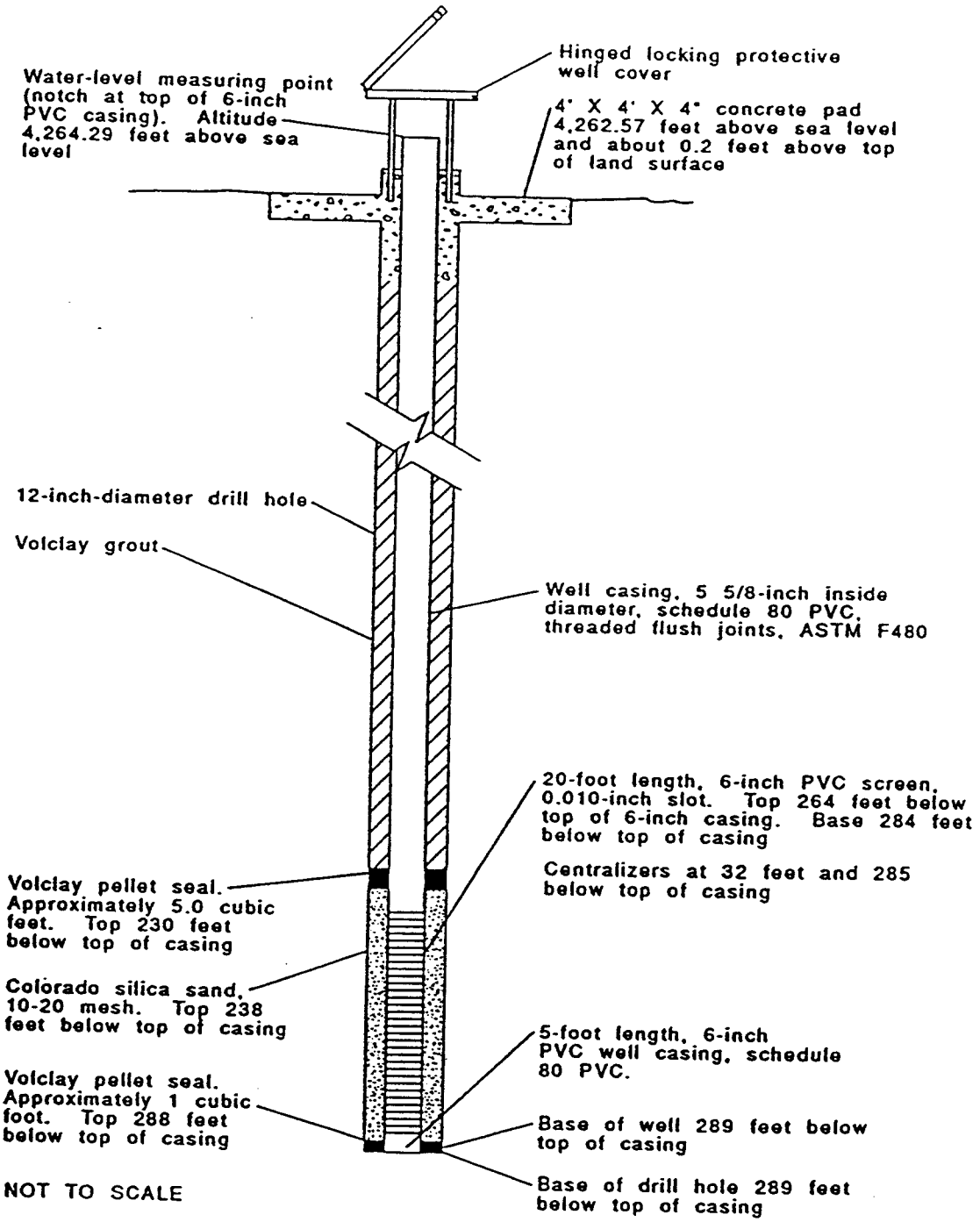


Figure 1.--Well-completion diagram for monitoring well CAFB-M drilled and completed by U.S. Geological Survey, Coal Branch, Denver, Colo. Started on 01-31-92. Completed on 02-05-92. Well drilled using mud-rotary method and Wyoming sodium bentonite drilling fluid.

This figure accurately represents the construction of well M at Cannon Air Force Base.

Peter F. Frenzel Professional Engineer,
Certificate Number 9989

MONITORING WELL IDENTIFICATION REPORT

ENVIRONMENTAL IMPROVEMENT DIVISION
HAZARDOUS WASTE SECTION
1190 ST. FRANCIS DR./HAROLD RUNNELS BLDG.
SANTA FE, NEW MEXICO 87503

FACILITY NAME Cannon Air Force Base

EPA I.D. NUMBER

COUNTY Curry

WELL NUMBER Well M - Landfill 5

WELL LOCATION (LONGITUDE) 103° 18' 00"

WELL LOCATION (LATITUDE) 34° 22' 01"

AQUIFER NAME Ogallala

AQUIFER CONFINED _____ UNCONFINED X

WELL INSTALLATION DATE February 4, 1992

DRILLING METHOD HYDRT: (mud rotary)

INNER CASING DIAMETER 5.8 inch

BOREHOLE DIAMETER 12 inch

CASING MATERIAL PVC

METHOD OF DEVELOPMENT BAILD

ELEV BOTTOM OF BOREHOLE 3975.~~70~~ 29

ELEV BOTTOM OF WELL CASING 3975.~~70~~ 29

ELEV BOTTOM OF SCREENED INT 3980.~~07~~ 29

ELEVATION OF SCREENED INT ~~3999.82~~ 4000.29 - 3980.~~07~~ 29

SURVEYED ELEV OF CASING TOP 4264.29

DATE OF REPORT 6-2-92 SIGNATURE Jerry D. Larson

NAME (TYPED) Jerry D. Larson

Cannon Air Force Base

Well M

Lithologic Description

0-5	Top soil with red and yellow clay streaks
5-10	Red silty clay with streaks of white caliche
10-15	Red silty clay with streaks of white caliche
15-20	Alternating streaks of caliche and red silty sand
20-25	White-Tan caliche and silty sand
25-30	Reddish tan silt and sand - some caliche
35-40	Caliche-very hard with cemented sand silt
40-45	Reddish brown silt with cemented siltstone layers
45-50	Siltstone layers grading to silty sand
50-55	Red cemented siltstone with uncemented sand and silt
55-60	Red cemented siltstone with uncemented sand and silt
60-65	Mostly cemented red sand - streaks of caliche
65-70	Mostly cemented red sand - streaks of caliche
70-75	Becoming unconsolidated reddish brown silty sand
75-80	Soft reddish brown silty sand
80-85	Hard reddish brown sandstone becoming softer
85-90	Hard cemented sandstone
90-95	Med-fine red sand and sandstone
95-100	Med-fine red sand and sandstone
100-105	Med-fine red sand and sandstone and some caliche stringers
105-110	Mostly fine red sand - caliche stringers
110-115	Mostly fine red sand - caliche stringers
115-120	Mostly fine red sand - caliche stringers

Cannon Air Force Base

Well M

Lithologic Description

120-125	Medium fine reddish-brown sand
125-130	Medium fine reddish-brown sand
130-135	Medium fine reddish-brown sand
135-140	Medium fine reddish-brown sand coarser 138-140
140-145	Fine reddish-brown sand
145-150	Fine reddish-brown sand
150-155	Fine reddish-brown sand some caliche
155-160	Fine reddish-brown sand - caliche
160-180	Fine reddish-brown sand - caliche
180-195	Fine reddish brown sand - becoming silty
195-205	Reddish brown - fine silty sand
205-220	Hard caliche and gravel - very coarse
220-225	Coarse gravel
225-235	Coarse gravel turning to fine sand and clay @ 230
235-245	Fine tight sand with sandstone streaks
245-255	Fine tight sand with sandstone streaks
255-287	Hard cemented sandstone

BOH at 287

ATTACHMENT 2

THREE POINT PROBLEM CALCULATIONS

THREE-POINT CALCULATIONS FOR FIGURE 1.6

The general formula three point calculations:

$$\frac{\Delta h}{\Delta H} = \frac{x}{l}$$

ΔH = Difference in static groundwater elevation between the endpoint wells for each line in the three point calculations.
Δh = For each line used in the three point calculations, the difference in groundwater elevation between the contour line elevation (e.g., 4001 ft, 4002 ft, 4003 ft, etc.) and the static groundwater elevation at the endpoint well displaying the highest static groundwater elevation.
l = The length of the three-point calculation line, in inches.
x = The point where the contour line crosses the line used for three point calculations (measured in inches, from the endpoint well displaying the highest static groundwater elevation).

Line between Well A and Well D:

A.) ΔH = 4005.26 ft (*static groundwater elevation at Well A*) - 4001.07 ft (*static groundwater elevation at Well D*) = 4.19 ft
B.) l = Length of three-point calculation line between Well A and Well D = 7.56 inches

4005 ft contour:
Δh = 4005.26 ft (Well A) - 4005 ft contour line = 0.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.26 \text{ ft}}{4.19 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 0.47 inches, therefore, the 4005 ft groundwater elevation line crosses the A-D three point calculation line 0.47 inches from Well A.

4004 ft contour:
Δh = 4005.26 ft (Well A) - 4004 ft contour line = 1.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.26 \text{ ft}}{4.19 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 2.27 inches, therefore, the 4004 ft groundwater elevation line crosses the A-D three point calculation line 2.27 inches from Well A.

4003 ft contour:
Δh = 4005.26 ft (Well A) - 4003 ft contour line = 2.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.26 \text{ ft}}{4.19 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 4.08 inches, therefore, the 4003 ft groundwater elevation line crosses the A-D three point calculation line 4.08 inches from Well A.

4002 ft contour:
Δh = 4005.26 ft (Well A) - 4002 ft contour line = 3.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.26 \text{ ft}}{4.19 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 5.88 inches, therefore, the 4002 ft groundwater elevation line crosses the A-D three point calculation line 5.88 inches from Well A.

4001 ft contour: Contour line does not cross the A-D three point calculation line.

Line between Well A and Well C:

A.) ΔH = 4005.26 ft (*static groundwater elevation at Well A*) - 4000.3 ft (*static groundwater elevation at Well C*) = 4.96 ft
B.) l = Length of three-point calculation line between Well A and Well C = 8.50 inches

4005 ft contour:
Δh = 4005.26 ft (Well A) - 4005 ft contour line = 0.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.26 \text{ ft}}{4.96 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 0.45 inches, therefore, the 4005 ft groundwater elevation line crosses the A-C three point calculation line 0.45 inches from Well A.

4004 ft contour:
Δh = 4005.26 ft (Well A) - 4004 ft contour line = 1.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.26 \text{ ft}}{4.96 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 2.16 inches, therefore, the 4004 ft groundwater elevation line crosses the A-C three point calculation line 2.16 inches from Well A.

4003 ft contour:
Δh = 4005.26 ft (Well A) - 4003 ft contour line = 2.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.26 \text{ ft}}{4.96 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 3.89 inches, therefore, the 4003 ft groundwater elevation line crosses the A-C three point calculation line 3.89 inches from Well A.

4002 ft contour:
Δh = 4005.26 ft (Well A) - 4002 ft contour line = 3.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.26 \text{ ft}}{4.96 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 5.57 inches, therefore, the 4002 ft groundwater elevation line crosses the A-C three point calculation line 5.57 inches from Well A.

4001 ft contour:
Δh = 4005.26 ft (Well A) - 4001 ft contour line = 4.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.26 \text{ ft}}{4.96 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 7.3 inches, therefore, the 4001 ft groundwater elevation line crosses the A-C three point calculation line 7.3 inches from Well A.

4000 ft contour: Contour line does not cross the A-C three point calculation line.

Line between Well A and Well B:

A.) ΔH = 4005.26 ft (*static groundwater elevation at Well A*) - 4000.63 ft (*static groundwater elevation at Well B*) = 4.63 ft
B.) l = Length of three-point calculation line between Well A and Well B = 7.96 inches

4005 ft contour:
Δh = 4005.26 ft (Well A) - 4005 ft contour line = 0.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.26 \text{ ft}}{4.63 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 0.45 inches, therefore, the 4005 ft groundwater elevation line crosses the A-B three point calculation line 0.45 inches from Well A.

4004 ft contour:
Δh = 4005.26 ft (Well A) - 4004 ft contour line = 1.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.26 \text{ ft}}{4.63 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 2.17 inches, therefore, the 4004 ft groundwater elevation line crosses the A-B three point calculation line 2.17 inches from Well A.

4003 ft contour:
Δh = 4005.26 ft (Well A) - 4003 ft contour line = 2.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.26 \text{ ft}}{4.63 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 3.89 inches, therefore, the 4003 ft groundwater elevation line crosses the A-B three point calculation line 3.89 inches from Well A.

4002 ft contour:
Δh = 4005.26 ft (Well A) - 4002 ft contour line = 3.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.26 \text{ ft}}{4.63 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 5.6 inches, therefore, the 4002 ft groundwater elevation line crosses the A-B three point calculation line 5.6 inches from Well A.

4001 ft contour:
Δh = 4005.26 ft (Well A) - 4001 ft contour line = 4.26 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.26 \text{ ft}}{4.63 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 7.32 inches, therefore, the 4001 ft groundwater elevation line crosses the A-B three point calculation line 7.32 inches from Well A.

4000 ft contour: Contour line does not cross the A-B three point calculation line.

Line between Well D and Well C:

A.) ΔH = 4001.07 ft (*static groundwater elevation at Well D*) - 4000.3 ft (*static groundwater elevation at Well C*) = 0.77 ft
B.) l = Length of three-point calculation line between Well C and Well D = 2.25 inches

4001 ft contour:
Δh = 4001.07(Well D) - 4001 ft contour line = 0.07 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.07 \text{ ft}}{0.77 \text{ ft}} = \frac{x}{2.25 \text{ inches}}$$

x = 0.2 inches, therefore, the 4001 ft groundwater elevation line crosses the C-D three point calculation line 0.2 inches from Well D.

4000 ft contour: Contour line does not cross the C-D three point calculation line.

THREE-POINT CALCULATIONS FOR FIGURE 1.7

The general formula three point calculations:

$$\frac{\Delta h}{\Delta H} = \frac{x}{l}$$

ΔH = Difference in static groundwater elevation between the endpoint wells for each line in the three point calculations.
Δh = For each line used in the three point calculations, the difference in groundwater elevation between the contour line elevation (e.g., 4001 ft, 4002 ft, 4003 ft, etc.) and the static groundwater elevation at the endpoint well displaying the highest static groundwater elevation.
l = The length of the three-point calculation line, in inches.
x = The point where the contour line crosses the line used for three point calculations (measured in inches, from the endpoint well displaying the highest static groundwater elevation).

Line between Well A and Well D:

A.) ΔH = 4003.38 ft (*static groundwater elevation at Well A*) - 3999.05 ft (*static groundwater elevation at Well D*) = 4.33 ft
B.) l = Length of three-point calculation line between Well A and Well D = 7.56 inches

4003 ft contour:
Δh = 4003.38 ft (Well A) - 4003 ft contour line = 0.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.38 \text{ ft}}{4.33 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 0.67 inches, therefore, the 4003 ft groundwater elevation line crosses the A-D three point calculation line 0.67 inches from Well A.

4002 ft contour:
Δh = 4003.38 ft (Well A) - 4002 ft contour line = 1.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.38 \text{ ft}}{4.33 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 2.45 inches, therefore, the 4002 ft groundwater elevation line crosses the A-D three point calculation line 2.45 inches from Well A.

4001 ft contour:
Δh = 4005.26 ft (Well A) - 4001 ft contour line = 2.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.38 \text{ ft}}{4.33 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 4.17 inches, therefore, the 4001 ft groundwater elevation line crosses the A-D three point calculation line 4.17 inches from Well A.

4000 ft contour:
Δh = 4005.26 ft (Well A) - 4000 ft contour line = 3.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.38 \text{ ft}}{4.33 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 5.90 inches, therefore, the 4000 ft groundwater elevation line crosses the A-D three point calculation line 5.90 inches from Well A.

3999 ft contour: Contour line does not cross the A-D three point calculation line.

Line between Well A and Well C:

A.) ΔH = 4003.38 ft (*static groundwater elevation at Well A*) - 3998.18 ft (*static groundwater elevation at Well C*) = 4.82 ft
B.) l = Length of three-point calculation line between Well A and Well C = 8.50 inches

4003 ft contour:
Δh = 4003.38 ft (Well A) - 4003 ft contour line = 0.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.38 \text{ ft}}{4.82 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 0.67 inches, therefore, the 4003 ft groundwater elevation line crosses the A-C three point calculation line 0.67 inches from Well A.

4002 ft contour:
Δh = 4003.38 ft (Well A) - 4002 ft contour line = 1.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.38 \text{ ft}}{4.82 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 2.43 inches, therefore, the 4002 ft groundwater elevation line crosses the A-C three point calculation line 2.43 inches from Well A.

4001 ft contour:
Δh = 4003.38 ft (Well A) - 4001 ft contour line = 2.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.38 \text{ ft}}{4.82 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 4.19 inches, therefore, the 4001 ft groundwater elevation line crosses the A-C three point calculation line 4.19 inches from Well A.

4000 ft contour:
Δh = 4003.38 ft (Well A) - 4000 ft contour line = 3.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.38 \text{ ft}}{4.82 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 5.96 inches, therefore, the 4000 ft groundwater elevation line crosses the A-C three point calculation line 5.96 inches from Well A.

3999 ft contour:
Δh = 4003.38 ft (Well A) - 3999 ft contour line = 4.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.38 \text{ ft}}{4.82 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 7.72 inches, therefore, the 3999 ft groundwater elevation line crosses the A-C three point calculation line 7.72 inches from Well A.

3998 ft contour: Contour line does not cross the A-C three point calculation line.

Line between Well A and Well B:

A.) ΔH = 4003.38 ft (*static groundwater elevation at Well A*) - 3998.1 ft (*static groundwater elevation at Well B*) = 5.28 ft
B.) l = Length of three-point calculation line between Well A and Well B = 7.96 inches

4003 ft contour:
Δh = 4003.38 ft (Well A) - 4003 ft contour line = 0.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.38 \text{ ft}}{5.28 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 0.57 inches, therefore, the 4003 ft groundwater elevation line crosses the A-B three point calculation line 0.57 inches from Well A.

4002 ft contour:
Δh = 4003.38 ft (Well A) - 4002 ft contour line = 1.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.38 \text{ ft}}{5.28 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 2.08 inches, therefore, the 4002 ft groundwater elevation line crosses the A-B three point calculation line 2.08 inches from Well A.

4001 ft contour:
Δh = 4003.38 ft (Well A) - 4001 ft contour line = 2.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.38 \text{ ft}}{5.28 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 3.59 inches, therefore, the 4001 ft groundwater elevation line crosses the A-B three point calculation line 3.59 inches from Well A.

4000 ft contour:
Δh = 4003.38 ft (Well A) - 4000 ft contour line = 3.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.38 \text{ ft}}{5.28 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 5.10 inches, therefore, the 4000 ft groundwater elevation line crosses the A-B three point calculation line 5.10 inches from Well A.

3999 ft contour:
Δh = 4003.38 ft (Well A) - 3999 ft contour line = 4.38 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.38 \text{ ft}}{5.28 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 6.60 inches, therefore, the 3999 ft groundwater elevation line crosses the A-B three point calculation line 6.60 inches from Well A.

3998 ft contour: Contour line does not cross the A-B three point calculation line.

Line between Well C and Well D:

A.) ΔH = 3999.05 ft (*static groundwater elevation at Well D*) - 3998.18 ft (*static groundwater elevation at Well C*) = 0.87 ft
B.) l = Length of three-point calculation line between Well C and Well D = 2.25 inches

3999 ft contour:
Δh = 3999.05 ft (Well D) - 3999 ft contour line = 0.05 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.05 \text{ ft}}{0.87 \text{ ft}} = \frac{x}{2.25 \text{ inches}}$$

x = 0.13 inches, therefore, the 3999 ft groundwater elevation line crosses the C-D three point calculation line 0.13 inches from Well D.

3998 ft contour: Contour line does not cross the C-D three point calculation line.

THREE-POINT CALCULATIONS FOR FIGURE 1.8

The general formula three point calculations:

$$\frac{\Delta h}{\Delta H} = \frac{x}{l}$$

ΔH = Difference in static groundwater elevation between the endpoint wells for each line in the three point calculations.
Δh = For each line used in the three point calculations, the difference in groundwater elevation between the contour line elevation (e.g., 4001 ft, 4002 ft, 4003 ft, etc.) and the static groundwater elevation at the endpoint well displaying the highest static groundwater elevation.
l = The length of the three-point calculation line, in inches.
x = The point where the contour line crosses the line used for three point calculations (measured in inches, from the endpoint well displaying the highest static groundwater elevation).

Line between Well A and Well D:

A.) ΔH = 4004.42 ft (*static groundwater elevation at Well A*) - 3999.81 ft (*static groundwater elevation at Well D*) = 4.61 ft
B.) l = Length of three-point calculation line between Well A and Well D = 7.56 inches

4004 ft contour:
Δh = 4004.42 ft (Well A) - 4004 ft contour line = 0.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.42 \text{ ft}}{4.61 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 0.69 inches, therefore, the 4004 ft groundwater elevation line crosses the A-D three point calculation line 0.69 inches from Well A.

4003 ft contour:
Δh = 4004.42 ft (Well A) - 4003 ft contour line = 1.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.42 \text{ ft}}{4.61 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 2.33 inches, therefore, the 4003 ft groundwater elevation line crosses the A-D three point calculation line 2.33 inches from Well A.

4002 ft contour:
Δh = 4004.42 ft (Well A) - 4002 ft contour line = 2.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.42 \text{ ft}}{4.61 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 3.97 inches, therefore, the 4002 ft groundwater elevation line crosses the A-D three point calculation line 3.97 inches from Well A.

4001 ft contour:
Δh = 4004.42 ft (Well A) - 4001 ft contour line = 3.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.42 \text{ ft}}{4.61 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 5.60 inches, therefore, the 4001 ft groundwater elevation line crosses the A-D three point calculation line 5.60 inches from Well A.

4000 ft contour:
Δh = 4004.42 ft (Well A) - 4000 ft contour line = 4.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.42 \text{ ft}}{4.61 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 7.25 inches, therefore, the 4000 ft groundwater elevation line crosses the A-D three point calculation line 7.25 inches from Well A.

3999 ft contour: Contour line does not cross the A-D three point calculation line.

Line between Well A and Well C:

A.) ΔH = 4004.42 ft (*static groundwater elevation at Well A*) - 3998.89 ft (*static groundwater elevation at Well C*) = 5.53 ft
B.) l = Length of three-point calculation line between Well A and Well C = 8.5 inches

4004 ft contour:
Δh = 4004.42 ft (Well A) - 4004 ft contour line = 0.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.42 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 0.65 inches, therefore, the 4004 ft groundwater elevation line crosses the A-C three point calculation line 0.65 inches from Well A.

4003 ft contour:
Δh = 4004.42 ft (Well A) - 4003 ft contour line = 1.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.42 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 2.18 inches, therefore, the 4003 ft groundwater elevation line crosses the A-C three point calculation line 2.18 inches from Well A.

4002 ft contour:
Δh = 4004.42 ft (Well A) - 4002 ft contour line = 2.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.42 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 3.72 inches, therefore, the 4002 ft groundwater elevation line crosses the A-C three point calculation line 3.72 inches from Well A.

4001 ft contour:
Δh = 4004.42 ft (Well A) - 4001 ft contour line = 3.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.42 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 5.26 inches, therefore, the 4001 ft groundwater elevation line crosses the A-C three point calculation line 5.26 inches from Well A.

4000 ft contour:
Δh = 4004.42 ft (Well A) - 4000 ft contour line = 4.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.42 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 6.79 inches, therefore, the 4000 ft groundwater elevation line crosses the A-C three point calculation line 6.79 inches from Well A.

3999 ft contour:
Δh = 4004.42 ft (Well A) - 3999 ft contour line = 5.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{5.42 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 8.33 inches, therefore, the 3999 ft groundwater elevation line crosses the A-C three point calculation line 8.33 inches from Well A.

3998 ft contour: Contour line does not cross the A-C three point calculation line.

Line between Well A and Well B:

A.) ΔH = 4004.42 ft (*static groundwater elevation at Well A*) - 3999.11 ft (*static groundwater elevation at Well B*) = 5.31 ft
B.) l = Length of three-point calculation line between Well A and Well B = 7.96 inches

4004 ft contour:
Δh = 4004.42 ft (Well A) - 4004 ft contour line = 0.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.42 \text{ ft}}{5.31 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 0.63 inches, therefore, the 4004 ft groundwater elevation line crosses the A-B three point calculation line 0.63 inches from Well A.

4003 ft contour:
Δh = 4004.42 ft (Well A) - 4003 ft contour line = 1.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.42 \text{ ft}}{5.31 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 2.13 inches, therefore, the 4003 ft groundwater elevation line crosses the A-B three point calculation line 2.13 inches from Well A.

4002 ft contour:
Δh = 4004.42 ft (Well A) - 4002 ft contour line = 2.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.42 \text{ ft}}{5.31 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 3.63 inches, therefore, the 4002 ft groundwater elevation line crosses the A-B three point calculation line 3.63 inches from Well A.

4001 ft contour:
Δh = 4004.42 ft (Well A) - 4001 ft contour line = 3.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.42 \text{ ft}}{5.31 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 5.17 inches, therefore, the 4001 ft groundwater elevation line crosses the A-B three point calculation line 5.17 inches from Well A.

4000 ft contour:
Δh = 4004.42 ft (Well A) - 4000 ft contour line = 4.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.42 \text{ ft}}{5.31 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 6.63 inches, therefore, the 4000 ft groundwater elevation line crosses the A-B three point calculation line 6.63 inches from Well A.

3999 ft contour: Contour line does not cross the A-B three point calculation line.

Line between Well C and Well D:

A.) ΔH = 3999.81 ft (*static groundwater elevation at Well D*) - 3998.89 ft (*static groundwater elevation at Well C*) = 0.92 ft
B.) l = Length of three-point calculation line between Well C and Well D = 2.25 inches

3999 ft contour:
Δh = 3999.81 ft (Well A) - 3999 ft contour line = 0.81 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.81 \text{ ft}}{0.92 \text{ ft}} = \frac{x}{2.25 \text{ inches}}$$

x = 1.98 inches, therefore, the 3999 ft groundwater elevation line crosses the C-D three point calculation line 1.98 inches from Well D.

3998 ft contour: Contour line does not cross the C-D three point calculation line.

THREE-POINT CALCULATIONS FOR FIGURE 1.9

The general formula three point calculations:

$$\frac{\Delta h}{\Delta H} = \frac{x}{l}$$

ΔH = Difference in static groundwater elevation between the endpoint wells for each line in the three point calculations.
Δh = For each line used in the three point calculations, the difference in groundwater elevation between the contour line elevation (e.g., 4001 ft, 4002 ft, 4003 ft, etc.) and the static groundwater elevation at the endpoint well displaying the highest static groundwater elevation.
l = The length of the three-point calculation line, in inches.
x = The point where the contour line crosses the line used for three point calculations (measured in inches, from the endpoint well displaying the highest static groundwater elevation).

Line between Well A and Well D:

A.) ΔH = 4004.31 ft (*static groundwater elevation at Well A*) - 4000.65 ft (*static groundwater elevation at Well D*) = 3.66 ft
B.) l = Length of three-point calculation line between Well A and Well D = 7.56 inches

4004 ft contour:
Δh = 4004.31 ft (Well A) - 4004 ft contour line = 0.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.31 \text{ ft}}{3.66 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 0.64 inches, therefore, the 4004 ft groundwater elevation line crosses the A-D three point calculation line 0.64 inches from Well A.

4003 ft contour:
Δh = 4004.31 ft (Well A) - 4003 ft contour line = 1.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.31 \text{ ft}}{3.66 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 2.71 inches, therefore, the 4003 ft groundwater elevation line crosses the A-D three point calculation line 2.71 inches from Well A.

4002 ft contour:
Δh = 4004.31 ft (Well A) - 4002 ft contour line = 2.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.31 \text{ ft}}{3.66 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 4.77 inches, therefore, the 4002 ft groundwater elevation line crosses the A-D three point calculation line 4.77 inches from Well A.

4001 ft contour:
Δh = 4004.31 ft (Well A) - 4001 ft contour line = 3.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.31 \text{ ft}}{3.66 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 6.84 inches, therefore, the 4001 ft groundwater elevation line crosses the A-D three point calculation line 6.84 inches from Well A.

4000 ft contour: Contour line does not cross the A-D three point calculation line.

Line between Well A and Well C:

A.) ΔH = 4004.31 ft (*static groundwater elevation at Well A*) - 3999.07 ft (*static groundwater elevation at Well C*) = 5.24 ft
B.) l = Length of three-point calculation line between Well A and Well C = 8.5 inches

4004 ft contour:
Δh = 4004.31 ft (Well A) - 4004 ft contour line = 0.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.31 \text{ ft}}{5.24 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 0.5 inches, therefore, the 4004 ft groundwater elevation line crosses the A-C three point calculation line 0.5 inches from Well A.

4003 ft contour:
Δh = 4004.31 ft (Well A) - 4003 ft contour line = 1.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.31 \text{ ft}}{5.24 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 2.12 inches, therefore, the 4003 ft groundwater elevation line crosses the A-C three point calculation line 2.12 inches from Well A.

4002 ft contour:
Δh = 4004.31 ft (Well A) - 4002 ft contour line = 2.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.31 \text{ ft}}{5.24 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 3.75 inches, therefore, the 4002 ft groundwater elevation line crosses the A-C three point calculation line 3.75 inches from Well A.

4001 ft contour:
Δh = 4004.31 ft (Well A) - 4001 ft contour line = 3.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.31 \text{ ft}}{5.24 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 5.37 inches, therefore, the 4001 ft groundwater elevation line crosses the A-C three point calculation line 5.37 inches from Well A.

4000 ft contour:
Δh = 4004.31 ft (Well A) - 4000 ft contour line = 4.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.31 \text{ ft}}{5.24 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 6.99 inches, therefore, the 4000 ft groundwater elevation line crosses the A-C three point calculation line 6.99 inches from Well A.

3999 ft contour: Contour line does not cross the A-C three point calculation line.

Line between Well A and Well B:

A.) ΔH = 4004.31 ft (*static groundwater elevation at Well A*) - 3999.46 ft (*static groundwater elevation at Well B*) = 4.85 ft
B.) l = Length of three-point calculation line between Well A and Well B = 7.96 inches

4004 ft contour:
Δh = 4004.31 ft (Well A) - 4004 ft contour line = 0.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.31 \text{ ft}}{4.85 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 0.51 inches, therefore, the 4004 ft groundwater elevation line crosses the A-B three point calculation line 0.51 inches from Well A.

4003 ft contour:
Δh = 4004.31 ft (Well A) - 4003 ft contour line = 1.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.31 \text{ ft}}{4.85 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 2.15 inches, therefore, the 4003 ft groundwater elevation line crosses the A-B three point calculation line 2.15 inches from Well A.

4002 ft contour:
Δh = 4004.31 ft (Well A) - 4002 ft contour line = 2.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.31 \text{ ft}}{4.85 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 3.79 inches, therefore, the 4002 ft groundwater elevation line crosses the A-B three point calculation line 3.79 inches from Well A.

4001 ft contour:
Δh = 4004.31 ft (Well A) - 4001 ft contour line = 3.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.31 \text{ ft}}{4.85 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 5.43 inches, therefore, the 4001 ft groundwater elevation line crosses the A-B three point calculation line 5.43 inches from Well A.

4000 ft contour:
Δh = 4004.31 ft (Well A) - 4000 ft contour line = 4.31 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.31 \text{ ft}}{4.85 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 7.07 inches, therefore, the 4001 ft groundwater elevation line crosses the A-B three point calculation line 7.07 inches from Well A.

3999 ft contour: Contour line does not cross the A-B three point calculation line.

Line between Well C and Well D:

A.) ΔH = 4000.65 ft (*static groundwater elevation at Well D*) - 3999.07 ft (*static groundwater elevation at Well C*) = 1.58 ft
B.) l = Length of three-point calculation line between Well C and Well D = 2.25 inches

4000 ft contour:
Δh = 4000.65 ft (Well D) - 4000 ft contour line = 0.65 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.65 \text{ ft}}{1.58 \text{ ft}} = \frac{x}{2.25 \text{ inches}}$$

x = 0.93 inches, therefore, the 4000 ft groundwater elevation line crosses the C-D three point calculation line 0.93 inches from Well D.

3999 ft contour: Contour line does not cross the C-D three point calculation line.

THREE-POINT CALCULATIONS FOR FIGURE 1.10

The general formula three point calculations:

$$\frac{\Delta h}{\Delta H} = \frac{x}{l}$$

ΔH = Difference in static groundwater elevation between the endpoint wells for each line in the three point calculations.
Δh = For each line used in the three point calculations, the difference in groundwater elevation between the contour line elevation (e.g., 4001 ft, 4002 ft, 4003 ft, etc.) and the static groundwater elevation at the endpoint well displaying the highest static groundwater elevation.
l = The length of the three-point calculation line, in inches.
x = The point where the contour line crosses the line used for three point calculations (measured in inches, from the endpoint well displaying the highest static groundwater elevation).

Line between Well A and Well D:

A.) ΔH = 4003.02 ft (*static groundwater elevation at Well A*) - 3999.77 ft (*static groundwater elevation at Well D*) = 3.25 ft
B.) l = Length of three-point calculation line between Well A and Well D = 7.56 inches

4003 ft contour:
Δh = 4003.02 ft (Well A) - 4003 ft contour line = 0.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.02 \text{ ft}}{3.25 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 0.05 inches, therefore, the 4003 ft groundwater elevation line crosses the A-D three point calculation line 0.05 inches from Well A.

4002 ft contour:
Δh = 4004.31 ft (Well A) - 4002 ft contour line = 1.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.02 \text{ ft}}{3.25 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 2.37 inches, therefore, the 4002 ft groundwater elevation line crosses the A-D three point calculation line 2.37 inches from Well A.

4001 ft contour:
Δh = 4004.31 ft (Well A) - 4001 ft contour line = 2.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.02 \text{ ft}}{3.25 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 4.7 inches, therefore, the 4001 ft groundwater elevation line crosses the A-D three point calculation line 4.7 inches from Well A.

4000 ft contour:
Δh = 4004.31 ft (Well A) - 4000 ft contour line = 3.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.02 \text{ ft}}{3.25 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 7.02 inches, therefore, the 4000 ft groundwater elevation line crosses the A-D three point calculation line 7.02 inches from Well A.

3999 ft contour: Contour line does not cross the A-D three point calculation line.

Line between Well A and Well C:

A.) ΔH = 4003.02 ft (*static groundwater elevation at Well A*) - 3999.07 ft (*static groundwater elevation at Well C*) = 3.95 ft
B.) l = Length of three-point calculation line between Well A and Well C = 8.50 inches

4003 ft contour:
Δh = 4003.02 ft (Well A) - 4003 ft contour line = 0.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.02 \text{ ft}}{3.95 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 0.04 inches, therefore, the 4003 ft groundwater elevation line crosses the A-C three point calculation line 0.04 inches from Well A.

4002 ft contour:
Δh = 4004.31 ft (Well A) - 4002 ft contour line = 1.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.02 \text{ ft}}{3.95 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 2.19 inches, therefore, the 4002 ft groundwater elevation line crosses the A-C three point calculation line 2.19 inches from Well A.

4001 ft contour:
Δh = 4004.31 ft (Well A) - 4001 ft contour line = 2.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.02 \text{ ft}}{3.95 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 4.35 inches, therefore, the 4001 ft groundwater elevation line crosses the A-C three point calculation line 4.35 inches from Well A.

4000 ft contour:
Δh = 4004.31 ft (Well A) - 4000 ft contour line = 3.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.02 \text{ ft}}{3.95 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 6.5 inches, therefore, the 4000 ft groundwater elevation line crosses the A-C three point calculation line 6.5 inches from Well A.

3999 ft contour: Contour line does not cross the A-C three point calculation line.

Line between Well A and Well B:

A.) ΔH = 4003.02 ft (*static groundwater elevation at Well A*) - 3998.33 ft (*static groundwater elevation at Well B*) = 3.95 ft
B.) l = Length of three-point calculation line between Well A and Well B = 8.50 inches

4003 ft contour:
Δh = 4003.02 ft (Well A) - 4003 ft contour line = 0.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.02 \text{ ft}}{3.95 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 0.04 inches, therefore, the 4003 ft groundwater elevation line crosses the A-B three point calculation line 0.04 inches from Well A.

4002 ft contour:
Δh = 4004.31 ft (Well A) - 4002 ft contour line = 1.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.02 \text{ ft}}{3.95 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 2.19 inches, therefore, the 4002 ft groundwater elevation line crosses the A-B three point calculation line 2.19 inches from Well A.

4001 ft contour:
Δh = 4004.31 ft (Well A) - 4001 ft contour line = 2.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.02 \text{ ft}}{3.95 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 4.35 inches, therefore, the 4001 ft groundwater elevation line crosses the A-B three point calculation line 4.35 inches from Well A.

4000 ft contour:
Δh = 4004.31 ft (Well A) - 4000 ft contour line = 3.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.02 \text{ ft}}{3.95 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 6.5 inches, therefore, the 4000 ft groundwater elevation line crosses the A-B three point calculation line 6.5 inches from Well A.

3999 ft contour: Contour line does not cross the A-B three point calculation line.

Line between Well A and Well I:

A.) ΔH = 4003.02 ft (*static groundwater elevation at Well A*) - 3997.15 ft (*static groundwater elevation at Well I*) = 5.87 ft
B.) l = Length of three-point calculation line between Well A and Well I = 9.0 inches

4003 ft contour:
Δh = 4003.02 ft (Well A) - 4003 ft contour line = 0.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.02 \text{ ft}}{5.87 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 0.03 inches, therefore, the 4003 ft groundwater elevation line crosses the A-I three point calculation line 0.03 inches from Well A.

4002 ft contour:
Δh = 4004.31 ft (Well A) - 4002 ft contour line = 1.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.02 \text{ ft}}{5.87 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 1.56 inches, therefore, the 4002 ft groundwater elevation line crosses the A-I three point calculation line 1.56 inches from Well A.

4001 ft contour:
Δh = 4004.31 ft (Well A) - 4001 ft contour line = 2.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.02 \text{ ft}}{5.87 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 3.1 inches, therefore, the 4001 ft groundwater elevation line crosses the A-I three point calculation line 3.1 inches from Well A.

4000 ft contour:
Δh = 4004.31 ft (Well A) - 4000 ft contour line = 3.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.02 \text{ ft}}{5.87 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 4.63 inches, therefore, the 4001 ft groundwater elevation line crosses the A-I three point calculation line 4.63 inches from Well A.

3999 ft contour:
Δh = 4004.31 ft (Well A) - 3999 ft contour line = 4.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.02 \text{ ft}}{5.87 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 6.16 inches, therefore, the 3999 ft groundwater elevation line crosses the A-I three point calculation line 6.16 inches from Well A.

3998 ft contour:
Δh = 4004.31 ft (Well A) - 3998 ft contour line = 5.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{5.02 \text{ ft}}{5.87 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 7.7 inches, therefore, the 3998 ft groundwater elevation line crosses the A-I three point calculation line 7.7 inches from Well A.

3997 ft contour: Contour line does not cross the A-I three point calculation line.

Line between Well A and Well B:

A.) ΔH = 4003.02 ft (*static groundwater elevation at Well A*) - 3998.33 ft (*static groundwater elevation at Well B*) = 4.69 ft
B.) l = Length of three-point calculation line between Well A and Well B = 7.96 inches

4003 ft contour:
Δh = 4003.02 ft (Well A) - 4003 ft contour line = 0.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.02 \text{ ft}}{4.69 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 0.03 inches, therefore, the 4003 ft groundwater elevation line crosses the A-B three point calculation line 0.03 inches from Well A.

4002 ft contour:
Δh = 4004.31 ft (Well A) - 4002 ft contour line = 1.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.02 \text{ ft}}{4.69 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 1.73 inches, therefore, the 4002 ft groundwater elevation line crosses the A-B three point calculation line 1.73 inches from Well A.

4001 ft contour:
Δh = 4004.31 ft (Well A) - 4001 ft contour line = 2.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.02 \text{ ft}}{4.69 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 3.43 inches, therefore, the 4001 ft groundwater elevation line crosses the A-B three point calculation line 3.43 inches from Well A.

4000 ft contour:
Δh = 4004.31 ft (Well A) - 4000 ft contour line = 3.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.02 \text{ ft}}{4.69 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 5.12 inches, therefore, the 4000 ft groundwater elevation line crosses the A-B three point calculation line 5.12 inches from Well A.

3999 ft contour:
Δh = 4004.31 ft (Well A) - 3999 ft contour line = 4.02 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.02 \text{ ft}}{4.69 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 6.82 inches, therefore, the 3999 ft groundwater elevation line crosses the A-B three point calculation line 6.82 inches from Well A.

3998 ft contour: Contour line does not cross the A-B three point calculation line.

Line between Well C and Well I:

A.) ΔH = 3999.07 ft (*static groundwater elevation at Well C*) - 3997.15 ft (*static groundwater elevation at Well I*) = 1.92 ft
B.) l = Length of three-point calculation line between Well C and Well I = 1.88 inches

3999 ft contour:
Δh = 3999.07 ft (Well C) - 3999 ft contour line = 0.07 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.07 \text{ ft}}{1.92 \text{ ft}} = \frac{x}{1.88 \text{ inches}}$$

x = 0.07 inches, therefore, the 3999 ft groundwater elevation line crosses the C-I three point calculation line 0.07 inches from Well C.

3998 ft contour:
Δh = 3999.07 ft (Well C) - 3998 ft contour line = 1.07 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.07 \text{ ft}}{1.92 \text{ ft}} = \frac{x}{1.88 \text{ inches}}$$

x = 1.09 inches, therefore, the 3998 ft groundwater elevation line crosses the C-I three point calculation line 1.09 inches from Well C.

3997 ft contour: Contour line does not cross the C-I three point calculation line.

Line between Well B and Well I:

A.) ΔH = 3998.33 ft (*static groundwater elevation at Well B*) - 3997.15 ft (*static groundwater elevation at Well I*) = 1.18 ft
B.) l = Length of three-point calculation line between Well B and Well I = 1.31 inches

3998 ft contour:
Δh = 3998.33 ft (Well B) - 3998 ft contour line = 0.33 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.33 \text{ ft}}{1.18 \text{ ft}} = \frac{x}{1.31 \text{ inches}}$$

x = 0.37 inches, therefore, the 3998 ft groundwater elevation line crosses the B-I three point calculation line 0.37 inches from Well B.

3997 ft contour: Contour line does not cross the B-I three point calculation line.

THREE-POINT CALCULATIONS FOR FIGURE 1.11

The general formula three point calculations:

$$\frac{\Delta h}{\Delta H} = \frac{x}{l}$$

ΔH = Difference in static groundwater elevation between the endpoint wells for each line in the three point calculations.
Δh = For each line used in the three point calculations, the difference in groundwater elevation between the contour line elevation (e.g., 4001 ft, 4002 ft, 4003 ft, etc.) and the static groundwater elevation at the endpoint well displaying the highest static groundwater elevation.
l = The length of the three-point calculation line, in inches.
x = The point where the contour line crosses the line used for three point calculations (measured in inches, from the endpoint well displaying the highest static groundwater elevation).

Line between Well A and Well D:

A.) ΔH = 4003.61 ft (*static groundwater elevation at Well A*) - 3999.98 ft (*static groundwater elevation at Well D*) = 3.63 ft
B.) l = Length of three-point calculation line between Well A and Well D = 7.56 inches

4003 ft contour:
Δh = 4003.61 ft (Well A) - 4003 ft contour line = 0.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.61 \text{ ft}}{3.63 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 1.27 inches, therefore, the 4003 ft groundwater elevation line crosses the A-D three point calculation line 1.27 inches from Well A.

4002 ft contour:
Δh = 4003.61 ft (Well A) - 4002 ft contour line = 1.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.61 \text{ ft}}{3.63 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 3.35 inches, therefore, the 4002 ft groundwater elevation line crosses the A-D three point calculation line 3.35 inches from Well A.

4001 ft contour:
Δh = 4003.61 ft (Well A) - 4001 ft contour line = 2.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.61 \text{ ft}}{3.63 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 5.44 inches, therefore, the 4001 ft groundwater elevation line crosses the A-D three point calculation line 5.44 inches from Well A.

4000 ft contour:
Δh = 4003.61 ft (Well A) - 4000 ft contour line = 3.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.61 \text{ ft}}{3.63 \text{ ft}} = \frac{x}{7.56 \text{ inches}}$$

x = 7.52 inches, therefore, the 4000 ft groundwater elevation line crosses the A-D three point calculation line 7.52 inches from Well A.

3999 ft contour: Contour line does not cross the A-D three point calculation line.

Line between Well A and Well C:

A.) ΔH = 4003.61 ft (*static groundwater elevation at Well A*) - 3999.19 ft (*static groundwater elevation at Well C*) = 4.42 ft
B.) l = Length of three-point calculation line between Well A and Well C = 8.5 inches

4003 ft contour:
Δh = 4003.61 ft (Well A) - 4003 ft contour line = 0.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.61 \text{ ft}}{4.42 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 1.17 inches, therefore, the 4003 ft groundwater elevation line crosses the A-C three point calculation line 1.17 inches from Well A.

4002 ft contour:
Δh = 4003.61 ft (Well A) - 4002 ft contour line = 1.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.61 \text{ ft}}{4.42 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 3.1 inches, therefore, the 4002 ft groundwater elevation line crosses the A-C three point calculation line 3.1 inches from Well A.

4001 ft contour:
Δh = 4003.61 ft (Well A) - 4001 ft contour line = 2.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.61 \text{ ft}}{4.42 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 5.02 inches, therefore, the 4001 ft groundwater elevation line crosses the A-C three point calculation line 5.02 inches from Well A.

4000 ft contour:
Δh = 4003.61 ft (Well A) - 4000 ft contour line = 3.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.61 \text{ ft}}{4.42 \text{ ft}} = \frac{x}{8.5 \text{ inches}}$$

x = 6.94 inches, therefore, the 4000 ft groundwater elevation line crosses the A-C three point calculation line 6.94 inches from Well A.

3999 ft contour: Contour line does not cross the A-C three point calculation line.

Line between Well A and Well I:

A.) ΔH = 4003.61 ft (*static groundwater elevation at Well A*) - 3998 ft (*static groundwater elevation at Well I*) = 5.61 ft
B.) l = Length of three-point calculation line between Well A and Well I = 9.0 inches

4003 ft contour:
Δh = 4003.61 ft (Well A) - 4003 ft contour line = 0.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.61 \text{ ft}}{5.61 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 0.98 inches, therefore, the 4003 ft groundwater elevation line crosses the A-I three point calculation line 0.98 inches from Well A.

4002 ft contour:
Δh = 4003.61 ft (Well A) - 4002 ft contour line = 1.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.61 \text{ ft}}{5.61 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 2.58 inches, therefore, the 4002 ft groundwater elevation line crosses the A-I three point calculation line 2.58 inches from Well A.

4001 ft contour:
Δh = 4003.61 ft (Well A) - 4001 ft contour line = 2.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.61 \text{ ft}}{5.61 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 4.19 inches, therefore, the 4001 ft groundwater elevation line crosses the A-I three point calculation line 4.19 inches from Well A.

4000 ft contour:
Δh = 4003.61 ft (Well A) - 4000 ft contour line = 3.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.61 \text{ ft}}{5.61 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 5.79 inches, therefore, the 4000 ft groundwater elevation line crosses the A-I three point calculation line 5.79 inches from Well A.

3999 ft contour:
Δh = 4003.61 ft (Well A) - 3999 ft contour line = 4.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.61 \text{ ft}}{5.61 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 7.4 inches, therefore, the 4000 ft groundwater elevation line crosses the A-I three point calculation line 7.4 inches from Well A.

3998 ft contour: Contour line cross the A-I three point calculation line at Well I.

Line between Well A and Well B:

A.) ΔH = 4003.61 ft (*static groundwater elevation at Well A*) - 3999.21 ft (*static groundwater elevation at Well B*) = 4.4 ft
B.) l = Length of three-point calculation line between Well A and Well B = 7.96 inches

4003 ft contour:
Δh = 4003.61 ft (Well A) - 4003 ft contour line = 0.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.61 \text{ ft}}{4.4 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 1.1 inches, therefore, the 4003 ft groundwater elevation line crosses the A-B three point calculation line 1.1 inches from Well A.

4002 ft contour:
Δh = 4003.61 ft (Well A) - 4002 ft contour line = 1.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.61 \text{ ft}}{4.4 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 2.91 inches, therefore, the 4002 ft groundwater elevation line crosses the A-B three point calculation line 2.91 inches from Well A.

4001 ft contour:
Δh = 4003.61 ft (Well A) - 4001 ft contour line = 2.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.61 \text{ ft}}{4.4 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 4.72 inches, therefore, the 4001 ft groundwater elevation line crosses the A-B three point calculation line 4.72 inches from Well A.

4000 ft contour:
Δh = 4003.61 ft (Well A) - 4000 ft contour line = 3.61 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.61 \text{ ft}}{4.4 \text{ ft}} = \frac{x}{7.96 \text{ inches}}$$

x = 6.53 inches, therefore, the 4000 ft groundwater elevation line crosses the A-B three point calculation line 6.53 inches from Well A.

3999 ft contour: Contour line does not cross the A-B three point calculation line.

Line between Well C and Well D:

A.) ΔH = 3999.98 ft (*static groundwater elevation at Well D*) - 3999.19 ft (*static groundwater elevation at Well C*) = 0.79 ft

No contour lines cross the C-D three point calculation line.

Line between Well C and Well I:

A.) ΔH = 3999.19 ft (*static groundwater elevation at Well C*) - 3998 ft (*static groundwater elevation at Well I*) = 1.19 ft
B.) l = Length of three-point calculation line between Well C and Well I = 1.88 inches

3999 ft contour:
Δh = 3999.19 ft (Well C) - 3999 ft contour line = 0.19 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.19 \text{ ft}}{1.19 \text{ ft}} = \frac{x}{1.88 \text{ inches}}$$

x = 0.3 inches, therefore, the 3999 ft groundwater elevation line crosses the C-I three point calculation line 0.3 inches from Well C.

3998 ft contour: Contour line cross the C-I three point calculation line at Well I.

Line between Well B and Well I:

A.) ΔH = 3999.21 ft (*static groundwater elevation at Well B*) - 3998 ft (*static groundwater elevation at Well I*) = 1.21 ft
B.) l = Length of three-point calculation line between Well B and Well I = 1.18 inches

3999 ft contour:
Δh = 3999.21 ft (Well B) - 3999 ft contour line = 0.21 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.21 \text{ ft}}{1.21 \text{ ft}} = \frac{x}{1.18 \text{ inches}}$$

x = 0.2 inches, therefore, the 3999 ft groundwater elevation line crosses the B-I three point calculation line 0.2 inches from Well B.

3998 ft contour: Contour line cross the B-I three point calculation line at Well I.

THREE-POINT CALCULATIONS FOR FIGURE 1.12

The general formula three point calculations:

$$\frac{\Delta h}{\Delta H} = \frac{x}{l}$$

ΔH = Difference in static groundwater elevation between the endpoint wells for each line in the three point calculations.
Δh = For each line used in the three point calculations, the difference in groundwater elevation between the contour line elevation (e.g., 4001 ft, 4002 ft, 4003 ft, etc.) and the static groundwater elevation at the endpoint well displaying the highest static groundwater elevation.
l = The length of the three-point calculation line, in inches.
x = The point where the contour line crosses the line used for three point calculations (measured in inches, from the endpoint well displaying the highest static groundwater elevation).

Line between Well A and Well I:

A.) ΔH = 4000.71 ft (*static groundwater elevation at Well A*) - 3995.42 ft (*static groundwater elevation at Well I*) = 5.29 ft
B.) l = Length of three-point calculation line between Well A and Well I= 9.0 inches

4000 ft contour:
Δh = 4000.71 ft (Well A) - 4000 ft contour line = 0.71 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.71 \text{ ft}}{5.29 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 1.21 inches, therefore, the 4000 ft groundwater elevation line crosses the A-I three point calculation line 1.21 inches from Well A.

3999 ft contour:
Δh = 4000.71 ft (Well A) - 3999 ft contour line = 1.71 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.71 \text{ ft}}{5.29 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 2.91 inches, therefore, the 3999 ft groundwater elevation line crosses the A-I three point calculation line 2.91 inches from Well A.

3998 ft contour:
Δh = 4000.71 ft (Well A) - 3998 ft contour line = 2.71 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.71 \text{ ft}}{5.29 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 4.61 inches, therefore, the 3998 ft groundwater elevation line crosses the A-I three point calculation line 4.61 inches from Well A.

3997 ft contour:
Δh = 4000.71 ft (Well A) - 3997 ft contour line = 3.71 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.71 \text{ ft}}{5.29 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 6.31 inches, therefore, the 3997 ft groundwater elevation line crosses the A-I three point calculation line 6.31 inches from Well A.

3996 ft contour:
Δh = 4000.71 ft (Well A) - 3996 ft contour line = 4.71 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.71 \text{ ft}}{5.29 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 8.01 inches, therefore, the 3996 ft groundwater elevation line crosses the A-I three point calculation line 8.01 inches from Well A.

3995 ft contour: Contour line does not cross the A-I three point calculation line.

Line between Well A and Well M:

A.) ΔH = 4000.71 ft (*static groundwater elevation at Well A*) - 3994.88 ft (*static groundwater elevation at Well M*) = 5.83 ft
B.) l = Length of three-point calculation line between Well A and Well M = 8.75 inches

4000 ft contour:
Δh = 4000.71 ft (Well A) - 4000 ft contour line = 0.71 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.71 \text{ ft}}{5.83 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 1.07 inches, therefore, the 4000 ft groundwater elevation line crosses the A-M three point calculation line 1.07 inches from Well A.

3999 ft contour:
Δh = 4000.71 ft (Well A) - 3999 ft contour line = 1.71 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.71 \text{ ft}}{5.83 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 2.57 inches, therefore, the 3999 ft groundwater elevation line crosses the A-M three point calculation line 2.57 inches from Well A.

3998 ft contour:
Δh = 4000.71 ft (Well A) - 3998 ft contour line = 2.71 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.71 \text{ ft}}{5.83 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 4.07 inches, therefore, the 3998 ft groundwater elevation line crosses the A-M three point calculation line 4.07 inches from Well A.

3997 ft contour:
Δh = 4000.71 ft (Well A) - 3997 ft contour line = 3.71 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.71 \text{ ft}}{5.83 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 5.56 inches, therefore, the 3997 ft groundwater elevation line crosses the A-M three point calculation line 5.56 inches from Well A.

3996 ft contour:
Δh = 4000.71 ft (Well A) - 3996 ft contour line = 4.71 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.71 \text{ ft}}{5.83 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 7.07 inches, therefore, the 3996 ft groundwater elevation line crosses the A-M three point calculation line 7.07 inches from Well A.

3995 ft contour:
Δh = 4000.71 ft (Well A) - 3995 ft contour line = 5.71 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{5.71 \text{ ft}}{5.83 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 8.57 inches, therefore, the 3995 ft groundwater elevation line crosses the A-M three point calculation line 8.57 inches from Well A.

3994 ft contour: Contour line does not cross the A-M three point calculation line.

Line between Well I and Well M:

A.) ΔH = 3995.42 ft (*static groundwater elevation at Well I*) - 3994.88 ft (*static groundwater elevation at Well M*) = 0.54 ft
B.) l = Length of three-point calculation line between Well I and Well M = 0.38 inches

3995 ft contour:
Δh = 3995.42 ft (Well I) - 3995 ft contour line = 0.42 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.42 \text{ ft}}{0.54 \text{ ft}} = \frac{x}{0.38 \text{ inches}}$$

x = 0.3 inches, therefore, the 3995 ft groundwater elevation line crosses the I-M three point calculation line 0.3 inches from Well I.

3994 ft contour: Contour does not cross the I-M three point calculation line.

THREE-POINT CALCULATIONS FOR FIGURE 1.13

The general formula three point calculations:

$$\frac{\Delta h}{\Delta H} = \frac{x}{l}$$

ΔH = Difference in static groundwater elevation between the endpoint wells for each line in the three point calculations.
Δh = For each line used in the three point calculations, the difference in groundwater elevation between the contour line elevation (e.g., 4001 ft, 4002 ft, 4003 ft, etc.) and the static groundwater elevation at the endpoint well displaying the highest static groundwater elevation.
l = The length of the three-point calculation line, in inches.
x = The point where the contour line crosses the line used for three point calculations (measured in inches, from the endpoint well displaying the highest static groundwater elevation).

Line between Well A and Well I:

A.) ΔH = 4000.01 ft (*static groundwater elevation at Well A*) - 3994.17 ft (*static groundwater elevation at Well I*) = 5.84 ft
B.) *l* = Length of three-point calculation line between Well A and Well I= 9.0 inches

4000 ft contour:
Δh = 4000.01 ft (Well A) - 4000 ft contour line = 0.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.01\text{ ft}}{5.84\text{ ft}} = \frac{x}{9.0\text{ inches}}$$

x = 0.02 inches, therefore, the 4000 ft groundwater elevation line crosses the A-I three point calculation line 0.02 inches from Well A.

3999 ft contour:
Δh = 4000.01 ft (Well A) - 3999 ft contour line = 1.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.01\text{ ft}}{5.84\text{ ft}} = \frac{x}{9.0\text{ inches}}$$

x = 1.56 inches, therefore, the 3999 ft groundwater elevation line crosses the A-I three point calculation line 1.59 inches from Well A.

3998 ft contour:
Δh = 4000.01 ft (Well A) - 3998 ft contour line = 2.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.01\text{ ft}}{5.84\text{ ft}} = \frac{x}{9.0\text{ inches}}$$

x = 3.1 inches, therefore, the 3998 ft groundwater elevation line crosses the A-I three point calculation line 3.1 inches from Well A.

3997 ft contour:
Δh = 4000.01 ft (Well A) - 3997 ft contour line = 3.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.01\text{ ft}}{5.84\text{ ft}} = \frac{x}{9.0\text{ inches}}$$

x = 4.64 inches, therefore, the 3997 ft groundwater elevation line crosses the A-I three point calculation line 4.64 inches from Well A.

3996 ft contour:
Δh = 4000.01 ft (Well A) - 3996 ft contour line = 4.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.01\text{ ft}}{5.84\text{ ft}} = \frac{x}{9.0\text{ inches}}$$

x = 6.18 inches, therefore, the 3996 ft groundwater elevation line crosses the A-I three point calculation line 6.18 inches from Well A.

3995 ft contour:
Δh = 4000.01 ft (Well A) - 3995 ft contour line = 5.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{5.01 \text{ ft}}{5.84 \text{ ft}} = \frac{x}{9.0 \text{ inches}}$$

x = 7.72 inches, therefore, the 3995 ft groundwater elevation line crosses the A-I three point calculation line 7.72 inches from Well A.

3995 ft contour: Contour line does not cross the A-I three point calculation line.

Line between Well A and Well M:

A.) ΔH = 4000.01 ft (*static groundwater elevation at Well A*) - 3994.48 ft (*static groundwater elevation at Well M*) = 5.53 ft
B.) l = Length of three-point calculation line between Well A and Well M= 8.75 inches

4000 ft contour:
Δh = 4000.01 ft (Well A) - 4000 ft contour line = 0.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.01 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 0.02 inches, therefore, the 4000 ft groundwater elevation line crosses the A-M three point calculation line 0.02 inches from Well A.

3999 ft contour:
Δh = 4000.01 ft (Well A) - 3999 ft contour line = 1.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{1.01 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 1.6 inches, therefore, the 3999 ft groundwater elevation line crosses the A-M three point calculation line 1.6 inches from Well A.

3998 ft contour:
Δh = 4000.01 ft (Well A) - 3998 ft contour line = 2.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{2.01 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 3.18 inches, therefore, the 3998 ft groundwater elevation line crosses the A-M three point calculation line 3.18 inches from Well A.

3997 ft contour:
Δh = 4000.01 ft (Well A) - 3997 ft contour line = 3.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{3.01 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 4.76 inches, therefore, the 3997 ft groundwater elevation line crosses the A-M three point calculation line 4.76 inches from Well A.

3996 ft contour:
Δh = 4000.01 ft (Well A) - 3996 ft contour line = 4.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{4.01 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 6.35 inches, therefore, the 3996 ft groundwater elevation line crosses the A-M three point calculation line 6.35 inches from Well A.

3995 ft contour:
Δh = 4000.01 ft (Well A) - 3995 ft contour line = 5.01 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{5.01 \text{ ft}}{5.53 \text{ ft}} = \frac{x}{8.75 \text{ inches}}$$

x = 7.93 inches, therefore, the 3995 ft groundwater elevation line crosses the A-M three point calculation line 7.93 inches from Well A.

3994 ft contour: Contour line does not cross the A-M three point calculation line.

Line between Well A and Well B:

A.) ΔH = 4000.01 ft (*static groundwater elevation at Well A*) - 3993.72 ft (*static groundwater elevation at Well B*) = 6.29 ft
B.) l = Length of three-point calculation line between Well A and Well B= 8.06 inches

4000 ft contour:
Δh = 4000.01 ft (Well A) - 4000 ft contour line = 0.01 ft.

$\frac{\Delta h}{\Delta H} = \frac{x}{l}$ $\quad \frac{0.01 \text{ ft}}{6.29 \text{ ft}} = \frac{x}{8.06 \text{ inches}}$ $\quad$ x = 0.01 inches, therefore, the 4000 ft groundwater elevation line crosses the A-B three point calculation line 0.01 inches from Well A.

3999 ft contour:
Δh = 4000.01 ft (Well A) - 3999 ft contour line = 1.01 ft.

$\frac{\Delta h}{\Delta H} = \frac{x}{l}$ $\quad \frac{1.01 \text{ ft}}{6.29 \text{ ft}} = \frac{x}{8.06 \text{ inches}}$ $\quad$ x = 1.29 inches, therefore, the 3999 ft groundwater elevation line crosses the A-B three point calculation line 1.29 inches from Well A.

3998 ft contour:
Δh = 4000.01 ft (Well A) - 3998 ft contour line = 2.01 ft.

$\frac{\Delta h}{\Delta H} = \frac{x}{l}$ $\quad \frac{2.01 \text{ ft}}{6.29 \text{ ft}} = \frac{x}{8.06 \text{ inches}}$ $\quad$ x = 2.58 inches, therefore, the 3998 ft groundwater elevation line crosses the A-B three point calculation line 2.58 inches from Well A.

3997 ft contour:
Δh = 4000.01 ft (Well A) - 3997 ft contour line = 3.01 ft.

$\frac{\Delta h}{\Delta H} = \frac{x}{l}$ $\quad \frac{3.01 \text{ ft}}{6.29 \text{ ft}} = \frac{x}{8.06 \text{ inches}}$ $\quad$ x = 3.86 inches, therefore, the 3997 ft groundwater elevation line crosses the A-B three point calculation line 3.86 inches from Well A.

3996 ft contour:
Δh = 4000.01 ft (Well A) - 3996 ft contour line = 4.01 ft.

$\frac{\Delta h}{\Delta H} = \frac{x}{l}$ $\quad \frac{4.01 \text{ ft}}{6.29 \text{ ft}} = \frac{x}{8.06 \text{ inches}}$ $\quad$ x = 5.13 inches, therefore, the 3996 ft groundwater elevation line crosses the A-B three point calculation line 5.13 inches from Well A.

3995 ft contour:
Δh = 4000.01 ft (Well A) - 3995 ft contour line = 5.01 ft.

$\frac{\Delta h}{\Delta H} = \frac{x}{l}$ $\quad \frac{5.01 \text{ ft}}{6.29 \text{ ft}} = \frac{x}{8.06 \text{ inches}}$ $\quad$ x = 6.42 inches, therefore, the 3995 ft groundwater elevation line crosses the A-B three point calculation line 6.42 inches from Well A.

3994 ft contour:
Δh = 4000.01 ft (Well A) - 3994 ft contour line = 6.01 ft.

$\frac{\Delta h}{\Delta H} = \frac{x}{l}$ $\quad \frac{6.01 \text{ ft}}{6.29 \text{ ft}} = \frac{x}{8.06 \text{ inches}}$ $\quad$ x = 7.7 inches, therefore, the 3994 ft groundwater elevation line crosses the A-B three point calculation line 7.7 inches from Well A.

3993 ft contour: Contour line does not cross the A-B three point calculation line.

Line between Well I and Well M:

A.) ΔH = 3994.48 ft (*static groundwater elevation at Well M*) - 3994.14 ft (*static groundwater elevation at Well I*) = 0.34 ft
B.) l = Length of three-point calculation line between Well I and Well M= 0.38 inches

3994 ft contour: Contour line does not cross the I-M three point calculation line.

Line between Well L and Well M:

A.) ΔH = 3994.48 ft (*static groundwater elevation at Well M*) - 3993.72 ft (*static groundwater elevation at Well L*) = 0.76 ft
B.) l = Length of three-point calculation line between Well L and Well M= 0.38 inches

3994 ft contour:
Δh = 3994.48 ft (Well M) - 3994 ft contour line = 0.48 ft.

$$\frac{\Delta h}{\Delta H} = \frac{x}{l} \qquad \frac{0.48 \text{ ft}}{0.76 \text{ ft}} = \frac{x}{0.38 \text{ inches}}$$

x = 0.24 inches, therefore, the 3994 ft groundwater elevation line crosses the L-M three point calculation line 0.24 inches from Well M.

3993 ft contour: Contour line does not cross the L-M three point calculation line.

Evaluation of Erosion Potential for the Geocomposite Soil Cap and Vegetative Cover

The U.S. Army Corps of Engineers (USCOE) designed the geocomposite soil cap at Cell 3 of Landfill 5 using the U.S. Department of Agriculture Universal Soil Loss equation for predicting erosion due to rainfall. The calculations that appear here are adapted from the USCOE "Landfill #5 Cell #3 Cannon AFB, New Mexico Final Design Analysis" document dated July 21, 1992.

The soil loss equation is:

A=R*K*LS*C*P

where:

A=average annual soil loss (tons/acre);

R=rainfall and runoff erosivity index;
for eastern New Mexico- R=100

K=soil erodibility factor (tons/acre);
for 4% organic matter and sandy clay loam- K=0.21

LS=combination of slope-length factor and slope-steepness factor;
for 3% slope and 800 ft slope length- LS=0.54
for 25% side slope and 12.5 ft length- LS=3

C=cover/management factor;
for moderately productive grass- C=0.01

P=practice factor;
for spring-seeded grain- P=0.60

(Sources for the above coefficients are listed in the USCOE document referenced above.)

Assume density of soil = 90 lb/ft^3

Annual Erosion Calculations for Top Slope (3% grade)

Surface area of final cover = $\frac{60 \text{ ft} * 810 \text{ ft}}{43{,}600 \text{ ft/acre}}$ = 1.115 acres

Calculation for a 3% grade:

A = 100*(0.21 tons/acre)*0.54*0.01*0.60 = 0.068 tons/acre
A = 136 lb/acre

Annual erosion: $\frac{136 \text{ lb/acre} * 1.115 \text{ acres}}{90 \text{ lb/ft}^3} = 1.69 \text{ ft}^3$

Annual Erosion Calculations for Side Slopes (25% grade)

Surface area of side slopes = [835 ft + 2(60 ft) + 317.5 ft + 167.5 ft] * 12.5 ft
= 18,000 ft^2
= 0.413 acres

Calculation for 25% side slopes:

A = 100*(0.21 tons/acre)*3*.01*0.60 = 0.378 tons/acre
A = 756 lb/acre

Annual erosion: $\frac{756 \text{ lb/acre} * 0.413 \text{ acres}}{90 \text{ lb/ft}^3} = 3.47 \text{ ft}^3$

Total Erosion per year: 1.69 ft^3 + 3.47 ft^3 = 5.16 ft^3

The geocomposite soil cap has a 3% top slope, with side slopes of 25% (4:1) and is covered with native grasses, which act as a net to collect and deposit wind blown soils onto the cap thus tending to reverse any soil erosion due to rainfall. Using the soil loss equation, the anticipated soil erosion for the 3% top slope was calculated to be 1.69 cubic feet per year. The controlling anticipated soil erosion is for the 25% side slopes, and was calculated to be 3.47 cubic feet per year. Considering the 24-inch soil covering and the 18,000 square foot side slope area:

$\frac{18{,}000 \text{ ft}^2}{3.47 \text{ ft}^3/\text{yr}} * 2 \text{ ft} = 10{,}375$ years

complete erosion of the side slopes would occur in 10,375 years.

OBSERVATION AND INSPECTION CHECKLIST
CAFB Landfill 5, Cell 3
Post-Closure Care

Item Inspected	General Condition	Change From Previous Inspection	Action Taken By Inspector
Condition of Cap and Vegetative Cover			
a) Signs of Sloughing or Sliding at Outslopes	_____	_____	_____
b) Signs of Differential Subsidence	_____	_____	_____
c) Evidence of Sheet Erosion	_____	_____	_____
d) Evidence of Gully	_____	_____	_____
e) Evidence of Boggy Areas	_____	_____	_____
f) Extent of Vegetative Cover	_____	_____	_____
g) Condition of Vegetative Cover	_____	_____	_____
h) Changes in Vegetative Cover	_____	_____	_____
i) Evidence of Rodent Damage	_____	_____	_____
j) Evidence of Undesirable Weeds	_____	_____	_____
Condition of Gas Venting System	_____	_____	_____
Condition of Survey Control Points	_____	_____	_____
Condition of Security Equipment			
a) Fence/Gate	_____	_____	_____
b) Warning Placards	_____	_____	_____
Condition of Groundwater Monitoring Equipment			
a) Pumps	_____	_____	_____
b) Sampling Equipment (non-dedicated)	_____	_____	_____
c) Monitoring Wells	_____	_____	_____

Discussion: _____

_____

_____

_____

_____

Legend Reporting Code

'General Condition' Column
NA - Not Applicable
NU - Nothing Unusual
AR - Action Required
D - See Discussion

'Changes' Column
NA - Not Applicable
NC - No Change
I - Improved from Previous Inspection
D - See Discussion

'Action Taken' Column
RM - Routine Maintenance
ND - Notify Designer
RC - Repair Completed
D - See Discussion

_____

Inspector's Signature and Date of Inspection

CORRECTIVE ACTION FORM
Landfill 5, Cell 3
Post-Closure Care

Date of Inspection: _____

Name(s) of Inspector: _____

Location of Inspection: _____

UPGRADE WORK ORDER:

Type of Problem _____

_____

_____

Required Upgrade _____

_____

_____

Corrective Action Assigned To: _____
(Name and Date)

WORK COMPLETION REPORT

Received On: _____ By: _____

Completed On: _____ By: _____

Comments:

_____

_____

_____

REINSPECTION REPORT

Observation: _____

_____

_____

Comments: _____

_____

_____

Signature of Inspector: _____

DEPARTMENT OF THE AIR FORCE

HEADQUARTERS 27th FIGHTER WING (ACC)

CANNON AIR FORCE BASE, NEW MEXICO

25 AUG 1993

27 FW/CC
100 S DL Ingram Blvd Suite 100
Cannon AFB NM 88103-5214

Ms Barbara Hoditschek
Program Manager, RCRA Permits
Hazardous and Radioactive Materials Bureau
New Mexico Environment Department
1190 St Francis Drive
PO Box 26110
Sante Fe NM 87502

RE: Cannon Air Force Base Landfill 5 Ground Water Monitoring

Dear Ms Hoditschek

Please find enclosed a summary of sampling results from ground water monitoring wells at Cannon AFB Landfill 5. These results are from sampling events which occurred between July 1992 and April 1993.

These results are being supplied in accordance with 40 CFR 265.92(c)(1) to establish initial background concentrations for this site. With these results Cannon AFB has established background concentrations. Therefore, we propose additional monitoring at Landfill 5 take place as follows. This sampling schedule will continue until directed otherwise by NMED.

First quarter 1994:
40 CFR 265 Appendix III constituents
40 CFR 264 Appendix IX constituents
chloride, iron, manganese, phenols, sodium, sulfate nitrate, nitrite, total dissolved solids, pH, specific conductance, total organic carbon, and total organic halogen

Third quarter 1994:
indicators of ground water contamination (pH, total organic halogens, total organic carbon, and specific conductance).

As discussed during telephone conversations with Mr John Pfeil (NMED) and Dr Janice Stowell (Cannon AFB) on July 20, 1993 and August 5, 1993, laboratory results (seven volumes) will be furnished to NMED upon request.

As we are proposing to eliminate the fourth quarter 1993 sampling event, we must have a response from your office by September 30, 1993 concerning the proposed sampling schedule. If we do not receive a response, we will assume that the proposed sampling schedule is satisfactory to NMED and will not implement a fourth quarter 1993 sampling event.

If there are any questions concerning this results summary, please contact Dr Janice Stowell at (505)784-4348.

Sincerely

Lance L. Smith

LANCE L. SMITH, Colonel, USAF
Commander, 27th Fighter Wing

cc: Dave Morgan, NMED

ATTACHMENT 1

FIELD LOG BOOK FORMAT

CANNON AFB, GROUNDWATER FIELD LOGBOOK
SAMPLING EVENT RECORD

Well No. _____ Sampling Date and Time _____

Weather Conditions _____

Comments/Field Observations _____

_____

_____

Samplers Names _____

Are nearby wells pumping? _____ Total estimated flow _____

Describe dedicated equipment _____

_____

_____

Organic vapors detected? _____ Retest? _____

Elevation top of well (EW)(1) _____ Depth of well (DW)(2) _____

Elevation bottom of well (EW – DW) _____

Reading Water Level Indicator Before Purging

Time	Reading	+	Well Factor(3)	=	Depth of Liquid (feet)

Average Depth in feet before purging (ADB) _____

(1) Surveyed top of well casing.
(2) Total depth of well as determined by sounding cable.
(3) Well factor is established when the water level indicator is installed. It is the height the indicator is above the bottom of the well.

Date _____ Well No. _____

Determination of Casing Volume and Purge Time

Well Volume (WV) ____ gal = ADB ___ ft x 0.04086[4] × casing dia. (inches) ___^{2}(squared)

WV _____ gal × baseline volumes = Purge volume (PV) _____ gal

PV _____ gal divided by pump rate[5] _____ gpm. = Purge Time _____ min.

Purging procedure and equipment: _____

Reading Water Level Indicator After Purging

Time	Reading	+	Well Factor[3]	=	Depth of Liquid (feet)
_____	_____		_____		_____
_____	_____		_____		_____
_____	_____		_____		_____

Average Depth in feet after purging (ADA) _____

Maximum drawdown in feet _____ = ADB _____ – ADA _____

Well Yield

Low yield well _____ (well was pumped dry during purging). Specify time needed for recovery before sampling: _____

High yield well _____ (well was not pumped dry during purging). Annually specify time required for complete recovery to ADB: _____

Sampling and Testing

Purpose of sampling: Detection _____ Compliance _____ Other _____

Sampling procedures for groundwater and equipment _____

_____

Type of temperature preservative (Blue Ice, bagged ice, etc.) _____

Flow rate of groundwater during sampling _____

Sample Identification No. _____

---

(4) 0.048 is the conversion factor to convert well length in feet and casing diameter in inches to gallons.

(5) Pump rate in gallons per minute to be determined in the field.

Date _____ Well No. _____

Field Analysis Data and Methods for pH, Conductivity, Temperature and Turbidity

	Time	Meter Type	Calibration	Measurement
pH				
Conductivity				
Temperature				
Turbidity				

Comments: _____

_____

_____

_____

_____

Shipping Information

Number of containers							VOA Count	
Glass	Sterilized Bags	Plastic	Vials	Chest #	Custody Seal #	VOAs	Chest #	Custody Seal #

Bus Bill No. _____

Samplers Signatures: _____

CANNON AFB, GROUNDWATER FILED LOG BOOK
OPERATIONS AND MAINTENANCE RECORD

Wells and Dedicated Equipment

Well No.:_____ Date:_____

Name(s) of Inspector:_____

Purpose of Inspection: Pre-sampling _____

Sampling Event _____

Post-sampling _____

Other (describe) _____

Well Condition:

Security of Well Cap _____

Condition of Protective Posts _____

Condition of Concrete Pad _____

Condition of Casing _____

Other (vegetation, animal, burrows, etc.) _____

_____

Describe Maintenance/Operation of Well and Dedicated Equipment:

_____

_____

_____

Problems Encountered/Corrective Action:

_____

_____

_____

Conductivity reading: _____

pH reading: _____

Annual turbidity measurement: _____

Annual recharge observation: _____(hours)

5-year survey of well elevation: _____(feet)

Well factor: _____

CANNON AFB, GROUNDWATER FIELD LOG BOOK
OPERATION AND MAINTENANCE RECORD

Sampling Equipment Inspection (non-dedicated)

Date of Inspection: _____

Name(s) of Inspector: _____

Location of Inspection: _____

Purpose of Inspection:

Pre-sampling _____

Sampling event _____

Post-sampling _____

Other _____

Describe Operation/Maintenance of Equipment:

_____

_____

_____

_____

_____

Problems Encountered/Corrective Action:

_____

_____

_____

_____

_____

Comments:

_____

_____

_____

Signature: _____

ATTACHMENT 2

CHAIN OF CUSTODY FORM

*** RETURN SIGNED, COMPLETED FORM TO 27 MED GP/SGPB CANNON AFB, NM 88103-5300 ***

CHAIN OF CUSTODY RECORD

Project No.	Project Name:
Samplers: (Signature)	

Station No.	Date	Time	Comp	Grab	Station Location	Number of Containers	Container Type(s) & Quantity of each type					Remarks (Specify Preservatives)

Relinquished by: (Signature)	Date	Time	Received by: (Signature)	Relinquished by: (Signature)	Date	Time	Received by: (Signature)
Relinquished by: (Signature)	Date	Time	Received by: (Signature)	Relinquished by: (Signature)	Date	Time	Received by: (Signature)
Relinquished by: (Signature)	Date	Time	Received for Laboratory by: (Signature)	Date	Time	Remarks: SAMPLING RECEIVING PERSONNEL WILL ANNOTATE THE FOLLOWING:	
						1: Presence of Ice ____Yes ____No	
						2. Samples Seals Intact ____Yes ____No	

*** RETURN SIGNED, COMPLETED FORM TO 27 MED GP/SGPB CANNON AFB, NM 88103-5300

ATTACHMENT 3

SAMPLE REQUEST FORMS

ENVIRONMENTAL SAMPLING DATA

(Use this space for mechanical imprint)

OEHL USE ONLY

SAMPLING SITE IDENTIFIER (AFR 19-7)

BASE WHERE SAMPLE COLLECTED

SAMPLING SITE DESCRIPTION

DATE COLLECTION BEGAN (YYMMDD)

TIME COLLECTION BEGAN (24 hour clock)

COLLECTION METHOD ☐ GRAB ☐ COMPOSITE _____ HOURS

MAIL REPORTS TO (circle if changed)

ORIGINAL	
COPY 1	
COPY 2	

SAMPLE COLLECTED BY (Name, Grade, AFSC)

SIGNATURE

AUTOVON

REASON FOR SUBMISSION E

A-ACCIDENT/INCIDENT
R-ROUTINE/PERIODIC
C-COMPLAINT
N-NPDES
F-FOLLOWUP/CLEANUP
O-OTHER (specify) _____

BASE SAMPLE NUMBER

OEHL ID

ANALYSES REQUESTED (Check appropriate blocks)

GROUP A		Hardness	00900	Silica	00955	2, 4, 5-T	39740
Ammonia	00610	Iron	01045	Specific Conductance	00095	2, 4, 5-TP-Silvex	39760
Chemical Oxygen Demand	00340	Lead	01051	Sulfate	00945		
Kjeldahl Nitrogen	00625	Magnesium	00927	Surfactants-MBAS	38260		
Nitrate	00620	Manganese	01055	Turbidity	00076		
Nitrite	00615	Mercury	71900				
Oil & Grease	00560	Nickel	01067				
Organic Carbon	00680	Potassium	00937				
Orthophosphate	00671	Selenium	01147	GROUP H			
Phosphorus, Total	00665	Silver	01077	Aldrin	39330		
		Sodium	00929	BHC Isomers	39340		
GROUP D		Thallium	01059	a-BHC	39337		
Cyanide, Total	00720	Zinc	01092	b-BHC	39338		
Cyanide, Free	00722			d-BHC	34259		
				Chlordane	39350	GROUP J	
GROUP E		GROUP G		DDT Isomers	39370	Sulfides	00745
Phenols	32730	Acidity, Total	70508	p, p-DDD	39310		
		Alkalinity, Total	00410	p, p-DDE	39320		
GROUP F		Alkalinity, Bicarbonate	00425	p, p-DDT	39300		
Antimony	01097	Bromide	71870	Dieldrin	39380	ON SITE ANALYSES	
Arsenic	01002	Carbon Dioxide	00405	Dursban	77969	PARAMETER	VALUE
Barium	01007	Chloride	00940	Endrin	39390	Flow 50050	mgd
Beryllium	01012	Color	00080	Heptachlor	39410	Chlorine, Total 50060	mg/l
Boron	01022	Fluoride	00951	Heptachlor Epoxide	39420	Dissolved Oxygen 00300	mg/l
Cadmium	01027	Residue, Total	00500	Lindane	39782	pH 00400	units
Calcium	00916	Residue, Filterable (TDS)	70300	Methoxychlor	39480	Temperature 00010	°C
Chromium, Total	01034	Residue, Nonfilterable	00530	Pramitol (Prometon)	XY4200000	Odor 00086	
Chromium VI	01032	Residue, Settleable	50085	Toxaphene	39400	Iodide 71865	
Copper	01042	Residue, Volatile	00505	2, 4-D	39730	Sulfite 00740	

REMARKS

TRACE ORGANICS

(Use this space for mechanical imprint)

OEHL USE ONLY

SAMPLING SITE IDENTIFIER (AFR 19-7)

BASE WHERE SAMPLE COLLECTED

SAMPLING SITE DESCRIPTION

DATE COLLECTION BEGAN (YYMMDD)

TIME COLLECTION BEGAN (24 hour clock)

COLLECTION METHOD ☐ GRAB ☐ COMPOSITE _____ HOURS

MAIL REPORTS TO (circle if changed)

ORIGINAL

COPY 1

COPY 2

SAMPLE COLLECTED BY (Name, Grade, AFSC)

SIGNATURE

AUTOVON

REASON FOR SUBMISSION: E

A-ACCIDENT/INCIDENT
R-ROUTINE/PERIODIC
C-COMPLAINT
N-NPDES
F-FOLLOWUP/CLEANUP
O-OTHER (specify) _____

BASE SAMPLE NUMBER

OEHL PID

ANALYSES REQUESTED (check appropriate blocks)

VOLATILE HALOCARBONS (VOH) (10860)					
PRES GROUP T1		Trichlorofluoromethane	34488	MISCELLANEOUS	
Volatile Halocarbon Screen	1001460PH	Vinyl Chloride	39175	VOLATILES	
Bromodichloromethane	32101			PRES GROUP T1	
Bromoform	32104			Xylene	81710
Bromomethane	34413	TRIHALOMETHANES (THM)	(10860)	Methylethyl ketone	81595
Carbon Tetrachloride	32102	PRES GROUP T1		Methylisobutyl ketone	81596
Chlorobenzene	34301	Trihalomethane Potential	1001465MT	Total organic halides	10021060H
Chloroethane	34311	Total Trihalomethanes	82080		
2-Chloroethylvinyl ether	34576				
Chloroform	32106	VOLATILE AROMATICS (VOA)	(10850)		
Chloromethane	34418	PRES GROUP T1			
Dibromochloromethane	32105	Volatile Aromatic Screen	1001461PA		
1,2-dichlorobenzene	34536	Benzene	34030	MISCELLANEOUS	
1,3-dichlorobenzene	34566	Chlorobenzene	34301	EXTRACTABLES	
1,4-dichlorobenzene	34571	1,2-dichlorobenzene	34536	PRES GROUP T4	
Dichlorodifluoromethane	34668	1,3-dichlorobenzene	34566	PCB's	39516
1,1-dichloroethane	34496	1,4-dichlorobenzene	34571	Phthalate Esters Screen	1000069PH
1,2-dichloroethane	34531	Ethylbenzene	34371	bis (2-ethylhexyl) phthalate	39100
1,1-dichloroethene	34501	Toluene	34010	Butyl Benzyl phthalate	34292
trans-1,2-dichloroethene	34546			Di-n-butyl phthalate	39110
1,2-dichloropropane	34541			Diethyl phthalate	34336
cis-1,3-dichloropropene	34704			Dimethyl phthalate	34341
trans-1,3-dichloropropene	34699			Di-n-octyl phthalate	34596
Methylene Chloride	34423				
1,1,2,2-tetrachloroethane	34516				
Tetrachloroethylene	34475				
1,1,1-trichloroethane	34506				
1,1,2-trichloroethane	34511				
Trichloroethylene	39180				

REMARKS

RADIOLOGICAL SAMPLING DATA

(Use this space for mechanical imprint)

OEHL USE ONLY

WORKPLACE OR SITE IDENTIFIER

BASE

ORGANIZATION

WORKPLACE OR SITE

DATE COLLECTED (YYMMDD)

TIME COLLECTION BEGAN (24 hour clock)

BLDG NO/LOCATION

ROOM/AREA

MAIL REPORTS TO (circle if changed)

ORIGINAL

COPY 1

COPY 2

SAMPLE COLLECTED BY (Name, Grade, AFSC)

SIGNATURE

AUTOVON

REASON FOR SUBMISSION

A-ACCIDENT/INCIDENT
C-COMPLAINT
F-FOLLOWUP/CLEANUP
N-NPDES
R-ROUTINE BACKGROUND/PERIODIC SURVEY
O-OTHER (specify)

EMPLOYEE NAME

EMPLOYEE SSAN

BASE SAMPLE NUMBER

OEHL PID NUMBER (OEHL use only)

COLLECTION METHOD (enter letter code)

C-Composite
G-Grab
V-Single Void
T-24 Hour Void
W-Wipe/Swipe
O-Other

SAMPLE TYPE (enter letter code)

X-Air, Ambient/Gen. Area
Y-Air, Emission, Source
Z-Air, Breathing Zone
B-Blood
O-Biological, Other
F-Food
G-Gas/Air, Compressed
H-Human
M-Industrial Material
R-Nasal Swab
D-Residue/Ash
L-Sludge
S-Soil
W-Surface Contaminant
C-Unclassified/Other
U-Urine
V-Vegetation
T-Waste, Hazardous, Toxic
N-Water, Nonpotable
P-Water, Potable

PRESERVATION GROUP

R1-NITRIC ACID, pH < 2.0 (plastic container)
R2-HYDROCHLORIC ACID, pH < 2.0 (with $Na_2S_2O_3$ in glass container)
ND-NONE

ANALYSES REQUESTED

- GROSS ALPHA
- GROSS BETA
- GAMMA
- OTHER (specify)
- CARBON 14
- TRITIUM
- URANIUM
- PLUTONIUM
- RADIUM
- RADON
- STRONTIUM
- DRINKING WATER STANDARDS (AFR 161-44)

AIR FILTER DATA

COLLECTION TIME min

FLOW RATE

VOLUME COLLECTED

COMMENTS

TABLE 1

SUMMARY OF SAMPLE CONTAINERS, SAMPLE PRESERVATION METHODS, AND HOLDING TIMES

TABLE 1
SUMMARY OF SAMPLE CONTAINERS, SAMPLE PRESERVATION METHODS, AND HOLDING TIMES

Analytical Parameter	Analytical Method (a)	Preservation Method	Number of Containers Type of Sample Container	Holding Time
APPENDIX IX METHODS				
VOCs	SW8240	HCl to pH < 2 Cool to 4 deg C	2 x 40-ml glass with Teflon septa	14 days
SVOCs (except PAHs)	SW3510/SW8270	Cool to 4 deg C	2 x 1-liter amber glass with Teflon-lined caps	7 days to extraction then 40 days to analysis
PAHs	SW3510/SW8310	Cool to 4 deg C	2 x 1-liter amber glass with Teflon-lined caps	7 days to extraction then 40 days to analysis
Pesticides & PCBs	SW3510/SW8080	Cool to 4 deg C	2 x 1-liter amber glass with Teflon-lined caps	7 days to extraction then 40 days to analysis
Other Pesticides	SW3510/SW8410	Cool to 4 deg C	2 x 1-liter amber glass with Teflon-lined caps	7 days to extraction then 40 days to analysis
Herbicides	SW3510/SW8510	Cool to 4 deg C	2 x 1-liter amber glass with Teflon-lined caps	7 days to extraction then 40 days to analysis
Metals	SW3005/SW6010	HNO3 to pH < 2 Cool to 4 deg C	1 x 1-liter plastic	180 days
Arsenic	SW3005/SW7060	HNO3 to pH < 2 Cool to 4 deg C	1 x 1-liter plastic	180 days
Mercury	SW3005/SW7470	HNO3 to pH < 2 Cool to 4 deg C	1 x 1-liter plastic	180 days
Selenium	SW3005/SW7740	HNO3 to pH < 2 Cool to 4 deg C	1 x 1-liter plastic	180 days

TABLE 1 (continued)
SUMMARY OF SAMPLE CONTAINERS, SAMPLE PRESERVATION METHODS, AND HOLDING TIMES

Analytical Parameter	Analytical Method (a)	Preservation Method	Number of Containers Type of Sample Container	Holding Time
Cyanide	SW3552/SW9010	NaOH to pH > 12 Cool to 4 deg C	1 x 1-liter plastic	14 days
Gross Alpha/ Gross Beta	SW9310	HNO3 to pH < 2	1 x 1-gallon plastic or glass	6 months
Total Coliform	SW9391	Na2S2O3	1 x 250-ml plastic or glass	6 hours
Sulfate	SW9035	Cool to 4 deg C	1 x 100-ml plastic or glass	28 days
Flouride	EPA 340.2	None	1 x 250-ml plastic or glass	28 days
Chloride	SW9250	Cool to 4 deg C	1 x 100-ml plastic or glass	28 days
Nitrate	EPA 353.1	H2SO4 to pH < 2 Cool to 4 deg C	1 x 1-liter plastic or glass	28 days
Phenols	SW9065	H2SO4 to pH < 2 Cool to 4 deg C	1 x 500-ml amber glass with Teflon-lined caps	28 days
Sulfide	SW9030	Zn Acetate + NaOH to pH > 9	1 x 500-ml amber glass with Teflon-lined caps	7 days
Dioxin	SW8280	Cool to 4 deg C	2 x 1-liter amber glass with Teflon-lined caps	30 days to extraction 45 days to analysis

TABLE 1 (continued)
SUMMARY OF SAMPLE CONTAINERS, SAMPLE PRESERVATION METHODS, AND HOLDING TIMES

Analytical Parameter	Analytical Method (a)	Preservation Method	Number of Containers Type of Sample Container	Holding Time
INDICATOR PARAMETER METHODS				
Chromium	SW3005/SW7191	HNO3 to PH < 2 Cool to 4 deg C	1 x 1-liter plastic	180 days
Lead	SW3005/SW7421	HNO3 to pH < 2 Cool to 4 deg C	1 x 1-liter plastic	180 days
TOC	SW9060	H2SO4 to pH < 2 Cool to 4 deg C	1 x 500-ml amber glass with Teflon-lined cap	28 days
TOX	SW9020	H2SO4 to pH < 2 Cool to 4 deg C	4 x 100-ml amber glass with Teflon-lined cap	28 days
pH	SW9040	None	1 x 100-ml plastic or glass	Upon receipt
Conductivity	SW9050	Cool to 4 deg C	1 x 100-ml plastic or glass	28 days

(a) Extraction method/Analysis method

TABLE 2

GROUNDWATER SAMPLING PARAMETERS

TABLE 2
Groundwater Sampling Parameters
(ug/l)

CAS NO.	PARAMETER/METHOD	METHOD DET. LIMIT	40 CFR PART 264 TARGET PQLS
	APPENDIX IX VOLATILES/8010		
100-44-7	Benzyl chloride		N/A
108-86-1	Bromobenzene		N/A
75-27-4	Bromodichloromethane		1
75-25-2	Bromoform		2
74-83-9	Bromomethane		20
56-23-5	Carbon tetrachloride		1
108-90-7	Chlorobenzene		2
75-00-3	Chloroethane		5
110-75-8	2-Chloroethyl vinyl ether		N/A
67-66-3	Chloroform		0.5
74-87-3	Chloromethane		1
124-48-1	Dibromochloromethane		1
74-95-3	Dibromomethane		15
95-50-1	1,2-Dichlorobenzene		2
541-73-1	1,3-Dichlorobenzene		5
106-46-7	1,4-Dichlorobenzene		2
75-71-8	Dichlorodifluoromethane		10
75-34-3	1,1-Dichloroethane		1
107-06-2	1,2-Dichloroethane		0.5
75-35-4	1,1-Dichloroethene		1
156-60-5	trans-1,2-Dichloroethene		1
75-09-2	Dichloromethane		5
78-87-5	1,2-Dichloropropane		0.5
10061-01-5	cis-1,3-Dichloropropene		20
10061-02-6	trans-1,3-Dichloropropene		5
79-34-5	1,1,2,2-Tetrachloroethane		0.5
630-20-6	1,1,1,2-Tetrachloroethane		5
127-18-4	Tetrachloroethene		0.5
71-55-6	1,1,1-Trichloroethane		N/A
79-00-5	1,1,2-Trichloroethane		0.2
79-01-6	Trichloroethene		1
75-69-4	Trichlorofluoromethane		10
96-18-4	1,2,3-Trichloropropene		10
75-01-4	Vinyl chloride		2
	APPENDIX IX VOLATILES/8015		
60-29-7	Diethyl ether		N/A
64-17-5	Ethanol		N/A
78-93-3	Methyl ethyl ketone		10
108-10-1	Methyl isobutyl ketone		5
	APPENDIX IX VOLATILES/8240		
67-64-1	Acetone		100
107-02-8	Acrolein		5
107-13-1	Acrylonitrile		5
71-43-2	Benzene		2

TABLE 2
Groundwater Sampling Parameters
(ug/l)

CAS NO.	PARAMETER/METHOD	METHOD DET. LIMIT	40 CFR PART 264 TARGET PQLS
75-27-4	Bromodichloromethane	Laboratory	5
75-25-2	Bromoform	to	5
74-83-9	Bromomethane	supply	10
78-93-3	2-Butanone	method	100
75-15-0	Carbon disulfide	detection	5
56-23-5	Carbon tetrachloride	limits	5
108-90-7	Chlorobenzene		5
75-00-3	Chloroethane		10
67-66-3	Chloroform		5
124-48-1	Dibromochloromethane		5
106-93-4	1,2-Dibromoethane		5
75-71-8	Dichlorodifluoromethane		5
75-34-3	1,1-Dichloroethane		5
107-06-2	1,2-Dichloroethane		5
75-35-4	1,1-Dichloroethene		5
156-60-5	trans-1,2-Dichloroethene		5
540-59-0	1,2-Dichloroethene, Total		5
78-87-5	1,2-Dichloropropane		5
10061-01-5	cis-1,3-Dichloropropene		5
10061-02-6	trans-1,3-Dichloropropene		5
100-41-4	Ethylbenzene		5
97-63-2	Ethyl methacrylate		5
591-78-6	2-Hexanone		50
126-98-7	Methacrylonitrile		5
74-87-3	Methyl chloride		10
74-95-3	Methylene bromide		5
75-09-2	Methylene chloride		5
108-10-1	4-Methyl-2-pentanone		50
100-42-5	Styrene		5
79-34-5	1,1,2,2-Tetrachloroethane		5
127-18-4	Tetrachloroethylene		5
108-88-3	Toluene		5
71-55-6	1,1,1-Trichloroethane		5
79-00-5	1,1,2-Trichloroethane		5
79-01-6	Trichloroethene		5
96-18-4	1,2,3-Trichloropropane		5
108-05-4	Vinyl acetate		5
75-01-4	Vinyl chloride		10
1330-20-7	Xylenes, Total		5
75-05-8	Acetonitrile		100
75-69-4	Trichlorofluoromethane		5
96-12-8	1,2-Dibromo-3-chloropropane		5
107-05-1	Allyl chloride		100
126-99-8	Chloroprene		5
110-57-6	trans-1,4-Dichloro-2-butene		5

TABLE 2
Groundwater Sampling Parameters
(ug/l)

CAS NO.	PARAMETER/METHOD	METHOD DET. LIMIT	40 CFR PART 264 TARGET PQLS
107-12-0	Propionitrile		20
80-62-6	Methyl methacrylate		5
78-83-1	Isobutanol		50
74-88-4	Methyl iodide		5
630-20-6	1,1,1,2-Tetrachloroethane		5
123-91-1	1,4-Dioxane		150
	APPENDIX IX SEMIVOLATILES/8270		
98-86-2	Acetophenone		10
53-96-3	2-Acetylaminofluorene		10
92-67-1	4-Aminobiphenyl		10
62-53-3	Aniline		10
140-57-8	Aramite, Total		10
100-51-6	Benzyl alcohol	Laboratory	10
111-91-1	Bis(2-chloroethoxy)methane	to	10
111-44-4	Bis(2-chloroethyl)ether	supply	10
108-60-1	Bis(2-chloroisopropyl)ether	method	10
117-81-7	Bis(2-ethylhexyl)phthalate	detection	10
101-55-3	4-Bromophenyl phenyl ether	limits	10
85-68-7	Butyl benzyl phthalate		10
106-47-8	4-Chloroaniline		20
510-15-6	p-Chlorobenzilate		10
91-58-7	2-Chloronaphthalene		10
7005-72-3	4-Chlorophenyl phenyl ether		10
2303-16-4	Diallate, Total		10
132-64-9	Dibenzofuran		10
84-74-2	Di-n-butyl phthalate		10
95-50-1	1,2-Dichlorobenzene		10
541-73-1	1,3-Dichlorobenzene		10
106-46-7	1,4-Dichlorobenzene		10
91-94-1	3,3'-Dichlorobenzidine		20
84-66-2	Diethyl phthalate		10
60-51-5	Dimethoate		10
60-11-7	p-(Dimethylamino)azobenzene		10
57-97-6	7,12-Dimethylbenz[a]anthracene		10
119-93-7	3,3'-Dimethylbenzidine		10
122-09-8	alpha,alpha-Dimethylphenethylamine		10
131-11-3	Dimethyl phthalate		10
99-65-0	1,3-Dinitrobenzene		10
121-14-2	2,4-Dinitrotoluene		10
606-20-2	2,6-Dinitrotoluene		10
117-84-0	Di-n-octyl phthalate		10
122-39-4	Diphenylamine		10
298-04-4	Disulfoton		10
62-50-0	Ethyl methanesulfonate		10
52-85-7	Famphur		10

TABLE 2
Groundwater Sampling Parameters
(ug/l)

CAS NO.	PARAMETER/METHOD	METHOD DET. LIMIT	40 CFR PART 264 TARGET PQLS
118-74-1	Hexachlorobenzene		10
87-68-3	Hexachlorobutadiene		10
77-47-4	Hexachlorocyclopentadiene		10
67-72-1	Hexachloroethane		10
70-30-4	Hexachlorophene		10
1888-71-7	Hexachloropropene		10
78-59-1	Isophorone		10
120-58-1	Isosafrole, Total		10
91-80-5	Methapyrilene		10
56-49-5	3-Methylcholanthrene		10
66-27-3	Methyl methanesulfonate		10
91-57-6	2-Methylnaphthalene		10
130-15-4	1,4-Naphthoquinone		10
134-32-7	1-Naphthylamine		10
91-59-8	2-Naphthylamine	Laboratory	10
88-74-4	2-Nitroaniline	to	50
99-09-2	3-Nitroaniline	supply	50
100-01-6	4-Nitroaniline	method	50
98-95-3	Nitrobenzene	detection	10
56-57-5	4-Nitroquinoline-1-oxide	limits	10
924-16-3	N-Nitrosodi-n-butylamine		10
55-18-5	N-Nitrosodiethylamine		10
62-75-9	N-Nitrosodimethylamine		10
86-30-6	N-Nitrosodiphenylamine		10
621-64-7	N-Nitrosodi-n-propylamine		10
10595-95-6	N-Nitrosomethylethylamine		10
59-89-2	N-Nitrosomorpholine		10
100-75-4	N-Nitrosopiperidine		10
930-55-2	N-Nitrosopyrrolidine		10
99-55-8	5-Nitro-o-toluidine		10
608-93-5	Pentachlorobenzene		10
76-01-7	Pentachloroethane		5
82-68-8	Pentachloronitrobenzene		10
62-44-2	Phenacetin		10
106-50-3	p-Phenylene diamine		10
298-02-2	Phorate		10
109-06-8	2-Picoline		10
23950-58-5	Pronamide		10
110-86-1	Pyridine		10
94-59-7	Safrole, Total		10
95-94-3	1,2,4,5-Tetrachlorobenzene		10
3689-24-5	Tetraethyldithiopyrophosphate		10
95-53-4	o-Toluidine		10
120-82-1	1,2,4-Trichlorobenzene		10
126-68-1	O,O,O-Triethyl phosphorothioate		10

TABLE 2
Groundwater Sampling Parameters
(ug/l)

CAS NO.	PARAMETER/METHOD	METHOD DET. LIMIT	40 CFR PART 264 TARGET PQLS
99-35-4	1,3,5-Trinitrobenzene		10
59-50-7	4-Chloro-3-methylphenol		10
95-57-8	2-Chlorophenol		10
95-48-7	2-Methylphenol		10
108-39-4	3-Methylphenol		10
106-44-5	4-Methylphenol		10
120-83-2	2,4-Dichlorophenol		10
87-65-0	2,6-Dichlorophenol		10
105-67-9	2,4-Dimethylphenol		10
534-52-1	4,6-Dinitro-2-methylphenol		10
51-28-5	2,4-Dinitrophenol		10
88-85-7	Dinoseb		10
88-75-5	2-Nitrophenol		50
100-02-7	4-Nitrophenol		50
87-86-5	Pentachlorophenol		50
108-95-2	Phenol		10
58-90-2	2,3,4,6-Tetrachlorophenol		10
95-95-4	2,4,5-Trichlorophenol		10
88-06-2	2,4,6-Trichlorophenol		10
	APPENDIX IX DIOXIN/8280		
1746-01-6	2,3,7,8-TCDD		0.005
	APPENDIX IX PAHS/8310		
83-32-9	Acenaphthene		10
208-96-8	Acenaphthylene		10
120-12-7	Anthracene		10
56-55-3	Benzo(a)anthracene		10
50-32-8	Benzo(a)pyrene		10
205-99-2	Benzo(b)fluoranthene	Laboratory	10
191-24-2	Benzo(ghi)perylene	to	10
207-08-9	Benzo(k)fluoranthene	supply	10
218-01-9	Chrysene	method	10
206-44-0	Fluoranthene	detection	10
86-73-7	Fluorene	limits	10
193-39-5	Indeno(1,2,3-cd)pyrene		10
91-20-3	Naphthalene		10
85-01-8	Phenanthrene		10
129-00-0	Pyrene		10
53-70-3	Dibenz(a,h)anthracene		10
	APPENDIX IX PESTICIDES/PCBS/8080		
309-00-2	Aldrin		0.05
319-84-6	alpha-BHC		0.05
319-85-7	beta-BHC	Laboratory	0.05
319-86-8	delta-BHC	to	0.05
58-89-9	gamma-BHC (Lindane)	supply	0.05

TABLE 2
Groundwater Sampling Parameters
(ug/l)

CAS NO.	PARAMETER/METHOD	METHOD DET. LIMIT	40 CFR PART 264 TARGET PQLS
57-74-9	Chlordane	method	0.1
72-54-8	4,4'-DDD	detection	0.1
72-55-9	4,4'-DDE	limits	0.1
50-29-3	4,4'-DDT		0.1
60-57-1	Dieldrin		0.1
959-98-8	Endosulfan I		0.1
33213-65-9	Endosulfan II		0.05
1031-07-8	Endosulfan sulfate		0.05
72-20-8	Endrin		0.1
7421-93-4	Endrin aldehyde		0.2
76-44-8	Heptachlor		0.05
1024-57-3	Heptachlor epoxide		1
465-73-6	Isodrin		0.05
143-50-0	Kepone		0.05
72-43-5	Methoxychlor		2
298-00-0	Methyl parathion		0.05
56-38-2	Parathion		0.05
8001-35-2	Toxaphene		2
12674-11-2	Aroclor-1016		50
11104-28-2	Aroclor-1221		50
11141-16-5	Aroclor-1232		50
53469-21-9	Aroclor-1242		50
12672-29-6	Aroclor-1248		50
11097-69-1	Aroclor-1254		50
11096-82-5	Aroclor-1260		50
	APPENDIX IX OTHER PESTS & HERBICIDES/VARIOUS		
297-97-2	Thionazin	Laboratory	10
94-75-7	2,4-D	to	10
93-76-5	2,4,5-T	supply	2
92-72-1	2,4,5-TP(Silvex)		2
	APPENDIX IX INORGANICS/VARIOUS		
7440-36-0	Antimony		300
7440-38-2	Arsenic		10
7440-39-3	Barium		20
7440-41-7	Beryllium		3
7440-43-9	Cadmium		1
7440-47-3	Chromium		10
7440-48-4	Cobalt		70
7440-50-8	Copper		60
7439-92-1	Lead	Laboratory	10
7439-97-6	Mercury	to	2
7440-02-0	Nickel	supply	50
7782-49-2	Selenium	method	20
7440-22-4	Silver	detection	100

TABLE 2
Groundwater Sampling Parameters
(ug/l)

CAS NO.	PARAMETER/METHOD	METHOD DET. LIMIT	40 CFR PART 264 TARGET PQLS
7440-28-0	Thallium	limits	10
7440-31-5	Tin		10
7440-62-2	Vanadium		80
7440-66-6	Zinc		20
57-12-5	Cyanide		40
18496-25-8	Sulfide		10,000
	INDICATOR PARAMETERS		
NA	pH	LAB TO SUPPLY	LAB TO SUPPLY
NA	Conductivity		
7440-47-3	Chromium (see Appendix IX list)		
7439-92-1	Lead (see Appendix IX list)		
NA	TOC		
NA	TOX		

TABLE 3

SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
EPA 353.1	Nitrate	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check preparation Blank(2) -Check field Blank(2) -Flag data
		Field Duplicate	Ten percent of all samples	RPD <= 20% (water)	-Review and discuss in report -Flag data where appropriate
		Laboratory QC			
		Initial and continuing calibration verification standard	Initial: Beginning of day Continuing: 10% or every 2 hours during run	Within 20% of true value	-Check instrument -Recalibrate -Reanalyze preceding samples
		Initial and continuing calibration Blank(2) & CCB)	Initial: immediately after ICV Continuing: immediately after CCV	Concentrations of analytes <= the project reporting level	-Check instrument -Recalibrate -Reanalyze preceding samples
		Preparation Blank(2)	1 per batch (maximum of 20 samples per batch)	Concentrations of analytes <= the project reporting level	-Reanalyze sample -Flag data
		Matrix spike	1 per batch (max 20 samples)	See Table 4	-Check LCS -Flag data
		Matrix Duplicate	1 per batch (max 20 samples)	See Table 4	-Check LCS -Flag data
		Laboratory Control Sample	1 per batch (max 20 samples)	See Table 4	-Reanalyze samples -Flag data
EPA 340.2	Fluoride	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check preparation Blank(2) -Check field Blank(2) -Flag data
		Field Duplicate	Ten percent of all samples	RPD <= 20% (water)	-Review and discuss in report -Flag data where appropriate

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
		Laboratory QC			
		Initial and continuing calibration verification standard	Initial: Beginning of day Continuing: 10% or every 2 hours during run	Within 20% of true value	-Check instrument -Recalibrate -Reanalyze preceding samples
		Initial and continuing calibration Blank(2) & CCB)	Initial: immediately after ICV Continuing: immediately after CCV	Concentrations of analytes <= the project reporting level	-Check instrument -Recalibrate -Reanalyze preceding samples
		Preparation Blank(2)	1 per batch (maximum of 20 samples per batch)	Concentrations of analytes <= the project reporting level	-Reanalyze sample -Flag data
		Matrix spike	1 per batch (max 20 samples)	See Table 4	-Check LCS -Flag data
		Matrix Duplicate	1 per batch (max 20 samples)	See Table 4	-Check LCS -Flag data
		Laboratory Control Sample	1 per batch (max 20 samples)	See Table 4	-Reanalyze samples -Flag data
SW6010 and 7XXX	Metals	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check preparation Blank(2) -Check field Blank(2) -Flag data
		Field Duplicate	Ten percent of all samples	RPD <= 20% (water) RPD <= 35% (soil)	-Review and discuss in report -Flag data where appropriate
		Laboratory QC			
		Initial and continuing	Initial: Beginning of day	+/-10% of expected value for ICP	-Check instrument

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
		calibration verification standard	Continuing: 10% or every 2 hours during run	and +/-20% of expected value for furnace and mercury	-Recalibrate -Reanalyze preceding samples
		Initial and continuing calibration Blank(2) & CCB)	Initial: immediately after ICV Continuing: immediately after CCV	Concentrations of analytes </= the project reporting level	-Check instrument -Recalibrate -Reanalyze preceding samples
		Interference check samples A and B (omit for mercury and GF metals).	At the beginning and end of each analysis run	+/-20% of true value for analytes present	-Check instrument -Recalibrate -Reanalyze preceding samples
		Preparation Blank(2)	1 per batch (maximum of 20 samples per batch)	Concentrations of analytes </= the project reporting level	-Reanalyze sample -Flag data
		Matrix spike	1 per batch (max 20 samples)	See See Table 4	-Check LCS -Flag data
		Matrix Duplicate	1 per batch (max 20 samples)	See See Table 4	-Check LCS -Flag data
SW6010 (cont)		Laboratory Control Sample (LCS, Blank(2)	1 per batch (max 20 samples)	See See Table 4	-Reanalyze samples -Flag data
SW8080	Organochlorine Pesticides & PCBs	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes </= 3X the project reporting level	-Check method Blank(2) -Flag data
		Field Duplicate	Ten percent of all samples	RPD </=20% (water) RPD </= 35% (soil)	-Review and discuss in report -Flag data where appropriate
		Laboratory QC:			
		Method Blank(2)	1 per batch (maximum of 20 field	Concentrations of analytes </=	-Reanalyze Blank(2)

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
			samples per batch) or 1 per day whichever is more frequent	the project reporting level	-If second method Blank(2) exceeds criteria, clean and recalibrate the analytical system -Document corrective action
		Initial calibration	Prior to the analysis of any samples and as dictated by the continuing calibration check	RSD </=20% over working range or correlation coefficient >/=0.995	-Check GC system -Rerun as needed to meet criteria
		Continuing calibration check.	Beginning of each sequence and after every 10 samples	Response factor (RF) must agree within +/-15% difference from average RF of initial calibration or calculated concentrations from the curve must agree within +/-15% of the true value	-Check GC system -Run initial calibration -Reanalyze associated samples
SW8080 (cont)		Surrogate Spikes	Every sample (field, standards, QC, Blank(2)	See See Table 4	-Check calculation -Reextract and reanalyze -Flag data
		Matrix Spike/Spike Duplicate	1 per batch (max 20 samples)	See See Table 4	-Check LCS -Discuss in case narrative -Flag data
		Laboratory Control Sample	1 per batch (max 20 samples)	See See Table 4	-Check calibration -Rerun LCS -Discuss in case narrative
SW8140	Organophosphorus Pesticides	<u>Field QC:</u>			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes </= 3X the project reporting level	-Check method Blank(2) -Flag data

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
		Field Duplicate	Ten percent of all samples	RPD <=20% (water) RPD <= 35% (soil)	-Review and discuss in report -Flag data where appropriate
		<u>Laboratory QC:</u>			
		Method Blank(2)	1 per batch (maximum of 20 field samples per batch) or 1 per day whichever is more frequent	Concentrations of analytes <= the project reporting level	-Reanalyze -If second method Blank(2) exceeds criteria, clean and recalibrate the analytical system -Document corrective action
		Initial calibration	Prior to the analysis of any samples and as dictated by the continuing calibration check	RSD <=20% over working range or correlation coefficient >=0.995	-Check GC system -Rerun as needed to meet criteria
SW8140 (cont)		Continuing calibration check.	Beginning of each sequence and after every 10 samples	Response factor (RF) must agree within +/-15% difference from average RF of initial calibration or calculated concentrations from the curve must agree within +/-15% of the true value	-Check GC system -Run initial calibration -Reanalyze associated samples
		Surrogate Spikes	Every sample (field, standards, QC, Blank(2)	See See Table 4	-Check calculation -Reextract and reanalyze -Flag data
		Matrix Spike/Spike Duplicate	1 per batch (max 20 samples)	See See Table 4	-Check LCS -Discuss in case narrative -Flag data
		Laboratory Control	1 per batch (max 20 samples)	See	-Check calibration

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
		Sample		See Table 4	-Rerun LCS -Discuss in case narrative
SW8150	Chlorinated Herbicides	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check method Blank(2) -Flag data
		Field Duplicate	Ten percent of all samples	RPD <=20% (water) RPD <= 35% (soil)	-Review and discuss in report -Flag data where appropriate
SW8150 (cont)		**Laboratory QC:**			
		Method Blank(2)	1 per batch (maximum of 20 field samples per batch) or 1 per day whichever is more frequent	Concentrations of analytes <= the project reporting level	-Reanalyze samples -If second method Blank(2) exceeds criteria, clean and recalibrate the analytical system -Document corrective action
		Initial calibration	Prior to the analysis of any samples and as dictated by the continuing calibration check	RSD <=20% over working range or correlation coefficient >=0.995	-Check GC system -Rerun as needed to meet criteria
		Continuing calibration check.	Beginning of each sequence and after every 10 samples	Response factor (RF) must agree within +/-15% difference from average RF of initial calibration or calculated concentrations from the curve must agree within +/-15% of the true value	-Check GC system -Run initial calibration -Reanalyze associated samples
		Surrogate Spikes	Every sample (field, standards, QC, Blank(2)	See See Table 4	-Check calculation -Reextract and reanalyze

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
					-Flag data
		Matrix Spike/Spike	1 per batch (max 20 samples)	See See Table 4	-Check LCS -Discuss in case narrative -Flag data
		Laboratory Control Sample	1 per batch (max 20 samples)	See See Table 4	-Check calibration -Rerun LCS -Flag data
SW8240	Volatile Organic Compounds	**Field QC:**			
		Trip Blank(2)	One per cooler of samples shipped to laboratory to be analyzed for VOC's	Concentrations of analytes <= 3X the project reporting level, except for common lab contaminants which shall be <=5X the project reporting level	-Check method Blank(2) laboratory problem -Flag sample data
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level, except for common lab contaminants which shall be <=5X the project reporting level	-Check method Blank(2) laboratory problem -Flag data
		Field Duplicate	Ten percent of all samples	RPD <=20% (water) RPD <= 35% (soil)	-Review and discuss in report -Flag data where appropriate
		Laboratory QC:			
		BFB tuning check	Every 12 hours	See Method 8240	-Retune as necessary -Document corrective action -Check GC/MS system
		Initial calibration.	As dictated by continuing	%RSD for CCCs <=30%	-Rerun as needed to meet criteria

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
			calibration check	Average RF for SPCC >/=0.30 except bromoform >/=0.25	
		Continuing calibration check.	Once every 12 hours	% D for CCCs </=25% SPCCs >/=0.30 except bromoform >/=0.25	-Check GC/MS system -Run initial calibration
SW8240 (cont)		Method Blank(2)	1 per batch (maximum of 20 field samples per batch) or 1 per day whichever is more frequent	Concentrations of analytes </= the project reporting level, except for common lab contaminants which shall be </=3X the project reporting level	-Reanalyze -If second method Blank(2) exceeds criteria, clean and recalibrate the analytical system -Document corrective action
		Surrogate Spikes	Every sample (field, standards, QC, Blank(2)	See See Table 4	-Check calculation -Reextract and reanalyze -Flag data
		Matrix Spike/ Spike Duplicate	1 per batch (max 20 samples)	See See Table 4	-Check laboratory control sample -Discuss in case narrative -Flag data
		Laboratory Control Sample.	1 per batch (max 20 samples)	See See Table 4	-Check calibration -Rerun LCS -Discuss in case narrative -Flag data
SW8270	Semivolatile Organics	<u>Field QC:</u>			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes </=3X the project reporting level, except for common lab contaminants	-Check method Blank(2) laboratory problem -Flag data

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
				which shall be </=5X the project reporting level	
		Field Duplicate	Ten percent of all samples	RPD </=20% RPD >/=35%	-Review and discuss in report -Flag data where appropriate
SW8270 (cont)		<u>Laboratory QC:</u>			
		DFTPP tuning check	Every 12 hours	See Method 8270	-Retune as necessary -Document corrective action
		Initial calibration	As dictated by continuing calibration check	%RSD for CCCs </=30% Average RF for SPCCs >/=0.050	-Check GC/MS system -Rerun as needed to meet criteria -Document corrective action
		Continuing calibration check	Once every 12 hours	Average RF for SPCCs >/=0.050 % D for CCCs </=30%	-Check GC/MS system -Run initial calibration -Document corrective action
		Method Blank(2)	1 per batch (maximum 20 field samples per batch) or 1 per day whichever is more frequent	Concentrations of analytes </= the project reporting level, except for common lab contaminants which shall be </=3X the project reporting level	-Reanalyze Blank(2) -If second method exceeds the criteria, clean work area and reanalyze samples -Document corrective action
		Surrogate Spikes	Every sample (field, standards, QC, Blank(2)	See See Table 4	-Check calculation -Reextract and reanalyze -Flag data
		Matrix Spike/ Spike Duplicate	1 per batch (max 20 samples)	See See Table 4	-Check laboratory control sample -Discuss in case narrative -Flag data

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
		Laboratory Control Sample	1 per batch (max 20 samples)	See See Table 4	-Check calibration -Rerun LCS -Discuss in case narrataive
SW8310	Polynuclear Aromatic Hydrocarbons	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check method Blank(2) -Flag data
		Field Duplicate	Ten percent of all samples	RPD <=20% (water) RPD <= 35% (soil)	-Review and discuss in report -Flag data where appropriate
		Laboratory QC:			
		Method Blank(2)	1 per batch (maximum of 20 field samples per batch) or 1 per day whichever is more frequent	Concentrations of analytes <= the project reporting level	-Reanalyze Blank(2) -If second method Blank(2) exceeds criteria, clean and recalibrate the analytical system -Document corrective action
		Initial calibration	Prior to the analysis of any samples and as dictated by the continuing calibration check	RSD <=20% over working range or correlation coefficient >=0.995	-Check GC system -Rerun as needed to meet criteria
		Continuing calibration check.	Beginning of each sequence and after every 10 samples	Response factor (RF) must agree within +/-15% difference from average RF of initial calibration or calculated concentrations from the curve must agree within +/-15% of the true value	-Check GC system -Run initial calibration -Reanalyze associated samples
		Surrogate Spikes	Every sample (field, standards,	See	-Check calculation

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
			QC, Blank(2)	See Table 4	-Reextract and reannalyze -Flag data
SW8310 (cont)		Matrix Spike/Spike	1 per batch (max 20 samples)	See See Table 4	-Check LCS -Discuss in case narrative -Flag data
		Laboratory Control Sample	1 per batch (max 20 samples)	See See Table 4	-Check calibration -Rerun LCS -Flag data
SW9010	Cyanide	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check method Blank(2) -Flag data
		Field Duplicate	Ten percent of all water samples	RPD <= 20%	-Review and discuss in report -Flag data
		Laboratory QC:			
		Calibration	Before each analytical batch	Correlation coefficient >=0.995 ICS +/- 15% of true value	-Check system -Rerun as required to meet criteria
		Continuing calibration	Every 10 samples	85-115% Rec	-Recalibrate
		Matrix Spike	1 per batch (max 20 samples)	See See Table 4	-Check laboratory control sample -Flag data -Discuss in case narrative
		Matrix Duplicate	1 per batch (max 20 samples)	See See Table 4	-Check laboratory control sample -Flag data -Discuss in case narrative

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
SW9010 (cont)		Laboratory Control Sample	1 per batch (max 20 samples)	See See Table 4	-Rerun LCS -Check calibration
		Method Blank(2)	1 per batch (maximlum of 20 field samples per batch) or 1 per day whichever is more frequent	Concentrations of analytes <= project reporting level	-Reanalyze Blank(2) -If second method Blank(2) exceeds criteria, clean and recalibrate the analytical system -Document corrective action
SW9020	Total Organic Halogens	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check method Blank(2) -Flag data
		Field Duplicate	Ten percent of all water samples	RPD <= 20%	-Review and discuss in report -Flag data
		Laboratory QC:			
		Adsorption Efficiency Standard	Before each analytical batch	Within 10% of true value	-Check system -Rerun as required to meet criteria
		Matrix Spike	1 per batch (maximum 20 samples)	75 - 125% recovery	-Check laboratory control sample -Flag data -Discuss in case narrative
		Matrix Duplicate	1 per batch (maximum 20 samples)	20% RPD	-Flag data -Discuss in case narrative
SW9020 (cont)		Laboratory Control Sample	1 per batch (maximum 20 samples)	80-120% Rec (liquids) In-house limits (solids)	-Rerun LCS -Check calibration -Flag data

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
		Method Blank(2)	1 per batch (maximlum of 20 field samples per batch) or 1 per day whichever is more frequent	Concentrations of analytes <= project reporting level	-Reanalyze Blank(2) -If second method Blank(2) exceeds criteria, clean and recalibrate the analytical system -Document corrective action
SW9035	Sulfate	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check preparation Blank(2) -Check field Blank(2) -Flag data
		Field Duplicate	Ten percent of all samples	RPD <= 20% (water)	-Review and discuss in report -Flag data where appropriate
		Laboratory QC			
		Initial and continuing calibration verification standard	Initial: Beginning of day Continuing: 10% or every 2 hours during run	Within 20% of true value	-Check instrument -Recalibrate -Reanalyze preceding samples
		Initial and continuing calibration Blank(2) & CCB)	Initial: immediately after ICV Continuing: immediately after CCV	Concentrations of analytes <= the project reporting level	-Check instrument -Recalibrate -Reanalyze preceding samples
SW9035 (cont)		Preparation Blank(2)	1 per batch (maximum of 20 samples per batch)	Concentrations of analytes <= the project reporting level	-Reanalyze Blank(2) -If second method Blank(2) exceeds criteria, clean and recalibrate the analytical system -Document corrective action
		Matrix spike	1 per batch (maximum 20 samples)	75 - 125% recovery	-Check LCS

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
					-Flag data
		Matrix Duplicate	1 per batch (maximum 20 samples)	20% RPD	-Check LCS -Flag data
		Laboratory Control Sample	1 per batch (maximum 20 samples)	75 - 125% recovery	-Rerun all non compliant analytes -Flag data
SW9060	Total Organic Carbon	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check method Blank(2) -Flag data
		Field Duplicate	Ten percent of all water samples	RPD <= 20%	-Review and discuss in report -Flag data
		Laboratory QC:			
		Calibration	Before each analytical batch	Correlation coefficient >=0.995 ICS +/- 15% of true value	-Check system -Rerun as required to meet criteria
		Continuing calibration	Every 10 samples	85-115% Rec	-Recalibrate
SW9060 (cont)		Matrix Spike	1 per batch (maximum 20 samples)	75 - 125% recovery	-Check laboratory control sample -Flag data -Discuss in case narrative
		Matrix Duplicate	1 per batch (maximum 20 samples)	75 - 125% recovery	-Flag data -Discuss in case narrative
		Laboratory Control Sample	1 per batch (maximum 20 samples)	80-120% Rec (liquids)	-Rerun LCS -Check calibration -Flag data
		Method Blank(2)	1 per batch (maximlum of 20 field	Concentrations of analytes <=	-Reanalyze Blank(2)

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
			samples per batch) or 1 per day whichever is more frequent	project reporting level	-If second method Blank(2) exceeds criteria, clean and recalibrate the analytical system -Document corrective action
SW9131	Total Coliform	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check preparation Blank(2) -Check field Blank(2) -Flag data
		Field Duplicate	Ten percent of all samples	RPD <= 20% (water)	-Review and discuss in report -Flag data where appropriate
		Laboratory QC			
		Laboratory Control Sample	1 per batch up to 20 samples	80 - 120% recovery	-Reanalyze sample -Flag data
SW9131 (cont)		Sample Duplicate	1 per batch up to 20 samples	<20% RPD	-Check LCS -Flag data -Discuss in case narrative
		Preparation Blank(2)	1 per batch (maximum of 20 samples per batch)	Concentrations of analytes <= the project reporting level	-Reanalyze sample -Flag data
SW9250	Chloride	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check preparation Blank(2) -Check field Blank(2) -Flag data
		Field Duplicate	Ten percent of all samples	RPD <= 20% (water)	-Review and discuss in report -Flag data where appropriate

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
		Laboratory QC			
		Initial and continuing calibration verification standard	Initial: Beginning of day Continuing: 10% or every 2 hours during run	Within 20% of true value	-Check instrument -Recalibrate -Reanalyze preceding samples
		Initial and continuing calibration Blank(2) & CCB)	Initial: immediately after ICV Continuing: immediately after CCV	Concentrations of analytes <= the project reporting level	-Check instrument -Recalibrate -Reanalyze preceding samples
		Preparation Blank(2)	1 per batch (maximum of 20 samples per batch)	Concentrations of analytes <= the project reporting level	-Reanalyze sample -Flag data
		Matrix spike/ spike duplicate	1 per batch up to 20 samples	See Table B	-Check LCS -Flag data
		Laboratory Control Sample (LCS, Blank(2)	1 per batch up to 20 samples	See Table B	-Rerun all non compliant analytes -Flag data
SW9310	Gross Alpha and Gross Beta	**Field QC:**			
		Field Duplicate	Ten percent of all samples	RPD <= 20% (water)	-Review and discuss in technical report -Flag data where appropriate
		Laboratory QC			
		Calibration			
		1. Set alpha/beta counting plateau	With each gas change or after periods of inactivity	Plateaus should be at least 200 volts long and slope at plateau <2.5%/100 volts	-Check system -Check gas supply -Check power source
		2. Descriminator set	With each setting of alpha/beta	Beta cross talk should not	-Check system

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
		(alpha)	plateau	exceed 2%	-Check gas supply -Check power source
		3. Background count	With each setting of alpha/beta plateau	Alpha cpm <0.2 Beta cpm <1.2	-Check system -Check gas supply -Check power source
		4. Set alpha/beta counting efficiency	With each setting of alpha/beta plateau	Alpha >16% Beta >35%	-Check system -Check gas supply -Check power source
SW9310 (cont)		5. Alpha/beta self adsorption curves	Once per month	>0.97	-If < 0.97 the values must be determined from the actual graph
		Continuing Calibration			
		1. Alpha Beta Standard	Once per day	Within 15% of true value	-Recalibrate
		2. Background	After each sample	Alpha cpm <0.2 Beta cpm <1.2	-Check system
		Matrix spike/ spike duplicate	1 per batch up to 20 samples	48 - 162% recovery	-Check LCS -Flag data -Discuss in case narrative
		Laboratory Control Sample (alpha or beta)	1 per batch up to 20 samples	80 - 120% recovery	-Recalibrate -Flag data
		Sample Duplicate	1 per batch up to 20 samples	<25% RPD	-Check LCS
SW9065	Phenols	**Field QC:**			
		Equipment Blank(2)	One per sampling event	Concentrations of analytes <= 3X the project reporting level	-Check method Blank(2) -Flag data

TABLE 3
SUMMARY OF INTERNAL QUALITY CONTROL PROCEDURES
FOR CANNON AFB

Analytical Method	Parameter	Quality Control Procedure	Frequency or Concentration (as appplicable)	Acceptance(1) Criteria	Corrective Action
		Field Duplicate	Ten percent of all water samples	RPD <= 20%	-Review and discuss in report -Flag data
		<u>Laboratory QC:</u>			
		Calibration	Before each analytical batch	Correlation coefficient >=0.995 ICS +/- 15% of true value	-Check system -Rerun as required to meet criteria
		Continuing calibration	Every 10 samples	85-115% Rec	-Recalibrate
		Matrix Spike	1 per batch (max 20 samples)	See See Table 4	-Check laboratory control sample -Flag data -Discuss in case narrative
		Matrix Duplicate	1 per batch (max 20 samples)	See See Table 4	-Check laboratory control sample -Flag data -Discuss in case narrative
SW9065 (cont)		Laboratory Control Sample	1 per batch (max 20 samples)	See See Table 4	-Rerun LCS -Check calibration
		Method Blank(2)	1 per batch (maximlum of 20 field samples per batch) or 1 per day whichever is more frequent	Concentrations of analytes <= project reporting level	-Reanalyze Blank(2) -If second method Blank(2) exceeds criteria, clean and recalibrate the analytical system -Document corrective action

(1) Common lab contaminants for volatile analysis include: acetone, methylene chloride and 2-butanone. Common lab contaminants for semivolatile analysis include common pthalates.

(2) Equipment Blanks only collected when non-dedicated sampling equipment is used.

TABLE 4

QUALITY CONTROL LIMITS FOR WATER SAMPLES - LABORATORY ACCURACY AND PRECISION

TABLE 4
QUALITY CONTROL LIMITS FOR WATER SAMPLES
LABORATORY ACCURACY AND PRECISION

Analytical Parameter	Analytical Method	Matrix Spike (MS) Compounds	MS/MSD (MD) (% Recovery)	MS/MSD (MD) (RPD)(a)	MS Blank (LCS) (% Recovery)	Surrogate Compounds	Surrogate (% Recovery)
VOCs	SW8240	1,1-Dichloroethane Trichloroethene Benzene Toluene Chlorobenzene	ANALYTICAL LAB TO PROVIDE	ANALYTICAL LAB TO PROVIDE	ANALYTICAL LAB TO PROVIDE	Toluene-d8 Bromofluorobenzene 1,2-Dichloroethane-d4	ANALYTICAL LAB TO PROVIDE
SVOCs (c)	SW8270	Phenol 2-Chlorophenol 1,4-Dichlorobenzene N-Nitroso-di-n-propylamine 1,2,4-Trichlorobenzene 4-Chloro-3-methylphenol Acenaphthene 4-Nitrophenol 2,4-Dinitrotoluene Pentachlorophenol Pyrene				Nitrobenzene-d5 2-Fluorobiphenyl Terphenyl-d14 Phenol-d5 2-Fluorophenol 2,4,6-Tribromophenol 2-Chlorophenol-d4 1,2-Dichlorobenzene-d4	
ORGANOCHLORINE PESTICIDES AND PCBs	SW8080	Gamma-BHC (Lindane) Heptachlor Aldrin Dieldrin Endrin 4,4'-DDT				Tetrachloro-m-xylene Decachlorobiphenyl	
Inorganics	SW6010 and 7xxx	Inorganic Analyte				NA	NA

(a) RPD = Relative Percent Difference

ATTACHMENT 1

PARAMETRIC ANOVA EXAMPLE

5.2 ANALYSIS OF VARIANCE

If contamination of the ground water occurs from the waste disposal facility and if the monitoring wells are hydraulically upgradient and hydraulically downgradient from the site, then contamination is unlikely to change the levels of a constituent in all wells by the same amount. Thus, contamination from a disposal site can be seen as differences in average concentration among wells, and such differences can be detected by analysis of variance.

Analysis of variance (ANOVA) is the name given to a wide variety of statistical procedures. All of these procedures compare the means of different groups of observations to determine whether there are any significant differences among the groups, and if so, contrast procedures may be used to determine where the differences lie. Such procedures are also known in the statistical literature as general linear model procedures.

Because of its flexibility and power, analysis of variance is the preferred method of statistical analysis when the ground-water monitoring is based on a comparison of background and compliance well data. Two types of analysis of variance are presented: parametric and nonparametric one-way analyses of variance. Both methods are appropriate when the only factor of concern is the different monitoring wells at a given sampling period.

The hypothesis tests with parametric analysis of variance usually assume that the errors (residuals) are normally distributed with constant variance. These assumptions can be checked by saving the residuals (the difference between the observations and the values predicted by the analysis of variance model) and using the tests of assumptions presented in Section 4. Since the data will generally be concentrations and since concentration data are often found to follow the lognormal distribution, the log transformation is suggested if substantial violations of the assumptions are found in the analysis of the original concentration data. If the residuals from the transformed data do not meet the parametric ANOVA requirements, then nonparametric approaches to analysis of variance are available using the ranks of the observations. A one-way analysis of variance using the ranks is presented in Section 5.2.2.

When several sampling periods have been used and it is important to consider the sampling periods as a second factor, then two-way analysis of variance, parametric or nonparametric, is appropriate. This would be one way to test for and adjust the data for seasonality. Also, trend analysis (e.g., time series) may be used to identify seasonality in the data set. If necessary, data that exhibit seasonal trends can be adjusted. Usually, however, seasonal variation will affect all wells at a facility by nearly the same amount, and in most circumstances, corrections will not be necessary. Further, the effects of seasonality will be substantially reduced by simultaneously comparing aggregate compliance well data to background well data. Situations that require an analysis procedure other than a one-way ANOVA should be referred to a professional statistician.

see 8.1.1 page 8-- regarding data below detection limit-

5.2.1 One-Way Parametric Analysis of Variance

In the context of ground-water monitoring, two situations exist for which a one-way analysis of variance is most applicable:

* Data for a water quality parameter are available from several wells but for only one time period (e.g., monitoring has just begun).

* Data for a water quality parameter are available from several wells for several time periods. However, the data do not exhibit seasonality.

In order to apply a parametric one-way analysis of variance, a minimum number of observations is needed to give meaningful results. At least $p \geq 2$ groups are to be compared (i.e., two or more wells). It is recommended that each group (here, wells) have at least three observations and that the total sample size, N, be large enough so that $N-p \geq 5$. A variety of combinations of groups and number of observations in groups will fulfill this minimum. One sampling interval with four independent samples per well and at least three wells would fulfill the minimum sample size requirements. The wells should be spaced so as to maximize the probability of intercepting a plume of contamination. The samples should be taken far enough apart in time to guard against autocorrelation.

PURPOSE

One-way analysis of variance is a statistical procedure to determine whether differences in mean concentrations among wells, or groups of wells, are statistically significant. For example, is there significant contamination of one or more compliance wells as compared to background wells?

PROCEDURE

Suppose the regulated unit has p wells and that n_i data points (concentrations of a constituent) are available for the ith well. These data can be from either a single sampling period or from more than one. In the latter case, the user could check for seasonality before proceeding by plotting the data over time. Usually the computation will be done on a computer using a commercially available program. However, the procedure is presented so that computations can be done using a desk calculator, if necessary.

Step 1. Arrange the $N = \sum_{i=1}^{p} n_i$ data points in a data table as follows (N is the total sample size at this specific regulated unit):

	Observations	Well Total (from Step 1)	Well Mean (from Step 2)
Well No. 1	X_{11} ..... X_{1n_i}	$X_{1.}$	$\bar{X}_{1.}$
2	.		
3	.		
.	.		
u	X_{u1}	$X_{u.}$	$\bar{X}_{u.}$
.	.		
.	.		
p	X_{p1} ..... X_{pn_p}	$X_{p.}$	$\bar{X}_{p.}$
		$X_{..}$	$\bar{X}_{..}$

Step 2. Compute well totals and well means as follows:

$$X_{i.} = \sum_{j=1}^{n_i} X_{ij} \text{ , total of all } n_i \text{ observations at well } i$$

$$\bar{X}_{i.} = \frac{1}{n_i} X_{i.} \text{ , average of all } n_i \text{ observations at well } i$$

$$X_{..} = \sum_{i=1}^{p} \sum_{j=1}^{n_i} X_{ij} \text{ , grand total of all } n_i \text{ observations}$$

$$\bar{X}_{..} = \frac{1}{N} X_{..} \text{ , grand mean of all observations}$$

These totals and means are shown in the last two columns of the table above.

Step 3. Compute the sum of squares of differences <u>between</u> well means and the grand mean:

$$SS_{Wells} = \sum_{i=1}^{p} n_i (\bar{X}_{i.} - \bar{X}_{..})^2 = \sum_{i=1}^{p} \frac{1}{n_i} X_{i.}^2 - \frac{1}{N} X_{..}^2$$

= of 4 in Bkgd

(The formula on the far right is usually most convenient for calculation.) This sum of squares has (p-1) degrees of freedom associated with it and is a measure of the variability <u>between</u> wells.

Step 4. Compute the corrected total sum of squares

$$SS_{Total} = \sum_{i=1}^{p} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})^2 = \sum_{i=1}^{p} \sum_{j=1}^{n_i} X_{ij}^2 - (X_{..}^2/N)$$

(The formula on the far right is usually most convenient for calculation.) This sum of squares has (N-1) degrees of freedom associated with it and is a measure of the variability in the whole data set.

Step 5. Compute the sum of squares of differences of observations <u>within</u> wells from the well means. This is the sum of squares due to error and is obtained by subtraction:

$$SS_{Error} = SS_{Total} - SS_{Wells}$$

It has associated with it (N-p) degrees of freedom and is a measure of the variability <u>within</u> wells.

Step 6. Set up the ANOVA table as shown below in Table 5-1. The sums of squares and their degree of freedom were obtained from Steps 3 through 5. The mean square quantities are simply obtained by dividing each sum of squares by its corresponding degrees of freedom.

TABLE 5-1. ONE-WAY PARAMETRIC ANOVA TABLE

Source of Variation	Sums of squares	Degrees of freedom	Mean squares	F
Between wells	SS_{Wells}	p-1	$MS_{Wells} = SS_{Wells}/(p-1)$	$F = \frac{MS_{Wells}}{MS_{Error}}$
Error (within wells)	SS_{Error}	N-p	$MS_{Error} = SS_{Error}/(N-p)$	
Total	SS_{Total}	N-1		

Step 7. To test the hypothesis of equal means for all p wells, compute $F = MS_{Wells}/MS_{Error}$ (last column in Table 5-1). Compare this statistic to the tabulated F statistic with (p-1) and (N-p) degrees of freedom (Table 2, Appendix B) at the 5% significance level. If the calculated F value exceeds the tabulated value, reject the hypothesis of equal well means. Otherwise,

conclude that there is no significant difference between the concentrations at the p wells and thus no evidence of well contamination.

In the case of a significant F (calculated F greater than tabulated F in Step 7), the user will conduct the next few steps to determine which compliance well(s) is (are) contaminated. This will be done by comparing each compliance well with the background well(s). Concentration differences between a pair of background wells and compliance wells or between a compliance well and a set of background wells are called <u>contrasts</u> in the ANOVA and multiple comparisons framework.

Step 8. Determine if the significant F is due to differences between background and compliance wells (computation of Bonferroni t-statistics)

Assume that of the p wells, u are background wells and m are compliance wells (thus u + m = p). Then m differences--m compliance wells each compared with the average of the background wells--need to be computed and tested for statistical significance. If there are more than five downgradient wells, the individual comparisons are done at the comparisonwise significance level of 1%, which may make the experimentwise significance level greater than 5%.

- Obtain the total sample size of all u background wells.

$$n_{up} = \sum_{i=1}^{u} n_i$$

- Compute the average concentration from the u background wells.

$$\overline{X}_{up} = \frac{1}{n_{up}} \sum_{i=1}^{u} \overline{X}_{i.}$$

- Compute the m differences between the average concentrations from each compliance well and the average background wells.

$$\overline{X}_{i.} - \overline{X}_{up} \ , \quad i = 1, \ldots, m$$

- Compute the standard error of each difference as

$$SE_i = [MS_{Error} \ (1/n_{up} + 1/n_i)]^{\frac{1}{2}}$$

where MS_{Error} is determined from the ANOVA table (Table 5-1) and n_i is the number of observations at well i.

- Obtain the t-statistic $t = t_{(N-p),(1-\alpha/m)}$ from Bonferroni's t-table (Table 3, Appendix B) with $\alpha = 0.05$ and (N-p) degrees of freedom.

- Compute the m quantities $D_i = SE_i \times t$ for each compliance well i. If m > 5 use the entry for $t_{(N-p),(1-0.01)}$. That is, use the entry at m = 5.

INTERPRETATION

If the difference $\bar{X}_{i.} - \bar{X}_{up}$ exceeds the value D_i, conclude that the ith compliance well has significantly higher concentrations than the average background wells. Otherwise conclude that the well is not contaminated. This exercise needs to be performed for each of the m compliance wells individually. The test is designed so that the overall experimentwise error is 5% if there are no more than five compliance wells.

CAUTIONARY NOTE

Should the regulated unit consist of more than five compliance wells, then the Bonferroni t-test should be modified by doing the individual comparisons at the 1% level so that the Part 264 Subpart F regulatory requirement pursuant to §264.97(i)(2) will be met. Alternately, a different analysis of contrasts, such as Scheffe's, may be used. The more advanced user is referred to the second reference below for a discussion of multiple comparisons.

REFERENCES

Johnson, Norman L., and F. C. Leone. 1977. *Statistics and Experimental Design in Engineering and the Physical Sciences.* Vol. II, Second Edition, John Wiley and Sons, New York.

Miller, Ruppert G., Jr. 1981. *Simultaneous Statistical Inference.* Second Edition, Springer-Verlag, New York.

EXAMPLE

Four lead concentration values at each of six wells are given in Table 5-2 below. The wells consist of u=2 background and m=4 compliance wells. (The values in Table 5-2 are actually the natural logarithms of the original lead concentrations.)

Step 1. Arrange the 4 x 6 = 24 observations in a data table as follows:

TABLE 5-2. EXAMPLE DATA FOR ONE-WAY PARAMETRIC ANALYSIS OF VARIANCE

		Natural log of Pb concentrations (μg/L)						
Well No.	Date:	Jan 1	Feb 1	Mar 1	Apr 1	Well total ($X_{i.}$)	Well mean ($\bar{X}_{i.}$)	Well std. dev.
1	Background wells	4.06	3.99	3.40	3.83	15.28	3.82	0.295
2		3.83	4.34	3.47	4.22	15.86	3.96	0.398
3	Compliance wells	5.61	5.14	3.47	3.97	18.18	4.55	0.996 (max)
4		3.53	4.54	4.26	4.42	16.75	4.19	0.456
5		3.91	4.29	5.50	5.31	19.01	4.75	0.771
6		5.42	5.21	5.29	5.08	21.01	5.25	0.142 (min)
						$X_{..}$ = 106.08	$\bar{X}_{..}$ = 4.42	

Step 2. The calculations are shown on the right-hand side of the data table above. Sample standard deviations have been computed also.

Step 3. Compute the between-well sum of squares.

$$SS_{Wells} = \frac{1}{4}(15.28^2 + \ldots. + 21.01^2) - \frac{1}{24} \times 106.08^2 = 5.76$$

with [6 (wells) - 1] = 5 degrees of freedom.

Step 4. Compute the corrected total sum of squares.

$$SS_{Total} = 4.06^2 + 3.99^2 + \ldots. + 5.08^2 - \frac{1}{24} \times 106.08^2 = 11.94$$

with [24 (observations) - 1] = 23 degrees of freedom.

Step 5. Obtain the within-well or error sum of squares by subtraction.

$$SS_{Error} = 11.94 - 5.76 = 6.18$$

with [24 (observations) - 6 (wells)] = 18 degrees of freedom.

Step 6. Set up the one-way ANOVA as in Table 5-3 below:

TABLE 5-3. EXAMPLE COMPUTATIONS IN ONE-WAY PARAMETRIC ANOVA TABLE

Source of variation	Sums of squares	Degrees of freedom	Mean squares	F
Between wells	5.76	5	5.76/5 = 1.15	1.15/0.34 = 3.38
Error (within wells)	6.18	18	6.18/18 = 0.34	
Total	11.94	23		

Step 7. The calculated F statistic is 3.38. The tabulated F value with 5 and 18 degrees of freedom at the $\alpha = 0.05$ level is 2.77 (Table 2, Appendix B). Since the calculated value exceeds the tabulated value, the hypothesis of equal well means must be rejected, and *post hoc* comparisons are necessary.

Step 8. Computation of Bonferroni t-statistics.

- Note that there are four compliance wells, so m = 4 comparisons will be made
- $n_{up} = 8$ total number of samples in background wells
- $\bar{X}_{up} = 3.89$ average concentration of background wells
- Compute the differences between the four compliance wells and the average of the two background wells:

$$\bar{X}_{3\cdot} - \bar{X}_{up} = 4.55 - 3.89 = 0.66$$

$$\bar{X}_{4\cdot} - \bar{X}_{up} = 4.19 - 3.89 = 0.3$$

$$\bar{X}_{5\cdot} - \bar{X}_{up} = 4.75 - 3.89 = 0.86$$

$$\bar{X}_{6\cdot} - \bar{X}_{up} = 5.25 - 3.89 = 1.36$$

- Compute the standard error of each difference. Since the number of observations is the same for all compliance wells, the standard errors for the four differences will be equal.

$$SE_i = [0.34\ (1/8 + 1/4)]^{\frac{1}{2}} = 0.357 \text{ for } i = 3, \ldots, 6$$

- From Table 3, Appendix B, obtain the critical t with (24 - 6) = 18 degrees of freedom, $m = 4$, and for $\alpha = 0.05$. The approximate value is 2.43 obtained by linear interpolation between 15 and 20 degrees of freedom.

- Compute the quantities D_i. Again, due to equal sample sizes, they will all be equal.

$$D_i = SE_i \times t = 0.357 \times 2.43 = \underline{0.868} \text{ for } i = 3, \ldots, 6$$

INTERPRETATION

The F test was significant at the 5% level. The Bonferroni multiple comparisons procedure was then used to determine for which wells there was statistically significant evidence of contamination. Of the four differences $\bar{X}_{i.} - \bar{X}_{up}$, only $\bar{X}_{6.} - \bar{X}_{up} = 1.36$ exceeds the critical value of 0.868. From this it is concluded that there is significant evidence of contamination at Well 6. Well 5 is right on the boundary of significance. It is likely that Well 6 has intercepted a plume of contamination with Well 5 being on the edge of the plume.

All the compliance well concentrations were somewhat above the mean concentration of the background levels. The well means should be used to indicate the location of the plume. The findings should be reported to the Regional Administrator.

5.2.2 One-Way Nonparametric Analysis of Variance

This procedure is appropriate for interwell comparisons when the data or the residuals from a parametric ANOVA have been found to be significantly different from normal and when a log transformation fails to adequately normalize the data. In one-way nonparametric ANOVA, the assumption under the null hypothesis is that the data from each well come from the same continuous distribution and hence have the same median concentrations of a specific hazardous constituent. The alternatives of interest are that the data from some wells show increased levels of the hazardous constituent in question.

The procedure is called the Kruskal-Wallis test. For meaningful results, there should be at least three groups with a minimum sample size of three in each group. For large data sets use of a computer program is recommended. In the case of large data sets a good approximation to the procedure is to replace each observation by its rank (its numerical place when the data are ordered from least to greatest) and perform the (parametric) one-way analysis of variance (Section 5.2.1) on the ranks. Such an approach can be done with some commercially statistical packages such as SAS.

PURPOSE

The purpose of the procedure is to test the hypothesis that all wells (or groups of wells) around regulated units have the same median concentration of a hazardous constituent. If the wells are found to differ, *post-hoc* comparisons are again necessary to determine if contamination is present.

Note that the wells define the groups. All wells will have at least four observations. Denote the number of groups by K and the number of observations in each group by n_i, with N being the total number of all observations. Let X_{ij} denote the jth observation in the ith group, where j runs from 1 to the number of observations in the group, n_i, and i runs from 1 to the number of groups, K.

PROCEDURE

Step 1. Rank all N observations of the groups from least to greatest. Let R_{ij} denote the rank of the jth observation in the ith group. As a convention, denote the background well(s) as group 1.

Step 2. Add the ranks of the observations in each group. Call the sum of the ranks for the ith group R_i. Also calculate the average rank for each group, $\bar{R}_i = R_i/n_i$.

Step 3. Compute the Kruskal-Wallis statistic:

$$H = \left[\frac{12}{N(N+1)} \sum_{i=1}^{K} \frac{R_i^2}{N_i} \right] - 3(N+1)$$

Step 4. Compare the calculated value H to the tabulated chi-squared value with (K-1) degrees of freedom, where K is the number of groups (Table 1, Appendix B). Reject the null hypothesis if the computed value exceeds the tabulated critical value.

Step 5. If the computed value exceeds the value from the chi-squared table, compute the critical difference for well comparisons to the background, assumed to be group 1:

$$C_i = Z_{(\alpha/(K-1))} \left[\frac{N(N+1)}{12} \right]^{1/2} \left[\frac{1}{n_1} + \frac{1}{n_i} \right],$$

for i taking values 2,..., K,

where $Z_{(\alpha/(K-1))}$ is the upper $(\alpha/(K-1))$-percentile from the standard normal distribution found in Table 4, Appendix B. Note: If there are more than five compliance wells at the regulated unit (K > 6), use $Z_{.01}$, the upper one-percentile from the standard normal distribution.

ATTACHMENT 2

SHAPIRO-WILK TEST EXAMPLE

The Skewness Coefficient may be computed using the following formula:

$$\gamma_1 = \frac{\frac{1}{n}\sum_i (x_i - \bar{x})^3}{\left(\frac{n-1}{n}\right)^{\frac{3}{2}} (SD)^3}$$

where the numerator represents the average cubed residual and SD denotes the standard deviation of the measurements. Most statistics computer packages (e.g., Minitab, GEO-EAS) will compute the Skewness Coefficient automatically via a simple command.

EXAMPLE 2

Using the data in Example 1, compute the Skewness Coefficient to test for approximate symmetry in the data.

SOLUTION

Step 1. Compute the mean, standard deviation (SD), and average cubed residual for the nickel concentrations:

$$\bar{x} = 169.52 \text{ ppb}$$

$$SD = 259.72 \text{ ppb}$$

$$\frac{1}{n}\sum_i (x_i - \bar{x})^3 = 2.98923 * 10^8 \text{ ppb}^3$$

Step 2. Calculate the Coefficient of Skewness using the previous formula to get $\gamma_1 = 1.84$. Since the skewness is much larger than 1, the data appear to be significantly positively skewed. Do not assume that the data follow a Normal distribution.

Step 3. Since the original data evidence a high degree of skewness, one can attempt to compute the Skewness Coefficient on the logged data instead. In that case, the skewness works out to be $|\gamma_1| = 0.24 < 1$, indicating that the logged data values are slightly skewed, but not enough to reject an assumption of Normality in the logged data. In other words, the original data may be Lognormally distributed.

1.1.4 The Shapiro-Wilk Test of Normality ($n \leq 50$)

The Shapiro-Wilk test is recommended as a superior alternative to the Chi-square test for testing Normality of the data. It is based on the premise that if a set of data are Normally distributed, the ordered values should be highly correlated with corresponding quantiles taken from a Normal distribution (Shapiro and Wilk, 1965). In particular, the Shapiro-Wilk test gives

substantial weight to evidence of non-Normality in the tails of a distribution, where the robustness of statistical tests based on the Normality assumption is most severely affected. The Chi-square test treats departures from Normality in the tails nearly the same as departures in the middle of a distribution, and so is less sensitive to the types of non-Normality that are most crucial. One cannot tell from a significant Chi-square goodness-of-fit test what sort of non-Normality is indicated.

The Shapiro-Wilk test statistic (W) will tend to be large when a Probability Plot of the data indicates a nearly straight line. Only when the plotted data show significant bends or curves will the test statistic be small. The Shapiro-Wilk test is considered to be one of the very best tests of Normality available (Miller, 1986; Madansky, 1988).

To calculate the test statistic W, one can use the following formula:

$$W = \left[\frac{b}{SD\sqrt{n-1}}\right]^2$$

where the numerator is computed as

$$b = \sum_{i=1}^{k} a_{n-i+1}(x_{(n-i+1)} - x_{(i)}) = \sum_{i=1}^{k} b_i$$

In this last formula, $x_{(j)}$ represents the jth smallest ordered value in the sample and coefficients a_j depend on the sample size n. The coefficients can be found for any sample size from 3 up to 50 in Table A-1 of Appendix A. The value of k can be found as the greatest integer less than or equal to n/2.

Normality of the data should be rejected if the Shapiro-Wilk statistic is too low when compared to the critical values provided in Table A-2 of Appendix A. Otherwise one can assume the data are approximately Normal for purposes of further statistical analysis. As before, it is recommended that the test first be performed on the logarithms of the original data to test for Lognormality. If the logged data indicate non-Normality by the Shapiro-Wilk test, a re-test can be performed on the original data to test for Normality of the original concentrations.

EXAMPLE 3

Use the data of Example 1 to compute the Shapiro-Wilk test of Normality.

SOLUTION

Step 1. Order the data from smallest to largest and list, as in the following table. Also list the data in reverse order alongside the first column.

Step 2. Compute the differences $x_{(n-i+1)}-x_{(i)}$ in column 3 of the table by subtracting column 1 from column 2.

i	$x_{(i)}$	$x_{(n-i+1)}$	$x_{(n-i+1)}-x_{(i)}$	a_{n-i+1}	b_i
1	1.0	942.0	941.0	.4734	445.47
2	3.1	637.0	633.9	.3211	203.55
3	8.7	578.0	569.3	.2565	146.03
4	10.0	331.0	321.0	.2085	66.93
5	14.0	262.0	248.0	.1686	41.81
6	19.0	151.0	132.0	.1334	17.61
7	21.4	85.6	64.2	.1013	6.50
8	27.0	81.5	54.5	.0711	3.87
9	39.0	64.4	25.4	.0422	1.07
10	56.0	58.8	2.8	.0140	0.04
11	58.8	56.0	-2.8		b=932.88
12	64.4	39.0	-25.4		
13	81.5	27.0	-54.5		
14	85.6	21.4	-64.2		
15	151.0	19.0	-132.0		
16	262.0	14.0	-248.0		
17	331.0	10.0	-321.0		
18	578.0	8.7	-569.3		
19	637.0	3.1	-633.9		
20	942.0	1.0	-941.0		

Step 3. Compute k as the greatest integer less than or equal to n/2. Since n=20, k=10 in this example.

Step 4. Look up the coefficients a_{n-i+1} from Table A-1 and list in column 4. Multiply the differences in column 3 by the coefficients in column 4 and add the first k products to get quantity b. In this case, b=932.88.

Step 5. Compute the standard deviation of the sample, SD=259.72. Then

$$W = \left[\frac{932.88}{259.72\sqrt{19}}\right]^2 = 0.679.$$

Step 6. Compare the computed value of W=0.679 to the 5% critical value for sample size 20 in Table A-2, namely $W_{.05,20}$=0.905. Since W < 0.905, the sample shows significant evidence of non-Normality by the Shapiro-Wilk test. The data should be transformed using natural logs and rechecked using the Shapiro-Wilk test before proceeding with further statistical analysis (Actually, the logged data should have been tested first. The

original concentration data are used in this example to illustrate how the assumption of Normality can be rejected.)

1.1.5 The Shapiro-Francia Test of Normality (n>50)

The Shapiro-Wilk test of Normality can be used for sample sizes up to 50. When the sample is larger than 50, a slight modification of the procedure called the Shapiro-Francia test (Shapiro and Francia, 1972) can be used instead.

Like the Shapiro-Wilk test, the Shapiro-Francia test statistic (W') will tend to be large when a Probability Plot of the data indicates a nearly straight line. Only when the plotted data show significant bends or curves will the test statistic be small.

To calculate the test statistic W', one can use the following formula:

$$W' = \frac{\left[\Sigma_i m_i x_{(i)}\right]^2}{(n-1)SD^2 \Sigma_i m_i^2}$$

where $x_{(i)}$ represents the ith ordered value of the sample and where m_i denotes the approximate expected value of the ith ordered Normal quantile. The values for m_i can be approximately computed as

$$m_i = \Phi^{-1}\left(\frac{i}{n+1}\right)$$

where Φ^{-1} denotes the inverse of the standard Normal distribution with zero mean and unit variance. These values can be computed by hand using a Normal probability table or via simple commands in many statistical computer packages.

Normality of the data should be rejected if the Shapiro-Francia statistic is too low when compared to the critical values provided in Table A-3 of Appendix A. Otherwise one can assume the data are approximately Normal for purposes of further statistical analysis. As before, the logged data should be tested first to see if a Lognormal model is appropriate. If these data indicate non-Normality by the Shapiro-Francia test, a re-test can be performed on the original data.

ATTACHMENT 3

BARTLETT'S TEST EXAMPLE

PURPOSE

Bartlett's test is a test of homogeneity of variances. In other words, it is a means of testing whether a number of population variances of normal distributions are equal. Homogeneity of variances is an assumption made in analysis of variance when comparing concentrations of constituents between background and compliance wells, or among compliance wells. It should be noted that Bartlett's test is itself sensitive to nonnormality in the data. With long-tailed distributions the test too often rejects equality (homogeneity) of the variances.

PROCEDURE

Assume that data from k wells are available and that there are n_i data points for well i.

Step 1. Compute the k sample variances $S_1^2,\ldots,S_k^2$. The sample variance, S^2, is the square of the sample standard deviation and is given by the general equation

$$S^2 = \sum_{i=1}^{n} (X_i-\bar{X})^2/(n-1)$$

where $\bar{X}$ is the average of the $X_1,\ldots,X_n$ values. Each variance has associated with it $f_i = n_i-1$ degrees of freedom. Take the natural logarithm of each variance, $\ln(S_1^2),\ldots,\ln(S_k^2)$.

Step 2. Compute the test statistic

$$X^2 = f \ln(S_p^2) - \sum_{i=1}^{k} f_i \ln(S_i^2)$$

$$\text{where} \quad f = \sum_{i=1}^{k} f_i = \left(\sum_{i=1}^{k} n_i\right) - k$$

thus f is the total sample size minus the number of wells (groups); and

$$S_p^2 = \frac{1}{f} \sum_{i=1}^{k} f_i S_i^2 \text{, is the pooled variance across wells.}$$

Step 3. Using the chi-squared table (Table 1, Appendix B), find the critical value for X^2 with (k-1) degrees of freedom at a predetermined significance level, for example, 5%.

INTERPRETATION

If the calculated value X^2 is larger than the tabulated value, then conclude that the variances are not equal at that significance level.

REFERENCE

Johnson N. L., and F. C. Leone. *Statistics and Experimental Design in Engineering and the Physical Sciences*. Vol. I, John Wiley and Sons, New York, 1977.

EXAMPLE

Manganese concentrations are given for k=6 wells in Table 4-5 below.

TABLE 4-5. EXAMPLE DATA FOR BARTLETT'S TEST

Sampling date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
January 1	50	46	272	34	48	68
February 1	73	77	171	3,940	54	991
March 1	244		32			54
April 1	202		53			
n_i =	4	2	4	2	2	3
$f_i = n_i - 1$ =	3	1	3	1	1	2
S_i =	95	22	112	2,762	3	537
S_i^2 =	9,076	481	12,454	7,628,418	8	288,349
$f_i * S_i^2$ =	27,229	481	37,362	7,628,418	8	576,698
$\ln(S_i^2)$ =	9	6	9	16	2	13
$f_i * \ln(S_i^2)$ =	27	6	28	16	2	25

Step 1. • Compute the six sample variances and take their natural logarithm, $\ln(S_1^2)), \ldots, \ln(S_6^2)$, as 9, 6,..., 13, respectively.

Step 2. • Compute $\sum_{i=1}^{6} f_i \ln(S_i^2) = 105$,

This is the sum of the last line in Table 4-5.

- Compute $f = \sum_{i=1}^{6} f_i = 3 + 1 + \ldots + 2 = 11$

- Compute S_p^2

$$S_p^2 = \frac{1}{11} \sum_{i=1}^{6} f_i S_i^2 = \frac{1}{11} (27{,}299 + \ldots + 576{,}698) = \frac{1}{11} (8{,}270{,}195) = 751{,}836$$

- Take the natural logarithm of S_p^2: $\ln(S_p^2) = 14$

- Compute $X^2 = 11(14) - 105 = 44$

Step 3. The critical X^2 value with 6-1 = 5 degrees of freedom at the 5% significance level is 11.1 (Table 1 in Appendix B). Since 44 is larger than 11.1, we conclude that the six variances $S_1^2, \ldots, S_6^2$, are not homogeneous at the 5% significance level.

INTERPRETATION

The sample variances of the data from the six wells were compared by means of Bartlett's test. The test was significant at the 5% level, suggesting that the variances are significantly unequal (heterogeneous). A log-transform of the data can be done and the same test performed on the transformed data. Generally, if the data followed skewed distribution, this approach resolves the problem of unequal variances and the user can proceed with an ANOVA for example.

On the other hand, unequal variances among well data could be a direct indication of well contamination, since the individual data could come from different distributions (i.e., different means and variances). Then the user may wish to test which variance differs from which one. The reader is referred here to the literature for a gap test of variance (Tukey, 1949; David, 1956; or Nelson, 1987).

NOTE

- In the case of k=2 variances, the test of equality of variances is the F-test (Snedecor and Cochran, 1980).

- Bartlett's test simplifies in the <u>case of equal sample sizes</u>, $n_i=n$, $i=1,\ldots,k$. The test used then is Cochran's test. Cochran's test focuses on the largest variance and compares it to the sum of all the variances. Hartley introduced a quick test of homogeneity of variances that uses the ratio of the largest over the smallest variances. Technical aids for the procedures under the assumption of equal sample sizes are given by L. S. Nelson in the *Journal of Quality Technology*, Vol. 19, 1987, pp. 107 and 165.

ATTACHMENT 4

NON PARAMETRIC ANOVA (KRUSKAL-WALLIS EXAMPLE)

- From Table 3, Appendix B, obtain the critical t with (24 - 6) = 18 degrees of freedom, $m = 4$, and for $\alpha = 0.05$. The approximate value is 2.43 obtained by linear interpolation between 15 and 20 degrees of freedom.

- Compute the quantities D_i. Again, due to equal sample sizes, they will all be equal.

$$D_i = SE_i \times t = 0.357 \times 2.43 = \underline{0.868} \text{ for } i = 3, \ldots, 6$$

INTERPRETATION

The F test was significant at the 5% level. The Bonferroni multiple comparisons procedure was then used to determine for which wells there was statistically significant evidence of contamination. Of the four differences $\bar{X}_{i.} - \bar{X}_{up}$, only $\bar{X}_{6.} - \bar{X}_{up} = \underline{1.36}$ exceeds the critical value of 0.868. From this it is concluded that there is significant evidence of contamination at Well 6. Well 5 is right on the boundary of significance. It is likely that Well 6 has intercepted a plume of contamination with Well 5 being on the edge of the plume.

All the compliance well concentrations were somewhat above the mean concentration of the background levels. The well means should be used to indicate the location of the plume. The findings should be reported to the Regional Administrator.

5.2.2 One-Way Nonparametric Analysis of Variance

This procedure is appropriate for interwell comparisons when the data or the residuals from a parametric ANOVA have been found to be significantly different from normal and when a log transformation fails to adequately normalize the data. In one-way nonparametric ANOVA, the assumption under the null hypothesis is that the data from each well come from the same continuous distribution and hence have the same median concentrations of a specific hazardous constituent. The alternatives of interest are that the data from some wells show increased levels of the hazardous constituent in question.

The procedure is called the Kruskal-Wallis test. For meaningful results, there should be at least three groups with a minimum sample size of three in each group. For large data sets use of a computer program is recommended. In the case of large data sets a good approximation to the procedure is to replace each observation by its rank (its numerical place when the data are ordered from least to greatest) and perform the (parametric) one-way analysis of variance (Section 5.2.1) on the ranks. Such an approach can be done with some commercially statistical packages such as SAS.

PURPOSE

The purpose of the procedure is to test the hypothesis that all wells (or groups of wells) around regulated units have the same median concentration of a hazardous constituent. If the wells are found to differ, *post-hoc* comparisons are again necessary to determine if contamination is present.

Note that the wells define the groups. All wells will have at least four observations. Denote the number of groups by K and the number of observations in each group by n_i, with N being the total number of all observations. Let X_{ij} denote the jth observation in the ith group, where j runs from 1 to the number of observations in the group, n_i, and i runs from 1 to the number of groups, K.

PROCEDURE

Step 1. Rank all N observations of the groups from least to greatest. Let R_{ij} denote the rank of the jth observation in the ith group. As a convention, denote the background well(s) as group 1.

Step 2. Add the ranks of the observations in each group. Call the sum of the ranks for the ith group R_i. Also calculate the average rank for each group, $\bar{R}_i = R_i/n_i$.

Step 3. Compute the Kruskal-Wallis statistic:

$$H = \left[\frac{12}{N(N+1)} \sum_{i=1}^{K} \frac{R_i^2}{N_i} \right] - 3(N+1)$$

Step 4. Compare the calculated value H to the tabulated chi-squared value with (K-1) degrees of freedom, where K is the number of groups (Table 1, Appendix B). Reject the null hypothesis if the computed value exceeds the tabulated critical value.

Step 5. If the computed value exceeds the value from the chi-squared table, compute the critical difference for well comparisons to the background, assumed to be group 1:

$$C_i = Z_{(\alpha/(K-1))} \left[\frac{N(N+1)}{12} \right]^{1/2} \left[\frac{1}{n_1} + \frac{1}{n_i} \right],$$

for i taking values 2,..., K,

where $Z_{(\alpha/(K-1))}$ is the upper $(\alpha/(K-1))$-percentile from the standard normal distribution found in Table 4, Appendix B. Note: If there are more than five compliance wells at the regulated unit (K > 6), use $Z_{.01}$, the upper one-percentile from the standard normal distribution.

Step 6. Form the differences of the average ranks for each group to the background and compare these with the critical values found in step 5 to determine which wells give evidence of contamination. That is, compare $\bar{R}_i - \bar{R}_1$ to C_i for i taking the values 2 through K. (Recall that group 1 is the background.)

While the above steps are the general procedure, some details need to be specified further to handle special cases. First, it may happen that two or more observations are numerically equal or tied. When this occurs, determine the ranks that the tied observations would have received if they had been slightly different from each other, but still in the same places with respect to the rest of the observations. Add these ranks and divide by the number of observations tied at that value to get an average rank. This average rank is used for each of the tied observations. This same procedure is repeated for any other groups of tied observations. Second, if there are any values below detection, consider all values below detection as tied at zero. (It is irrelevant what number is assigned to nondetected values as long as all such values are assigned the same number, and it is smaller than any detected or quantified value.)

The effect of tied observations is to increase the value of the statistic, H. Unless there are many observations tied at the same value, the effect of ties on the computed test statistic is negligible (in practice, the effect of ties can probably be neglected unless some group contains 10 percent of the observations all tied, which is most likely to occur for concentrations below detection limit). In the present context, the term "negligible" can be more specifically defined as follows. Compute the Kruskal-Wallis statistic without the adjustment for ties. If the test statistic is significant at the 5% level then conclude the test since the statistic with correction for ties will be significant as well. If the test statistic falls between the 10% and the 5% critical values, then proceed with the adjustment for ties as shown below.

ADJUSTMENT FOR TIES

If there are 50% or more observations that fell below the detection limit, then this method for adjustment for ties is inappropriate. The user is referred to Section 8 "Miscellaneous Topics." Otherwise, if there are tied values present in the data, use the following correction for the H statistic

$$H' = \frac{H}{1 - \left(\sum_{i=1}^{g} T_i/(N^3-N) \right)}$$

where g = the number of groups of distinct tied observations and $T_i = (t_i^3 - t_i)$, where t_i is the number of observations in the tied group i. Note that unique observations can be considered groups of size 1, with the corresponding $T_i = (1^3-1) = 0$.

REFERENCE

Hollander, Myles, and D. A. Wolfe. 1973. *Nonparametric Statistical Methods*. John Wiley and Sons, New York.

EXAMPLE

The data in Table 5-4 represent benzene concentrations in water samples taken at one background and five compliance wells.

Step 1. The 20 observations have been ranked from least to greatest. The limit of detection was 1.0 ppm. Note that two values in Well 4 were below detection and were assigned value zero. These two are tied for the smallest value and have consequently been assigned the average of the two ranks 1 and 2, or 1.5. The ranks of the observations are indicated in parentheses after the observation in Table 5-4. Note that there are 3 observations tied at 1.3 that would have had ranks 4, 5, and 6 if they had been slightly different. These three have been assigned the average rank of 5 resulting from averaging 4, 5, and 6. Other ties occurred at 1.5 (ranks 7 and 8) and 1.9 (ranks 11 and 12).

Step 2. The values of the sums of ranks and average ranks are indicated at the bottom of Table 5-4.

Step 3. Compute the Kruskal-Wallis statistic

$$H = \frac{12}{20(20-1)} (34^2/4 + \ldots + 35.5^2/3) - 3(20+1) = \underline{14.68}$$

ADJUSTMENT FOR TIES

There are four groups of ties in the data of Table 5-4:

$T_1 = (2^3-2) = 6$ for the 2 observations of 1,900.
$T_2 = (2^3-2) = 6$ for the 2 observations of 1,500.
$T_3 = (3^3-3) = 24$ for the 3 observations of 1,300.
$T_4 = (2^3-2) = 6$ for the 2 observations of 0.

Thus $\sum_{i=1}^{4} T_i = 6+6+24+6 = 42$

and $H' = \frac{14.68}{1-(42/(20^3-20))} = \frac{14.68}{0.995} = 14.76$, a negligible change from 14.68.

Step 4. To test the null hypothesis of no contamination, obtain the critical chi-squared value with (6-1) = 5 degrees of freedom at the 5% significance level from Table 1, Appendix B. The value is 11.07. Compare the calculated value, H', with the tabulated value. Since 14.76 is greater than 11.07, reject the hypothesis of no contamination at the 5% level. If the site was in detection monitoring it should move into compliance monitoring. If the

TABLE 5-4. EXAMPLE DATA FOR ONE-WAY NONPARAMETRIC ANOVA--BENZENE CONCENTRATIONS (ppm)

Date	Background Well 1	Compliance wells Well 2	Well 3	Well 4	Well 5	Well 6
Jan 1	1.7 (10)	11.0 (20)	1.3 (5)	0 (1.5)	4.9 (17)	1.6 (9)
Feb 1	1.9 (11.5)	8.0 (18)	1.2 (3)	1.3 (5)	3.7 (16)	2.5 (15)
Mar 1	1.5 (7.5)	9.5 (19)	1.5 (7.5)	0 (1.5)	2.3 (14)	1.9 (11.5)
Apr 1	1.3 (5)			2.2 (13)		
	$n_1 = 4$	$n_2 = 3$	$n_3 - 3$	$n_4 = 4$	$n_5 = 3$	$n_6 = 3$
Sum of ranks:	$R_1 = 34$	$R_2 = 57$	$R_3 = 15.5$	$R_4 = 21$	$R_5 = 47$	$R_6 = 35.5$
Average rank:	$\bar{R}_1 = 8.5$	$\bar{R}_2 = 19$	$\bar{R}_3 = 5.17$	$\bar{R}_4 = 5.25$	$\bar{R}_5 = 15.67$	$\bar{R}_6 = 11.83$

K = 6, the number of wells

$N = \sum_{i=1}^{6} n_i = 20$, the total number of observations.

site was in compliance monitoring it should move into corrective action. If the site was in corrective action it should stay there.

In the case where the hydraulically upgradient wells serve as the background against which the compliance wells are to be compared, comparisons of each compliance well with the background wells should be performed in addition to the analysis of variance procedure. In this example, data from each of the compliance wells would be compared with the background well data. This comparison is accomplished as follows. The average ranks for each group, $\bar{R}_{i.}$ are used to compute differences. If a group of compliance wells for a regulated unit have larger concentrations than those found in the background wells, the average rank for the compliance wells at that unit will be larger than the average rank for the background wells.

Step 5. Calculate the critical values to compare each compliance well to the background well.

In this example, K=6, so there are 5 comparisons of the compliance wells with the background wells. Using an experimentwise significance level of α = 0.05, we find the upper 0.05/5 = 0.01 percentile of the standard normal distribution to be 2.33 (Table 4, Appendix B). The total sample size, N, is 20. The approximate critical value, C_2, is computed for compliance Well 2, which has the largest average rank, as:

$$C_2 = 2.32 \left[\frac{20(21)}{12}\right]^{1/2} \left[\frac{1}{4} + \frac{1}{3}\right]^{1/2} = 10.5$$

The critical values for the other wells are: 10.5 for Wells 3, 5, and 6: and 9.8 for Well 4.

Step 6. Compute the differences between the average rank of each compliance well and the average rank of the background well:

Differences	Critical values
D_2 = 19.0 - 8.5 = 10.5	C_2 = 10.5
D_3 = 5.17 - 8.5 = -3.33	C_3 = 10.5
D_4 = 5.25 - 8.5 = -3.25	C_4 = 9.8
D_5 = 15.67 - 8.5 = 7.17	C_5 = 10.5
D_6 = 11.83 - 8.5 = 3.13	C_6 = 10.5

Compare each difference with the corresponding critical difference. D_2 = 10.5 equals the critical value of C_2 = 10.5. We conclude that the concentration of benzene averaged over compliance Well 2 is significantly greater than that at the background well. None of the other compliance well concentration of benzene is significantly higher than the average background value. Based upon these results, only compliance Well 2 can be singled out as being contaminated.

ATTACHMENT 5

TEST OF PROPORTIONS EXAMPLE

It should be noted that the nonparametric methods presented earlier automatically deal with values below detection by regarding them as all tied at a level below any quantitated results. The nonparametric methods may be used if there is a moderate amount of data below detection. If the proportion of nonquantified values in the data exceeds 25%, these methods should be used with caution. They should probably not be used if less than half of the data consists of quantified concentrations.

8.1.1 The DL/2 Method

The amount of data that are below detection plays an important role in selecting the method to deal with the limit of detection problem. If a small proportion of the observations are not detected, these may be replaced with a small number, usually the method detection limit divided by 2 (MDL/2), and the usual analysis performed. This is the recommended method for use with the analysis of various procedure of Section 5.2.1. Seek professional help if in doubt about dealing with values below detection limit. The results of the analysis are generally not sensitive to the specific choice of the replacement number.

As a guideline, if 15% or fewer of the values are not detected, replace them with the method detection limit divided by two and proceed with the appropriate analysis using these modified values. Practical quantitation limits (PQL) for Appendix IX compounds were published by EPA in the Federal Register (Vol 52, No 131, July 9, 1987, pp 25947-25952). These give practical quantitation limits by compound and analytical method that may be used in replacing a small amount of nondetected data with the quantitation limit divided by 2. If approved by the Regional Administrator, site specific PQL's may be used in this procedure. If more than 15% of the values are reported as not detected, it is preferable to use a nonparametric method or a test of proportions.

8.1.2. Test of Proportions

If more than 50% of the data are below detection but at least 10% of the observations are quantified, a test of proportions may be used to compare the background well data with the compliance well data. Clearly, if none of the background well observations were above the detection limit, but all of the compliance well observations were above the detection limit, one would suspect contamination. In general the difference may not be as obvious. However, a higher proportion of quantitated values in compliance wells could provide evidence of contamination. The test of proportions is a method to determine whether a difference in proportion of detected values in the background well observations and compliance well observations provides statistically significant evidence of contamination.

The test of proportions should be used when the proportion of quantified values is small to moderate (i.e., between 10% and 50%). If very few quantified values are found, a method based on the Poisson distribution may be used as an alternative approach. A method based on a tolerance limit for the number of detected compounds and the maximum concentration found for any detected compound has been proposed by Gibbons (1988). This alternative would

be appropriate when the number of detected compounds is quite small relative to the number of compounds analyzed for as might occur in detection monitoring.

PURPOSE

The test of proportions determines whether the proportion of compounds detected in the compliance well data differs significantly from the proportion of compounds detected in the background well data. If there is a significant difference, this is statistically significant evidence of contamination.

PROCEDURE

The procedure uses the normal distribution approximation to the binomial distribution. This assumes that the sample size is reasonably large. Generally, if the proportion of detected values is denoted by P, and the sample size is n, then the normal approximation is adequate, provided that nP and n(1-P) both are greater than or equal to 5.

Step 1. Determine X, the number of background well samples in which the compound was detected. Let n be the total number of background well samples analyzed. Compute the proportion of detects:

$$\hat{P}_u = x/n$$

Step 2. Determine Y, the number of compliance well samples in which the compound was detected. Let M be the total number of compliance well samples analyzed. Compute the proportion of detects:

$$\hat{P}_d = y/m$$

Step 3. Compute the standard error of the difference in proportions:

$$S_D = \{[(x+y)/(n+m)]\cdot[1 - (x+y)/(n+m)]\cdot[1/n + 1/m]\}^{1/2}$$

and form the statistic:

$$Z = (\hat{P}_u - \hat{P}_d)/S_D$$

Step 4. Compare the absolute value of Z to the 97.5th percentile from the standard normal distribution, 1.96. If the absolute value of Z exceeds 1.96, this provides statistically significant evidence at the 5% significance level that the proportion of compliance well samples where the compound was detected exceeds the proportion of background well samples where the compound was detected. This would be interpreted as evidence of contamination. (The two-sided test is used to provide information about differences in either direction.)

EXAMPLE

Table 8-2 contains data on cadmium concentrations measured in background well and compliance wells at a facility. In the table, "BDL" is used for below detection limit.

TABLE 8-2. EXAMPLE DATA FOR A TEST OF PROPORTIONS

Cadmium concentration (μg/L) at background well (24 samples)		Cadmium concentration (μg/L) at compliance wells (64 samples)		
0.1	BDL	0.12	BDL	0.024
0.12	BDL	0.08	BDL	BDL
BDL*	BDL	BDL	BDL	BDL
0.26	BDL	0.2	0.11	BDL
BDL		BDL	0.06	BDL
0.1		0.1	BDL	BDL
BDL		BDL	0.23	0.1
0.014		0.012	BDL	0.04
BDL		BDL	0.11	BDL
BDL		BDL	BDL	BDL
BDL		BDL	0.031	0.1
BDL		BDL	BDL	BDL
BDL		BDL	BDL	0.01
0.12		0.12	BDL	BDL
BDL		0.07	BDL	BDL
0.21		BDL	BDL	BDL
BDL		0.19	0.12	BDL
0.12		BDL	0.08	BDL
BDL		0.1	BDL	
BDL		BDL	0.26	
		0.01	BDL	
		BDL	0.02	
		BDL	BDL	

*BDL means below detection limit.

Step 1. Estimate the proportion above detection in the background wells. As shown in Table 8-2, there were 24 samples from background wells analyzed for cadmium, so n= 24. Of these, 16 were below detection and x = 8 were above detection, so $P_u = 8/24 = 0.333$.

Step 2. Estimate the proportion above detection in the compliance wells. There were 64 samples from compliance wells analyzed for cadmium, with 40 below detection and 24 detected values. This gives m = 64, y = 24, so $P_d = 24/64 = 0.375$.

Step 3. Calculate the standard error of the difference in proportions.

$$S_D = \{[(8+24)/(24+64)][1-(8+24)/(24+64)](1/24 + 1/64)\}^{1/2} = 0.115$$

Step 4. Form the statistic Z and compare it to the normal distribution.

$$Z = \frac{0.375 - 0.333}{0.115} = 0.37$$

which is less in absolute value than the value from the normal distribution, 1.96. Consequently, there is no statistically significant evidence that the proportion of samples with cadmium levels above the detection limit differs in the background well and compliance well samples.

INTERPRETATION

Since the proportion of water samples with detected amounts of cadmium in the compliance wells was not significantly different from that in the background wells, the data are interpreted to provide no evidence of contamination. Had the proportion of samples with detectable levels of cadmium in the compliance wells been significantly higher than that in the background wells this would have been evidence of contamination. Had the proportion been significantly higher in the background wells, additional study would have been required. This could indicate that contamination was migrating from an off-site source, or it could mean that the hydraulic gradient had been incorrectly estimated or had changed and that contamination was occurring from the facility, but the ground-water flow was not in the direction originally estimated. Mounding of contaminants in the ground water near the background wells could also be a possible explanation of this observance.

8.1.3 Cohen's Method

If a confidence interval or a tolerance interval based upon the normal distribution is being constructed, a technique presented by Cohen (1959) specifies a method to adjust the sample mean and sample standard deviation to account for data below the detection limit. The only requirements for the use of this technique is that the data are normally distributed and that the detection limit be always the same. This technique is demonstrated below.

ATTACHMENT 6

DETAILED DISCUSSIONS AND ADDITIONAL EXAMPLES

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1. ANALYSIS OF VARIANCE (ANOVA)

In a previous section, we discussed tests for comparing the means of two independent samples. ANOVA is a set of statistical tests that can be employed when one is interested to detect differences among the means from several (more than two) samples.

1.1 One Way Parametric ANOVA

Let $X_{i1}, X_{i2}, \ldots, X_{in_i}$ be a random sample of size n_i from a normal distribution $N(\mu_i, \sigma^2)$, $i = 1,2,\ldots,m$. We wish to test the hypothesis that all means are equal; namely, H_0: $\mu_1 = \mu_2 = \ldots = \mu_m = \mu$, where μ is unknown, against all possible alternative hypotheses H_1.

				Means
X_{11}	X_{12}	...	X_{1n_1}	$\bar{X}_1$
X_{21}	X_{22}	...	X_{2n_2}	$\bar{X}_2$
.	.		.	.
.	.		.	.
X_{m1}	X_{m2}	...	X_{mn_m}	$\bar{X}_m$
Grand Mean:				$\bar{X}$

The sample and grand means above are estimated by

$$\overline{X} = \frac{1}{n}\sum_{i-1}^{m}\sum_{j-1}^{n_i} X_{ij} \quad and \quad \overline{X}_i = \frac{1}{n_i}\sum_{j-1}^{n_i} X_{ij}, \quad i=1,2,\ldots,m.$$

where $n = n_1 + n_2 + \ldots + n_m$.

Define the following sum of squares:

$$SS(TOT) = \sum_{i=1}^{m} \sum_{j=1}^{n_i} (X_{ij} - \overline{X})^2 \quad : \quad \textit{total sum of squares;}$$

$$SS(E) = \sum_{i=1}^{m} \sum_{j=1}^{n_i} (X_{ij} - \overline{X}_i)^2 \quad : \quad \textit{sum of squares within samples;}$$

$$SS(S) = \sum_{i=1}^{m} n_i(\overline{X}_i - \overline{X})^2 \quad : \quad \textit{sum of squares between samples.}$$

It can be shown that $SS(TOT) = SS(E) + SS(S)$ and, therefore,

$SS(TOT)/\sigma^2 = SS(E)/\sigma^2 + SS(S)/\sigma^2$.

However, under hypothesis H_0, $SS(TOT)/(n-1)$ is an unbiased estimator of σ^2, and $SS(TOT)/\sigma^2$ is a $\chi^2(n-1)$ variable.

Also, independently of H_0, unbiased estimators of σ^2 can be estimated from each sample by

$$S_i = \frac{\sum_{j=1}^{n_i} (X_{ij} - \overline{X}_i)^2}{n_i - 1}, \quad i=1,2,\ldots,m.$$

Since, $(n_i-1)S_i/\sigma^2$ is $\chi^2(n_i-1)$, it follows that

$$\sum_{i=1}^{m} \frac{(n_i - 1)S_i}{\sigma^2} = \frac{SS(E)}{\sigma^2}$$

is also a chi-square variable with $(n_1-1)+(n_2-1)+\ldots+(n_m-1) = n-m$ degrees of freedom.

Finally, based on the fact that SS(E) and SS(S) are independent and

$$\underset{\chi^2(n-1)}{SS(TOT)/\sigma^2} = \underset{\chi^2(n-m)}{SS(E)/\sigma^2} + SS(S)/\sigma^2 ,$$

it can be shown that $SS(S)/\sigma^2$ is a $\chi^2(m-1)$ variable and thus, if hypothesis H_0 is true, SS(S)/(m-1) is another unbiased estimator of σ^2.

If, on the other hand, H_0 is false and the means $\mu_1, \mu_2, \ldots, \mu_m$ are generally different, SS(S)/(m-1) usually overestimates σ^2 as indicated by the following fact

$$E[\frac{SS(S)}{m-1}] = \sigma^2 + \sum_{i=1}^{m} n_i \frac{(\mu_i - \bar{\mu})^2}{m-1},$$

$$\bar{\mu} = (1/n)\sum_{i=1}^{m} n_i \mu_i .$$

In summary, a suitable statistic for testing the validity of hypothesis H_0 is the ratio

$$\frac{SS(S)/(m-1)}{SS(E)/(n-m)} = \frac{[SS(S)/\sigma^2]/(m-1)}{[SS(E)/\sigma^2]/(n-m)} = F$$

which follows an F distribution with (m-1) and (n-m) degrees of freedom.

One would generally reject H_0 if the observed value of F is significantly larger than 1, indicating that SS(S)/(m-1) overestimates σ^2 as a result of unequal means.

Step-by-Step Procedure (One Way Parametric ANOVA)

1. Compute SS(TOT), SS(S), and SS(E) by the following formulas:

$$SS(TOT) = \sum_{i=1}^{m} \sum_{j=1}^{n_i} X_{ij}^2 - \frac{1}{n}\left[\sum_{i=1}^{m} \sum_{j=1}^{n_i} X_{ij}\right]^2,$$

$$SS(S) = \sum_{i=1}^{m} \frac{1}{n_i}\left[\sum_{j=1}^{n_i} X_{ij}\right]^2 - \frac{1}{n}\left[\sum_{i=1}^{m} \sum_{j=1}^{n_i} X_{ij}\right]^2,$$

$$SS(E) = SS(TOT) - SS(S).$$

where m is the number of samples, and $n = n_1+n_2+...+n_m$ with n_i, $i=1,2,...,m$, being the number of data in each sample.

2. Calculate the F statistic:

$$F = \frac{SS(S)/(m-1)}{SS(E)/(n-m)}$$

The results of the ANOVA are usually summarized in a table as follows:

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F
Between Samples	SS(S)	m-1	MS(S)= SS(S)/(m-1)	MS(S)/MS(E)
Within Samples	SS(E)	n-m	MS(E)= SS(E)/(n-m)	
Total	SS(TOT)	n-1		

3. Compare this statistic to the tabulated F statistic with (m-1) and (n-m) degrees of freedom at a specified significance level (usually 5%). If the calculated F statistic exceeds the tabulated value, reject the hypothesis of equal means. Otherwise, conclude that there is no significant difference between the sample means.

Example: Four lead concentration values at each of six wells are given in the following table. The wells consist of two background and four compliance wells. (The values in the table are actually the natural logarithms of the original lead concentrations.)

Well	Type	Jan 1	Feb 1	Mar 1	Apr 1	Totals	Means
1	b	4.06	3.99	3.40	3.83	15.28	3.82
2	b	3.83	4.34	3.47	4.22	15.86	3.96
3	c	5.61	5.14	3.47	3.97	18.18	4.55
4	c	3.53	4.54	4.26	4.42	16.75	4.19
5	c	3.91	4.29	5.50	5.31	19.01	4.75
6	c	5.42	5.21	5.29	5.08	21.01	5.25
						106.08	**4.42**

1. Computation of SS(TOT), SS(S), and SS(E):

   $SS(TOT) = 4.06^2 + 3.99^2 + \ldots + 5.08^2 - (1/24)\ 106.08^2 = 11.94$
   degrees of freedom = 24 -1 = 23

   $SS(S) = 1/4\ (15.28^2 + \ldots + 21.01^2) - (1/24)\ 106.08^2 = 5.76$
   degrees of freedom = 6-1 = 5

   $SS(E) = 11.94 - 5.76 = 6.18$
   degrees of freedom = 24 - 6 = 18

2. F statistic: $F = (5.76/5)/(6.18/18) = 3.38$

   Summary table:

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F
Between Samples	5.76	5	5.76/5= 1.15	1.15/0.34= 3.38
Within Samples	6.18	18	6.18/18= 0.34	
Total	11.94	23		

3. The tabulated F value with 5 and 18 degrees of freedom and confidence coefficient $\alpha = 5\%$ is 2.77. Since 3.38 > 2.77, the hypothesis of equal well concentration means must be rejected.

1.2 A Multiple Comparison Test

If the null hypothesis is rejected in the ANOVA analysis, one may wish to perform a follow-up study to determine which sample exhibits significant difference from the mean of the other samples (or a certain group of samples). For example, in the previous example the investigator may wish to determine which compliance well is contaminated. This can be accomplished via a Bonferroni *t*-test for each compliance well against the backgournd wells. This procedure is briefly discussed next.

1. Determine the sample size of all background wells b:

$$n_b - \sum_{i-b} n_i$$

2. Compute the average concentration of the background wells:

$$\overline{X_b} = \frac{1}{n_b} \sum_{i-b} n_i \overline{X_i}$$

3. Compute the difference between the average concentration of the compliance well and the average background wells.

$$d_c - \overline{X_c} - \overline{X_b}$$

4. Compute the standard error of each difference by

$$SE_c = \left[MS(E) \left(\frac{1}{n_b} + \frac{1}{n_c} \right) \right]^{1/2}$$

where MS(E) is obtained from the ANOVA table, and n_c is the number of observations at well c.

5. Obtain the *t*-statistic, $t_{(n-m),(1-\alpha/m_c)}$, from Bonferroni's *t*-table for a given significance level (usually α = 5%) and (n-m) degrees of freedom. m_c represents the number of compliance wells or, equivalently, the number of comparisons to be performed. If α = 5% and $m_c > 5$, use $t_{(n-m),(1-0.01)}$.

6. Compute $D_c = SE_c\, t$. If $d_c > D_c$, the conclusion is that compliance well c has significantly higher concentrations than the average background wells.

Otherwise, this well is not contaminated.

This test should be performed for each compliance well c.

The previous multiple comparison test is based on the following theorem:
Theorem: Let $Y_1, ..., Y_m$ be normally distributed random variables with means $\mu_1, ..., \mu_m$ and variances $\sigma_1^2, ..., \sigma_m^2$ respectively. The Y_i's may or may not be independent. Let $s_1^2, ..., s_m^2$ be χ^2 estimators of $\sigma_1^2, ..., \sigma_m^2$ on $\nu_1, ..., \nu_m$ degrees of freedom, respectively; that is, $\nu_i s_i^2/\sigma_i^2 \sim \chi^2_{\nu_i}$, $i=1, ..., m$. The s_i^2's may or may not be independent. However, it is assumed that Y_i is independent of s_i^2, $i=1, ..., m$, so that $T_i = (Y_i - \mu_i)/s_i$, $i=1, ..., m$, has a t distribution with ν_i degrees of freedom. Let $t_{\nu_i,\alpha/2m}$, $i=1, ..., m$, be the upper $\alpha/2m$ percentile points (or two-tailed α/m percentile points) of the t distribution with ν_i, $i=1, ..., m$ degrees of freedom, respectively. Then, with probability greater than or equal to $(1-\alpha)$, simultaneously,

$$\mu_i \in \overline{Y_i} \pm t_{\nu_i,\alpha/2m} s_i \ , \ i=1,...,m.$$

For each component interval above, the significance level was set at α/m. If some of the intervals should be more sensitive or conservative than others, equal significance levels may be replaced by unequal ones. Any combination $\alpha_1, ..., \alpha_m$ for which $\alpha_1 + \cdots + \alpha_m = \alpha$ will produce the same bound α for the simultaneous probability error rate.

The multiple ANOVA comparison test presented in this section results from the above theorem under the null hypothesis H_0 and the following specifications and facts:

$$Y_i - \overline{X_i} - \overline{X_b}, \quad i=1,...,m_c;$$

$$\overline{X_i} \sim N\left(\mu, \frac{\sigma^2}{n_i}\right) \ , \quad \overline{X_b} \sim N\left(\mu, \frac{\sigma^2}{n_b}\right);$$

$$\overline{X_i} - \overline{X_b} \sim N\left(0, \sigma^2\left(\frac{1}{n_i} + \frac{1}{n_b}\right)\right);$$

σ^2 is estimated by MS(E) with $(n-m)$ degrees of freedom;
$\overline{X_i} - \overline{X_b}$ is independent of MS(E), $i=1,...,m_c$;
the procedure is applied as one-tailed test.

Example: Test compliance well contamination in the example of the previous section.

1. Sample size of all background wells b:

$$n_b = 4 + 4 = 8$$

2. Average concentration of background wells:

$$\overline{X_b} = \frac{1}{8}[4x3.82 + 4x3.96] = 3.89$$

3. Differences between the average concentration of each compliance well and the background wells.

$$d_3 = \overline{X_3} - \overline{X_b} = 4.55 - 3.89 = 0.66$$
$$d_4 = 4.19 - 3.89 = 0.3$$
$$d_5 = 4.75 - 3.89 = 0.86$$
$$d_6 = 5.25 - 3.89 = 1.36$$

4. Compute the standard error of each difference by

$$SE_3 = \left[MS(E)\left(\frac{1}{n_b} + \frac{1}{n_3}\right)\right]^{1/2} = \left[0.34x\left(\frac{1}{8} + \frac{1}{4}\right)\right]^{\frac{1}{2}} = 0.357 = SE_4 = SE_5 = SE_6$$

5. Obtain the t-statistic, $t_{(n-m),(1-\alpha/m_c)}$ from Bonferroni's t-table for a significance level of α = 5% and (n-m) = (24 - 6) = 18 degrees of freedom. The value of t obtained through linear interpolation is 2.43.

6. Compute $D_3 = SE_3\, t = 0.357 \times 2.43 = 0.868 = D_4 = D_5 = D_6$, and compare with the values for d_3, d_4, d_5, d_6 obtained previously. From this comparison, it is seen that only well 6 exhibits statistically significant contamination (1.36 > 0.868). However, well 5 is also at the boundary of significance, indicating the possible existence of a contamination plume beginning to affect the compliance surface.

1.3 Remarks on the One Way Parametric ANOVA

As a minimum, at least $m \geq 2$ samples should be available for the ANOVA test. It is recommended that each sample has at least three observations and that the total sample size, n, satisfies $n-m \geq 5$.

The assumptions of normal populations and equal variance are not critical, provided that the data distribution is not highly skewed and the number of observations n_i are equal for each sample i. The normality assumption can be tested by the χ^2 or the K-S tests. If the data exhibit skewness, one could possibly normalize them via a logarithmic transformation and proceed with the analysis. Variance homogeneity may be tested via Bartlett's test.

1.4 One Way Nonparametric Analysis of Variance (ANOVA)

When the data cannot be normalized or exhibit significant variance non-homogeneity, the comparison of means of several samples may be preformed according to the nonparametric ANOVA, also known as the Kruskal-Wallis test. The null hypothesis H_0 is that the data samples come from the same distributions. The alternative hypothesis is that some of the samples come from different distributions.

As before, let n_i denote the observations in sample i; m the number of samples; n the total number of all observations; and X_{ij} the jth observation in sample i. The Kruskal-Wallis procedure is based on the fact that under H_0, the average rank in each sample is a random variable with mean $(n+1)/2$ and variance $(n-n_i)(n+1)/(12\ n_i)$. The test is designed to examine the significance of the observed deviations from the theoretical values and is performed as follows:

Step-by-Step Procedure (One Way Non-Parametric ANOVA / Kruskal-Wallis)

1. Rank all n observations of the groups from the one with the least value (rank = 1) to the one with the highest value (rank=n). Let R_{ij} denote the rank of the jth observation in the ith sample. If two or more observations are numerically equal (tied), determine the ranks that the tied observations would have if they had been slightly different from one another, but still in the same places with respect to the rest of the observations. Add these ranks and divide by the number of observations tied at that value to get an average rank. Assign this average rank to each of the tied observations.

2. Add the ranks of the observations in each sample and denote the sum R_i. Also calculate the average rank for each group, $\bar{R}_i = R_i/n_i$.

3. Compute the Kruskal-Wallis statistic:

$$H = \left[\frac{12}{n(n+1)} \sum_{i-1}^{m} \frac{R_i^2}{n_i} \right] - 3(n+1)$$

The effect of tied observations is to increase the value of the statistic H. If

there are 50% or less tied observations, adjust the H statistic as follows:

$$H' - \frac{H}{1 - \left(\sum_{i-1}^{K} \frac{T_i}{(n^3 - n)} \right)}$$

where K is the number of tied observation groups, $T_i = (t_i^3 - t_i)$, and t_i is the number of observations in the tied group i. If the percentage of ties exceeds 50% of the observations, one should use other statistical tests such as the test of proportions.

4. Compare the value of H or H′ to the tabulated $\chi^2(m-1)$ statistic for a certain significance level α. Reject the null hypothesis H_0 if the computed value exceeds the tabulated critical value.

If the nulll hypothesis is rejected, the individual samples can be compared with a base sample by performing the following test:

5. Compute the critical average rank difference for each sample i to the base sample as follows:

$$D_i = Z_{\alpha/m_c} \left[\frac{n(n+1)}{12} \right]^{\frac{1}{2}} \left[\frac{1}{n_b} + \frac{1}{n_i} \right]^{\frac{1}{2}},$$

where Z_{α/m_c} is the upper (α/m_c)-percentile of the standard normal distribution, where m_c represents the number of comparisons to be performed.

6. Determine the differences $d_i = \bar{R}_i - \bar{R}_b$ of the average ranks of each sample to the background and compare them with the critical values D_i calculated previously. If $d_i > D_i$, the conclusion is that sample i exhibits significantly higher median level than the base sample.

Example: The data in the following table represent benzene concentrations in water samples taken at one background and five compliance wells.

Well	Type	Jan 1	Feb 1	Mar 1	Apr 1	n_i	R_i	$\bar{R}_i$
1	b	1.7 (10)	1.9 (11.5)	1.5 (7.5)	1.3 (5)	4	34	8.5
2	c	11.0 (20)	8.0 (18)	9.5 (19)		3	57	19
3	c	1.3 (5)	1.2 (3)	1.5 (7.5)		3	15.5	5.17
4	c	0.0 (1.5)	1.3 (5)	0.0 (1.5)	2.2 (13)	4	21	5.25
5	c	4.9 (17)	3.7 (16)	2.3 (14)		3	47	15.67
6	c	1.6 (9)	2.5 (15)	1.9 (11.5)		3	35.5	11.83

1 & 2. Except for the actual concentration values, the above table also includes the ranks (adjusted for ties) in parenthesis, the number of observations in each sample, the sum of ranks in each sample, and the average rank in each sample.

3. Compute the Kruskal-Wallis statistic:

$$H = \frac{12}{20(20+1)}\left[\frac{34^2}{4} + \cdots + \frac{35.5^2}{3}\right] - 3(20+1) = 14.68$$

Adjustment for ties: There are four groups of ties (K=4) in the above data.

$T_1 = (2^3 - 2) = 6$ for the 2 observations of 1.9
$T_2 = (2^3 - 2) = 6$ for the 2 observations of 1.5
$T_3 = (3^3 - 3) = 24$ for the 3 observations of 1.3
$T_4 = (2^3 - 2) = 6$ for the 2 observations of 0.0

Thus,

$$\sum_{i-1}^{4} T_i = 6 + 6 + 24 + 6 = 42$$

$$H' = \frac{14.68}{1 - \left(\frac{42}{20^3 - 20}\right)} = \frac{14.68}{0.995} = 14.76.$$

which represents a negligible change from 14.68.

4. Compare the value of H′ to the tabulated $\chi^2(6\text{-}1)$ statistic for a significance level $\alpha = 5\%$. This value is 11.07 and, therefore, the null hypothesis of no contamination is rejected.

5. To compare each compliance well to the background well, we find $Z_{0.05/(6-1)} = 2.33$ from the tables of the standard normal distribution, and compute the critical thresholds D_i for each well i:

$$D_2 = 2.32\left[\frac{20(21)}{12}\right]^{\frac{1}{2}}\left[\frac{1}{4} + \frac{1}{3}\right]^{\frac{1}{2}} = 10.5$$
$$D_3 = D_5 = D_6 = 10.5$$
$$D_4 = 9.8$$

6. Compute the differences between the average rank of each compliance well and the average rank of the background well:

$d_2 = 19.0 - 8.5 = 10.5$
$d_3 = 5.17 - 8.5 = -3.33$
$d_4 = 5.25 - 8.5 = -3.25$
$d_5 = 15.67 - 8.5 = 7.17$
$d_6 = 11.83 - 8.5 = 3.13$

Comparing d_i with D_i, one concludes that only well 2 can be considered as being contaminated.

1.5 Remarks on the One Way Non-Parametric ANOVA

It is recommended that there are at least three samples with a minimum of three observations in each sample available. For data sets with more than 30 observations, a good approximation to the above procedure is to replace each observation by its rank and perform the parametric on-way analysis of variance on the ranks.

If there are more than five compliance wells, it is recommended that the value $Z_{0.01}$ from the standard normal distribution be used in step 5 above.

1.6 Two Way Parametric ANOVA

In the one way ANOVA, the equality of means was tested for observations classified as different samples of one factor (e.g., wells). In this section, this procedure is extended to include a two factor classification. The two factors will be denoted by A and B with α and β distinct levels, respectively. Each level combination (cell) will be assumed to include n observations. This layout is presented in the following table.

It is assumed that X_{ijk} are observations of independent normally distributed random variables which are modelled as follows:

$$X_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijk}$$

where
$i = 1,...,a, \quad j = 1,...,b, \quad k = 1,...,n;$
μ = overall or grand mean;
$\alpha_i = \mu_{i..} - \mu$ = effect of row i (level i of factor A);
$\beta_j = \mu_{.j.} - \mu$ = effect of column j (level j of factor B);
$(\alpha\beta)_{ij} = \mu_{ij.} - (\mu + \alpha_i + \beta_j)$ = interaction of factors A and B at levels i and j;
e_{ijk} = independent normally distributed random errors with zero mean and common variance σ^2.

The following constraints are also assumed without loss of generality: (They are necessary to yield unique estimates of the above parameters.)

$$\sum_{i=1}^{a} \alpha_i = \sum_{j=1}^{b} \beta_j = \sum_{i=1}^{a} (\alpha\beta)_{ij} = \sum_{j=1}^{b} (\alpha\beta)_{ij} = 0.$$

Parameters μ, α_i, β_j, and $(\alpha\beta)_{ij}$ can be estimated from the sample data as follows: First the row, column, and overall (grand) means can be computed from

Two Way ANOVA Layout

		Factor B					
		Level 1	...	Level j	...	Level b	Row Means
Factor A	Level 1	X_{111} ⋮ X_{11n}	...	X_{1j1} ⋮ X_{1jn}	...	X_{1b1} ⋮ X_{1bn}	$\overline{X}_{1..}$
	⋮	⋮		⋮		⋮	⋮
	Level i	X_{i11} ⋮ X_{i1n}	...	X_{ij1} ⋮ X_{ijn}	...	X_{ib1} ⋮ X_{ibn}	$\overline{X}_{i..}$
	⋮	⋮		⋮		⋮	⋮
	Level a	X_{a11} ⋮ X_{a1n}	...	X_{aj1} ⋮ X_{ajn}	...	X_{ab1} ⋮ X_{abn}	$\overline{X}_{a..}$
	Column Means	$\overline{X}_{.1.}$	...	$\overline{X}_{.j.}$	...	$\overline{X}_{.b.}$	$\overline{X}_{...}$

$$\overline{X_{ij.}} = \frac{\sum_{k=1}^{n} X_{ijk}}{n}$$

$$\overline{X_{i..}} = \frac{\sum_{j=1}^{b}\sum_{k=1}^{n} X_{ijk}}{bn} = \frac{\sum_{j=1}^{b} \overline{X_{ij.}}}{b}$$

$$\overline{X_{.j.}} = \frac{\sum_{i=1}^{a}\sum_{k=1}^{n} X_{ijk}}{an} = \frac{\sum_{i=1}^{a} \overline{X_{ij.}}}{a}$$

$$\overline{X_{...}} = \frac{\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n} X_{ijk}}{abn} = \frac{\sum_{i=1}^{a} \overline{X_{i..}}}{a} = \frac{\sum_{j=1}^{b} \overline{X_{.j.}}}{b}$$

Then,

$$\hat{\mu} = \overline{X_{...}} \ , \quad \hat{\alpha}_i = \overline{X_{i..}} - \overline{X_{...}} \ , \quad \hat{\beta}_j = \overline{X_{.j.}} - \overline{X_{...}} \ , \quad (\hat{\alpha}\hat{\beta})_{ij} = \overline{X_{ij.}} - \overline{X_{i..}} - \overline{X_{.j.}} + \overline{X_{...}}$$

As in the one way ANOVA procedure, the total sum of squares can be partitioned into terms representing the influence of factors A and B, the interaction between A and B, and the random errors. It can be shown that

$$\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n} (X_{ijk} - \overline{X_{...}})^2 = bn\sum_{i=1}^{a} (\overline{X_{i..}} - \overline{X_{...}})^2 + an\sum_{j=1}^{b} (\overline{X_{.j.}} - \overline{X_{...}})^2$$
$$+ n\sum_{i=1}^{a}\sum_{j=1}^{b} (\overline{X_{ij.}} - \overline{X_{i..}} - \overline{X_{.j.}} + \overline{X_{...}})^2 + \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n} (X_{ijk} - \overline{X_{ij.}})^2 .$$

Namely, SS(T) = SS(A) + SS(B) + SS(AB) + SS(E),

where SS(T) is the total sum of squares, SS(A) is the sum of squares due to factor A, SS(B) is the sum of squares due to factor B, SS(AB) is the sum of squares due to the interaction between A and B, and SS(E) is the sum of squares due to random errors.

One is generally interested to test the following hypotheses:

H_0: $\alpha_1 = \alpha_2 = \cdots = \alpha_a = 0$
H_1: not all α_i's are zero

H_0: $\beta_1 = \beta_2 = \cdots = \beta_a = 0$
H_1: not all β_i's are zero

H_0: $(\alpha\beta)_{11} = (\alpha\beta)_{12} = \cdots = (\alpha\beta)_{ab} = 0$
H_1: not all $(\alpha\beta)_{ij}$ are zero

It can be shown that under the null hypotheses above,

$SS(A)/\sigma^2$ is $\chi^2(a-1)$,
$SS(B)/\sigma^2$ is $\chi^2(b-1)$,
$SS(AB)/\sigma^2$ is $\chi^2[(a-1)(b-1)]$,
$SS(E)/\sigma^2$ is $\chi^2[ab(n-1)]$,
the previous random variables are independent.

Thus, one can test the previous hypotheses by forming the appropriate F statistics and comparing them to the tabulated values. The test is summarized on the table shown in the next page. The computation of the various sum of squares can be expedited by using the following formulas:

$$SS(T) = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n} X_{ijk}^2 - abn\overline{X}_{...}^2,$$

$$SS(A) = bn\sum_{i=1}^{a}\overline{X}_{i..}^2 - abn\overline{X}_{...}^2,$$

$$SS(B) = an\sum_{j=1}^{b}\overline{X}_{.j.}^2 - abn\overline{X}_{...}^2,$$

$$SS(AB) = n\sum_{i=1}^{a}\sum_{j=1}^{b}\overline{X}_{ij.}^2 - abn\overline{X}_{...}^2 - SS(A) - SS(B),$$

$$SS(E) = SS(T) - SS(A) - SS(B) - SS(AB).$$

Two Way ANOVA Procedure

Source of Variation	Sum of Squares, SS	Degrees of Freedom, ν	Mean Square, MS = SS/ν	Expected Mean Square	Test Statistic F
Factor A	SS(A)	a-1	MS(A)	$\sigma^2 + \frac{bn\sum_{i=1}^{a} \alpha_i^2}{a-1}$	MS(A)/MS(E)
Factor B	SS(B)	b-1	MS(B)	$\sigma^2 + \frac{an\sum_{j=1}^{b} \beta_j^2}{b-1}$	MS(B)/MS(E)
Interaction	SS(AB)	(a-1)(b-1)	MS(AB)	$\sigma^2 + \frac{n\sum_{i=1}^{a}\sum_{j=1}^{b} (\alpha\beta)_{ij}^2}{(a-1)(b-1)}$	MS(AB)/MS(E)
Random Error	SS(E)	abn-ab	MS(E)	σ^2	
Total	SS(T)	abn-1			

Example: The following table reports rye yields (bushels/acre) for two types of seed and three fertilizer levels--low, medium, and high. Are there appreciable yield differences between seeds and/or fertilizer levels?

		Fertilizer			
		Low	**Medium**	**High**	$\overline{X_{i..}}$
Seed Type	**Seed 1**	14.3	18.1	17.6	
		14.5	17.6	18.2	
		11.5	17.1	18.9	
		13.6	17.6	18.2	
	$\overline{X_{1j.}}$	13.475	17.600	18.225	16.433
	Seed 2	12.6	10.5	15.7	
		11.2	12.8	17.5	
		11.0	8.3	16.7	
		12.1	9.1	16.6	
	$\overline{X_{2j.}}$	11.725	10.175	16.625	12.842
	$\overline{X_{.j.}}$	12.600	13.888	17.425	$\overline{X_{...}}$ - 14.638

The above table except for the observed yields per seed type and fertilizer level also reports the cell, row, column, and overall means. The two-way ANOVA results and comparisons are summarized in the table that follows:

Two Way ANOVA Results

Source of Variation	Sum of Squares, SS	Degrees of Freedom, ν	Mean Square, MS = SS/ν	Test Statistic F
Factor A Seeds	SS(A)=77.4	a-1=1	MS(A)=77.4	MS(A)/MS(E)= 63.3
Factor B Fertilizer	SS(B)=99.9	b-1=2	MS(B)=49.9	MS(B)/MS(E)= 40.9
Interaction	SS(AB)=44.1	(a-1)(b-1)=2	MS(AB)=22.1	MS(AB)/MS(E) =18.0
Random Error	SS(E)=22.0	abn-ab=18	MS(E)=1.2	
Total	SS(T)=243.4	abn-1=23		

The tabulated F statistic values for a significance level of $\alpha = 0.05$ and degrees of freedom (1,18) and (2,18) are $F_{0.05;1,18} = 4.41$ and $F_{0.05;2,18} = 3.55$. A comparison with the last column of the previous table indicates that significant yield differences do exist between the seed types and the fertilizer levels. Furthermore, the test detects significant interactions between seed types and fertilizer levels.

1.7 Remarks on the Two Way Parametric ANOVA

When only one observation per cell is available, one has to postulate a model with no interactions because there can be estimate of cell error variance. In this special case, the basic model becomes

$$X_{ij} = \mu + \alpha_i + \beta_j + e_{ij}$$

and the ANOVA procedure is depicted on the following table:

Two Way ANOVA Procedure with One Observation per Cell

Source of Variation	Sum of Squares, SS	Degrees of Freedom, ν	Mean Square, MS = SS/ν	Expected Mean Square	Test Statistic F
Factor A	SS(A)	a-1	MS(A)	$\sigma^2 + \frac{b\sum_{i-1}^{a} \alpha_i^2}{a-1}$	MS(A)/MS(E)
Factor B	SS(B)	b-1	MS(B)	$\sigma^2 + \frac{a\sum_{j-1}^{b} \beta_j^2}{b-1}$	MS(B)/MS(E)
Random Error	SS(E)	(a-1)(b-1)	MS(E)	σ^2	
Total	SS(T)	ab-1			

The two way ANOVA requires that each cell has the same number of observations. If some observations are missing, they must first be estimated. The estimates can be obtained as follows:

(1) When one observation X_{ij} is missing from a two way ANOVA data set with one observation per cell, it can be estimated by finding the value which

minimizes the error sum of squares SS(E). The result is given by

$$\hat{X}_{ij} = \frac{ab}{(a-1)(b-1)}\left(\overline{X}_{i.} + \overline{X}_{.j} - \overline{X}_{..}\right)$$

and the degrees of freedom of the error sum of squares is reduced by one. When more than one observations are missing, one can again obtain estimates by minimizing SS(E). (This involves taking the partial derivatives of SS(E) with respect to all missing observations, setting them equal to zero, and solving the resulting system of equations.) For each estimated observation, the error sum of squares degrees of freedom must be reduced by one.

(2) When the observations per cell are more than one and only a few observations are missing, any missing value can be estimated by the corresponding cell mean $\overline{X}_{ij.}$. For each missing value estimated, the degrees of freedom of the error sum of squares must be reduced by one.

The analysis of variance can be extended to include more than two factors. The associated computations and tests are straightforward generalizations of the two factor case.

1.8 A Multiple Comparison Test

If the two way ANOVA rejects the stated hypotheses, one may ask whether two particular α_i or β_j levels are equal or whether a specific α_i or β_j is significantly nonzero. Let m be the number of comparisons or tests to be performed at an overall type I error probability α. Then, based on the theorem stated on page 8 (Bonferroni t-tests), one can derive the following tests:

α_i is significantly different from α_η, if the interval

$$\overline{X_{i..}} - \overline{X_{\eta..}} \pm t_{ab(n-1),(1-\alpha/2m)} \left(2\frac{MS(E)}{bn}\right)^{\frac{1}{2}},$$

where $t_{ab(n-1),(1-\alpha/2m)}$ is the tabulated t value with ab(n-1) degrees of freedom and (1-a/2m) confidence level and MS(E) is the estimate of σ^2 derived in the ANOVA procedure, does not include zero.

β_j is significantly different from β_η, if the interval

$$\overline{X_{.j.}} - \overline{X_{.\eta.}} \pm t_{ab(n-1),(1-\alpha/2m)} \left(2\frac{MS(E)}{an}\right)^{\frac{1}{2}},$$

where $t_{ab(n-1),(1-\alpha/2m)}$ and MS(E) as defined above, does not include zero.

α_i is significantly different from 0, if the interval

$$\overline{X_{i..}} - \overline{X_{...}} \pm t_{ab(n-1),(1-\alpha/2m)} \left(\frac{MS(E)(a-1)}{bn}\right)^{\frac{1}{2}},$$

does not include zero.

β_j is significantly different from 0, if the interval

$$\overline{X_{.j.}} - \overline{X_{...}} \pm t_{ab(n-1),(1-\alpha/2m)} \left(\frac{MS(E)(b-1)}{an}\right)^{\frac{1}{2}},$$

does not include zero.

$(\alpha\beta)_{ij}$ is significantly different from 0, if the interval

$$\overline{X_{ij.}} - \overline{X_{i..}} - \overline{X_{.j.}} + \overline{X_{...}} \pm t_{ab(n-1),(1-\alpha/2m)} \left(\frac{MS(E)(a-1)(b-1)}{abn} \right)^{\frac{1}{2}},$$

does not include zero.

Under the associated null hypothesis H_0, the probability of commiting at least one error in the m pairwise comparisons is bounded above by α.

Example: Let's suppose that in the example of the previous section, one is interested to examine whether (1) the effects of the two seed types are equal and (2) the effects of low and medium fertilizer levels are equal. Then,

$m=2$

$\overline{X_{1..}} = 16.433$

$\overline{X_{2..}} = 12.842$

$t_{18,(1-0.05/4)} = 2.829$

$MS(E)=1.2$

$$16.433 - 12.842 \pm 2.829\left(2\frac{1.2}{12}\right)^{\frac{1}{2}} = [2.326, 4.856].$$

$\overline{X_{.1.}} = 12.600$

$\overline{X_{.2.}} = 13.888$

$$12.600 - 13.888 \pm 2.829\left(2\frac{1.2}{12}\right)^{\frac{1}{2}} = [-2.553, -0.023].$$

Since the above intervals do not include zero, the effects of the two seed types and the low and medium fertilizer levels are unequal.

1.9 Two Way Non-Parametric ANOVA (Friedman Test)

Consider a two way ANOVA layout with n observations per cell. The assumption is that X_{ijk}, $i=1,...,a$, $j=1,...,b$, $k=1,...,n$, are independent random variables with distributions whose medians are equal to $(\mu + \alpha_i + \beta_j)$. The hypothesis to be tested is H_0: $\beta_1 = ... = \beta_b$ versus H_1: $\beta_1, ..., \beta_b$ not all equal. The test is as follows:

1. Rank the data within each row of cells from the least (rank=1) to the largest (rank=bn). If two or more observations are numerically equal (tied), determine the ranks that the tied observations would have if they had been slightly different from one another, but still in the same places with respect to the rest of the observations. Add these ranks and divide by the number of observations tied at that value to get an average rank. Assign this average rank to each of the tied observations.

2. Compute $R_{.j.}$ = the sum of ranks for the jth column of cells for $j=1,...,b$.

3. Compute the test statistic

$$K = \left[\frac{12}{abn^2(nb+1)} \sum_{j=1}^{b} R_{.j.}^2 \right] - 3a(nb+1)$$

4. Compare the value of K to the tabulated $\chi^2(b-1)$ statistic for a certain significance level α. Reject the null hypothesis H_0 if the computed value exceeds the tabulated critical value.

If the above test rejects H_0, the equality of individual pairs (β_j, β_η) can be tested via the following multiple comparison test.

5. Let m be the number of pairwise comparisons to be performed. Declare that β_j is significantly different from β_η at an overall type I error α, if

$$|R_{.j.} - R_{.\eta.}| \geq Z_{\alpha/2m} \sqrt{abn^2(nb+1)/6} \ ,$$

where $Z_{\alpha/2m}$ is the upper $(\alpha/2m)$-percentile of the standard normal distribution. Under the null hypothesis H_0, the probability of commiting at least one error in the m pairwise comparisons is bounded above by α.

Example: The following table includes quarterly SILVEX concentration observations from two wells. Test the hypothesis that the median levels are time invariant.

	Jan. 1	**Apr. 1**	**Jul. 1**	**Oct. 1**	
Well 1	3.17 (2) 2.32 (1) 7.37 (11) 4.44 (6)	9.50 (13) 21.36 (16) 5.15 (7) 15.70 (15)	5.58 (8) 3.39 (3) 8.44 (12) 10.25 (14)	3.65 (4) 6.15 (9) 6.94 (10) 3.74 (5)	
Well 2	3.52 (6) 12.32 (15) 2.28 (4) 5.30 (7)	8.12 (11) 3.36 (5) 11.02 (14) 35.05 (16)	2.20 (3) 0.00 (1.5) 9.30 (12) 10.30 (13)	5.93 (8) 6.39 (9) 0.00 (1.5) 6.53 (10)	
$R_{.j.}$	52	97	66.5	56.5	

1 & 2. The previous table also reports the ranks of each data value within each row and the sum of ranks in each column.

3. The test statistic is computed as follows:

$$K = \left[\frac{12}{2 \cdot 4 \cdot 4^2 (4 \cdot 4 + 1)} (52^2 + 97^2 + 66.5^2 + 56.5^2) \right] - 3 \cdot 2(4 \cdot 4 + 1) = 6.79 .$$

4. The tabulated value of $\chi^2(4\text{-}1)$ statistic at $\alpha = 0.05$ is equal to 7.815. It follows that the hypothesis of time invariant median levels cannot be rejected.

1.10 Comparison of Proportions

Let m independent data samples be available to compare the proportions of a certain attribute A in the underlying populations.

Sample	Data	Number with A	Proportion with A
1	$X_{11},\ldots, X_{1n_1}$	n_{1a}	$p_{1a} = n_{1a}/n_1$
2	$X_{21},\ldots, X_{2n_2}$	n_{2a}	$p_{2a} = n_{2a}/n_2$
⋮	⋮	⋮	⋮
m	$X_{m1},\ldots, X_{mn_m}$	n_{ma}	$p_{ma} = n_{ma}/n_m$
Total		n_a	$p_a = n_a/(n_1+\cdots+n_m)$

To test the significance of the differences among the m proportions, one may use the following statistic:

$$\chi^2 = \frac{1}{p_a q_a}\sum_{i=1}^{m} n_i (p_{ia}-p_a)^2,$$
$$q_a = 1-p_a,$$

which is distributed according to the χ^2(m-1) distribution. If the previous statistic is higher than the tabulated χ^2(m-1) statistic for a given significance level α, the hypothesis of equal proportions in the m samples is rejected.

Example: The following table contains data on cadmium concentrations (μg/L) measured in background and compliance wells at a facility. ("BDL" stands for below detection limit.) Compare the proportions of detects (data above the detection limit) at the 5% significance level.

Background	Compliance		
0.1	0.12	BDL	BDL
0.12	0.08	BDL	BDL
BDL	BDL	BDL	BDL
0.26	0.2	0.11	BDL
0.1	BDL	0.06	BDL
BDL	0.1	BDL	0.1
0.014	BDL	0.23	0.04
BDL	0.012	BDL	BDL
BDL	BDL	0.11	BDL
BDL	BDL	BDL	0.1
BDL	BDL	0.031	BDL
BDL	BDL	BDL	0.01
0.12	BDL	BDL	BDL
BDL	0.12	BDL	BDL
0.21	0.07	BDL	BDL
BDL	BDL	BDL	BDL
0.12	0.19	0.12	BDL
BDL	BDL	0.08	
BDL	0.1	BDL	
BDL	BDL	0.26	
BDL	0.01	BDL	
BDL	BDL	0.02	
BDL	BDL	BDL	
BDL	BDL	0.024	

In this case, m = 2 (two samples) with n_1 = 24 and n_2 = 65 observations. The proportion of detects in the background wells is p_{1a} = 8/24 = 0.333. The proportion of detects in the compliance wells is p_{2a} = 24/65 = 0.369. The overall proportion is p_a = (8+24)/(24+65) = 0.360. The critical statistic is computed as follows:

$$q_a = 1 - 0.360 = 0.640,$$

$$\chi^2 = \frac{1}{0.360\ 0.640}\left(24\,(0.333-0.360)^2 + 65\,(0.369-0.360)^2\right) = 0.0988.$$

The tabulated $\chi^2(2\text{-}1;0.05)$ value is 3.841 and, thus, the proportions of detects do not differ significantly in the background and compliance wells.

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APPENDIX B

STATISTICAL TABLES

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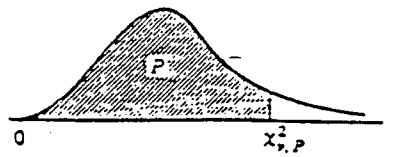
TABLE 1. PERCENTILES OF THE χ^2 DISTRIBUTION WITH ν DEGREES OF FREEDOM, $\chi^2_{\nu,P}$



ν \ P	0.750	0.900	0.950	0.975	0.990	0.995	0.999
1	1.323	2.706	3.841	5.024	6.635	7.879	10.83
2	2.773	4.605	5.991	7.378	9.210	10.60	13.82
3	4.108	6.251	7.815	9.348	11.34	12.84	16.27
4	5.385	7.779	9.488	11.14	13.28	14.86	18.47
5	6.626	9.236	11.07	12.83	15.09	16.75	20.52
6	7.841	10.64	12.59	14.45	16.81	18.55	22.46
7	9.037	12.02	14.07	16.01	18.48	20.28	24.32
8	10.22	13.36	15.51	17.53	20.09	21.96	26.12
9	11.39	14.68	16.92	19.02	21.67	23.59	27.88
10	12.55	15.99	18.31	20.48	23.21	25.19	29.59
11	13.70	17.28	19.68	21.92	24.72	26.76	31.26
12	14.85	18.55	21.03	23.34	26.22	28.30	32.91
13	15.98	19.81	22.36	24.74	27.69	29.82	34.53
14	17.12	21.06	23.68	26.12	29.14	31.32	36.12
15	18.25	22.31	25.00	27.49	30.58	32.80	37.70
16	19.37	23.54	26.30	28.85	32.00	34.27	39.25
17	20.49	24.77	27.59	30.19	33.41	35.72	40.79
18	21.60	25.99	28.87	31.53	34.81	37.16	42.31
19	22.72	27.20	30.14	32.85	36.19	38.58	43.82
20	23.83	28.41	31.41	34.17	37.57	40.00	45.32
21	24.93	29.62	32.67	35.48	38.93	41.40	46.80
22	26.04	30.81	33.92	36.78	40.29	42.80	48.27
23	27.14	32.01	35.17	38.08	41.64	44.18	49.73
24	28.24	33.20	36.42	39.36	42.98	45.56	51.18
25	29.34	34.38	37.65	40.65	44.31	46.93	52.62
26	30.43	35.56	38.89	41.92	45.64	48.29	54.05
27	31.53	36.74	40.11	43.19	46.96	49.64	55.48
28	32.62	37.92	41.34	44.46	48.28	50.99	56.89
29	33.71	39.09	42.56	45.72	49.59	52.34	58.30
30	34.80	40.26	43.77	46.98	50.89	53.67	59.70
40	45.62	51.80	55.76	59.34	63.69	66.77	73.40
50	56.33	63.17	67.50	71.42	76.15	79.49	86.66
60	66.98	74.40	79.08	83.30	88.38	91.95	99.61
70	77.58	85.53	90.53	95.02	100.4	104.2	112.3
80	88.13	96.58	101.9	106.6	112.3	116.3	124.8
90	98.65	107.6	113.1	118.1	124.1	128.3	137.2
100	109.1	118.5	124.3	129.6	135.8	140.2	149.4

SOURCE: Johnson, Norman L. and F. C. Leone. 1977. *Statistics and Experimental Design in Engineering and the Physical Sciences*. Vol. I. Second Edition. John Wiley and Sons, New York.

TABLE 2. 95th PERCENTILES OF THE F-DISTRIBUTION WITH ν_1 AND ν_2 DEGREES OF FREEDOM, $F_{\nu_1,\nu_2,0.95}$

ν_2 \ ν_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5	241.9	243.9	245.9	248.0	249.1	250.1	251.1	252.2	253.3	254.3
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35	1.25
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

NOTE: ν_1: Degrees of freedom for numerator
ν_2: Degrees of freedom for denominator

SOURCE: Johnson, Norman L. and F. C. Leone. 1977. *Statistics and Experimental Design in Engineering and the Physical Sciences*. Vol. I. Second Edition. John Wiley and Sons, New York.

TABLE 3. 95th PERCENTILES OF THE BONFERRONI t-STATISTICS, $t(\nu, \alpha/m)$

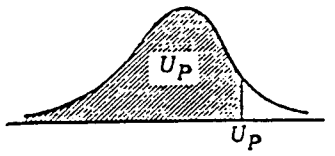
where ν = degrees of freedom associated with the mean squares error
m = number of comparisons
α = 0.05, the experimentwise error level

ν \ m	1	2	3	4	5
	α/m = 0.05	0.025	0.0167	0.0125	0.01
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
∞	1.65	1.96	2.13	2.24	2.33

SOURCE: For α/m = 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 α/m = 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.

TABLE 4. PERCENTILES OF THE STANDARD NORMAL DISTRIBUTION, U_P



P	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.50	0.0000	0.0025	0.0050	0.0075	0.0100	0.0125	0.0150	0.0175	0.0201	0.0226
0.51	0.0251	0.0276	0.0301	0.0326	0.0351	0.0376	0.0401	0.0426	0.0451	0.0476
0.52	0.0502	0.0527	0.0552	0.0577	0.0602	0.0627	0.0652	0.0677	0.0702	0.0728
0.53	0.0753	0.0778	0.0803	0.0828	0.0853	0.0878	0.0904	0.0929	0.0954	0.0979
0.54	0.1004	0.1030	0.1055	0.1080	0.1105	0.1130	0.1156	0.1181	0.1206	0.1231
0.55	0.1257	0.1282	0.1307	0.1332	0.1358	0.1383	0.1408	0.1434	0.1459	0.1484
0.56	0.1510	0.1535	0.1560	0.1586	0.1611	0.1637	0.1662	0.1687	0.1713	0.1738
0.57	0.1764	0.1789	0.1815	0.1840	0.1866	0.1891	0.1917	0.1942	0.1968	0.1993
0.58	0.2019	0.2045	0.2070	0.2096	0.2121	0.2147	0.2173	0.2198	0.2224	0.2250
0.59	0.2275	0.2301	0.2327	0.2353	0.2378	0.2404	0.2430	0.2456	0.2482	0.2508
0.60	0.2533	0.2559	0.2585	0.2611	0.2637	0.2663	0.2689	0.2715	0.2741	0.2767
0.61	0.2793	0.2819	0.2845	0.2871	0.2898	0.2924	0.2950	0.2976	0.3002	0.3029
0.62	0.3055	0.3081	0.3107	0.3134	0.3160	0.3186	0.3213	0.3239	0.3266	0.3292
0.63	0.3319	0.3345	0.3372	0.3398	0.3425	0.3451	0.3478	0.3505	0.3531	0.3558
0.64	0.3585	0.3611	0.3638	0.3665	0.3692	0.3719	0.3745	0.3772	0.3799	0.3826
0.65	0.3853	0.3880	0.3907	0.3934	0.3961	0.3989	0.4016	0.4043	0.4070	0.4097
0.66	0.4125	0.4152	0.4179	0.4207	0.4234	0.4261	0.4289	0.4316	0.4344	0.4372
0.67	0.4399	0.4427	0.4454	0.4482	0.4510	0.4538	0.4565	0.4593	0.4621	0.4649
0.68	0.4677	0.4705	0.4733	0.4761	0.4789	0.4817	0.4845	0.4874	0.4902	0.4930
0.69	0.4959	0.4987	0.5015	0.5044	0.5072	0.5101	0.5129	0.5158	0.5187	0.5215
0.70	0.5244	0.5273	0.5302	0.5330	0.5359	0.5388	0.5417	0.5446	0.5476	0.5505
0.71	0.5534	0.5563	0.5592	0.5622	0.5651	0.5681	0.5710	0.5740	0.5769	0.5799
0.72	0.5828	0.5858	0.5888	0.5918	0.5948	0.5978	0.6008	0.6038	0.6068	0.6098
0.73	0.6128	0.6158	0.6189	0.6219	0.6250	0.6280	0.6311	0.6341	0.6372	0.6403
0.74	0.6433	0.6464	0.6495	0.6526	0.6557	0.6588	0.6620	0.6651	0.6682	0.6713

NOTE: For values of P below 0.5, obtain the value of $U_{(1-P)}$ from Table 4 and change its sign. For example, $U_{0.45} = -U_{(1-0.45)} = -U_{0.55} = -0.1257$.

(Continued)

TABLE 4 (Continued)

P	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.75	0.6745	0.6776	0.6808	0.6840	0.6871	0.6903	0.6935	0.6967	0.6999	0.7031
0.76	0.7063	0.7095	0.7128	0.7160	0.7192	0.7225	0.7257	0.7290	0.7323	0.7356
0.77	0.7388	0.7421	0.7454	0.7488	0.7521	0.7554	0.7588	0.7621	0.7655	0.7688
0.78	0.7722	0.7756	0.7790	0.7824	0.7858	0.7892	0.7926	0.7961	0.7995	0.8030
0.79	0.8064	0.8099	0.8134	0.8169	0.8204	0.8239	0.8274	0.8310	0.8345	0.8381
0.80	0.8416	0.8452	0.8488	0.8524	0.8560	0.8596	0.8633	0.8669	0.8705	0.8742
0.81	0.8779	0.8816	0.8853	0.8890	0.8927	0.8965	0.9002	0.9040	0.9078	0.9116
0.82	0.9154	0.9192	0.9230	0.9269	0.9307	0.9346	0.9385	0.9424	0.9463	0.9502
0.83	0.9542	0.9581	0.9621	0.9661	0.9701	0.9741	0.9782	0.9822	0.9863	0.9904
0.84	0.9945	0.9986	1.0027	1.0069	1.0110	1.0152	1.0194	1.0237	1.0279	1.0322
0.85	1.0364	1.0407	1.0450	1.0494	1.0537	1.0581	1.0625	1.0669	1.0714	1.0758
0.86	1.0803	1.0848	1.0893	1.0939	1.0985	1.1031	1.1077	1.1123	1.1170	1.1217
0.87	1.1264	1.1311	1.1359	1.1407	1.1455	1.1503	1.1552	1.1601	1.1650	1.1700
0.88	1.1750	1.1800	1.1850	1.1901	1.1952	1.2004	1.2055	1.2107	1.2160	1.2212
0.89	1.2265	1.2319	1.2372	1.2426	1.2481	1.2536	1.2591	1.2646	1.2702	1.2759
0.90	1.2816	1.2873	1.2930	1.2988	1.3047	1.3106	1.3165	1.3225	1.3285	1.3346
0.91	1.3408	1.3469	1.3532	1.3595	1.3658	1.3722	1.3787	1.3852	1.3917	1.3984
0.92	1.4051	1.4118	1.4187	1.4255	1.4325	1.4395	1.4466	1.4538	1.4611	1.4684
0.93	1.4758	1.4833	1.4909	1.4985	1.5063	1.5141	1.5220	1.5301	1.5382	1.5464
0.94	1.5548	1.5632	1.5718	1.5805	1.5893	1.5982	1.6072	1.6164	1.6258	1.6352
0.95	1.6449	1.6546	1.6646	1.6747	1.6849	1.6954	1.7060	1.7169	1.7279	1.7392
0.96	1.7507	1.7624	1.7744	1.7866	1.7991	1.8119	1.8250	1.8384	1.8522	1.8663
0.97	1.8808	1.8957	1.9110	1.9268	1.9431	1.9600	1.9774	1.9954	2.0141	2.0335
0.98	2.0537	2.0749	2.0969	2.1201	2.1444	2.1701	2.1973	2.2262	2.2571	2.2904
0.99	2.3263	2.3656	2.4089	2.4573	2.5121	2.5758	2.6521	2.7478	2.8782	3.0902

SOURCE: Johnson, Norman L. and F. C. Leone. 1977. *Statistics and Experimental Design in Engineering and the Physical Sciences*. Vol. I, Second Edition. John Wiley and Sons, New York.

TABLE 5. TOLERANCE FACTORS (K) FOR ONE-SIDED NORMAL TOLERANCE INTERVALS WITH PROBABILITY LEVEL (CONFIDENCE FACTOR) Y = 0.95 AND COVERAGE P = 95%

n	K	n	K
3	7.655	75	1.972
4	5.145	100	1.924
5	4.202	125	1.891
6	3.707	150	1.868
7	3.399	175	1.850
8	3.188	200	1.836
9	3.031	225	1.824
10	2.911	250	1.814
11	2.815	275	1.806
12	2.736	300	1.799
13	2.670	325	1.792
14	2.614	350	1.787
15	2.566	375	1.782
16	2.523	400	1.777
17	2.486	425	1.773
18	2.543	450	1.769
19	2.423	475	1.766
20	2.396	500	1.763
21	2.371	525	1.760
22	2.350	550	1.757
23	2.329	575	1.754
24	2.309	600	1.752
25	2.292	625	1.750
30	2.220	650	1.748
35	2.166	675	1.746
40	2.126	700	1.744
45	2.092	725	1.742
50	2.065	750	1.740
55	2.036	775	1.739
60	2.017	800	1.737
65	2.000	825	0.736
70	1.986	850	1.734
		875	1.733
		900	1.732
		925	1.731
		950	1.729
		975	1.728
		1000	1.727

SOURCE: (a) for sample sizes ≤ 50: Lieberman, Gerald F. 1958. "Tables for One-sided Statistical Tolerance Limits." *Industrial Quality Control.* Vol. XIV, No. 10. (b) for sample sizes ≥ 50: K values were calculated from large sample approximation.

TABLE 6. PERCENTILES OF STUDENT's t-DISTRIBUTION

(F = 1-α; n = degrees of freedom)

n \ F	.60	.75	.90	.95	.975	.99	.995	.9995
1	.325	1.000	3.078	6.314	12.706	31.821	63.657	636.619
2	.289	.816	1.886	2.920	4.303	6.965	9.925	31.598
3	.277	.765	1.638	2.353	3.182	4.541	5.841	12.941
4	.271	.741	1.533	2.132	2.776	3.747	4.604	8.610
5	.267	.727	1.476	2.015	2.571	3.365	4.032	6.859
6	.265	.718	1.440	1.943	2.447	3.143	3.707	5.959
7	.263	.711	1.415	1.895	2.365	2.998	3.499	5.405
8	.262	.706	2.397	1.860	2.306	2.896	3.355	5.041
9	.261	.703	1.383	1.833	2.262	2.821	3.250	4.781
10	.260	.700	1.372	1.812	2.228	2.764	3.169	4.587
11	.260	.697	1.363	1.796	2.201	2.718	3.106	4.437
12	.259	.695	1.356	1.782	2.179	2.681	3.055	4.318
13	.259	.694	1.350	1.771	2.160	2.650	3.012	4.221
14	.258	.692	1.345	1.761	2.145	2.624	2.977	4.140
15	.258	.691	1.341	1.753	2.131	2.602	2.947	4.073
16	.258	.690	1.337	1.746	2.120	2.583	2.921	4.015
17	.257	.689	1.333	1.740	2.110	2.567	2.898	3.965
18	.257	.688	1.330	1.734	2.101	2.552	2.878	3.922
19	.257	.688	1.328	1.729	2.093	2.539	2.861	3.883
20	.257	.687	1.325	1.725	2.086	2.528	2.845	3.850
21	.257	.686	1.323	1.721	2.080	2.518	2.831	3.819
22	.256	.686	1.321	1.717	2.074	2.508	2.819	3.792
23	.256	.685	1.319	1.714	2.069	2.500	2.807	3.767
24	.256	.685	1.318	1.711	2.064	2.492	2.797	3.745
25	.256	.684	1.316	1.708	2.060	2.485	2.787	3.725
26	.256	.684	1.315	1.706	2.056	2.479	2.779	3.707
27	.256	.684	1.314	1.703	2.052	2.473	2.771	3.690
28	.256	.683	1.313	1.701	2.048	2.467	2.763	3.674
29	.256	.683	1.311	1.699	2.045	2.462	2.756	3.659
30	.256	.683	1.310	1.697	2.042	2.457	2.750	3.646
40	.255	.681	1.303	1.684	2.021	2.423	2.704	3.551
60	.254	.679	1.296	1.671	2.000	2.390	2.660	3.460
120	.254	.677	1.289	1.658	1.980	2.358	2.617	3.373
∞	.253	.674	1.282	1.645	1.960	2.326	2.576	3.291

SOURCE: *CRC Handbook of Tables for Probability and Statistics*. 1966. W. H. Beyer, Editor. Published by the Chemical Rubber Company. Cleveland, Ohio.

TABLE 7. VALUES OF THE PARAMETER $\hat{\lambda}$ FOR COHEN'S ESTIMATES ADJUSTING FOR NONDETECTED VALUES

τ \ h	.01	.02	.03	.04	.05	.06	.07	.08	.09	.10	.15	.20	τ
.00	.010100	.020400	.030903	.041383	.052307	.063627	.074953	.086468	.09824	.11020	.17242	.24268	.00
.05	.010331	.021294	.032223	.043330	.054670	.066189	.077909	.089834	.10197	.11431	.17925	.25032	.05
.10	.010590	.022082	.033398	.044902	.056396	.068483	.080968	.093252	.10534	.11804	.18479	.25741	.10
.15	.011310	.022798	.034466	.046318	.058336	.070586	.083009	.095629	.10845	.12148	.18985	.26405	.15
.20	.011642	.023450	.035433	.047629	.059990	.072539	.085280	.098216	.11133	.12469	.19460	.27031	.20
.25	.011952	.024076	.036377	.048858	.061322	.074372	.087413	.10065	.11406	.12772	.19910	.27626	.25
.30	.012243	.024658	.037246	.050018	.062946	.076106	.089423	.10295	.11667	.13038	.20338	.28193	.30
.35	.012520	.025211	.038077	.051120	.064343	.077754	.091335	.10515	.11914	.13323	.20747	.28737	.35
.40	.012784	.025738	.038866	.052173	.065660	.079322	.093193	.10723	.12150	.13595	.21139	.29260	.40
.45	.013038	.026243	.039624	.053182	.066821	.080848	.094958	.10928	.12377	.13847	.21317	.29763	.45
.50	.013279	.026728	.040332	.054133	.068133	.082301	.096657	.11121	.12595	.14090	.21882	.30253	.50
.55	.013513	.027194	.041034	.055086	.069306	.083708	.098298	.11308	.12806	.14325	.22223	.30723	.55
.60	.013739	.027649	.041723	.055995	.070439	.085068	.099887	.11490	.13011	.14552	.22578	.31184	.60
.65	.013958	.028087	.042391	.056874	.071528	.086386	.10143	.11666	.13209	.14771	.22910	.31630	.65
.70	.014171	.028513	.043038	.057728	.072603	.087670	.10292	.11837	.13402	.14987	.23234	.32068	.70
.75	.014378	.028927	.043652	.058556	.073643	.088917	.10428	.12004	.13590	.15196	.23550	.32489	.75
.80	.014579	.029330	.044258	.059364	.074655	.090133	.10560	.12167	.13773	.15400	.23858	.32903	.80
.85	.014773	.029722	.044848	.060153	.075642	.091319	.10719	.12325	.13952	.15599	.24158	.33307	.85
.90	.014967	.030107	.045423	.060923	.076608	.092477	.10854	.12480	.14128	.15793	.24452	.33703	.90
.95	.015154	.030483	.045989	.061676	.077548	.093611	.10987	.12632	.14297	.15983	.24740	.34091	.95
1.00	.015338	.030850	.046540	.062413	.078471	.094720	.11116	.12780	.14463	.16170	.25022	.34471	1.00

τ \ h	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.80	.90	τ
.00	.31362	.4021	.4941	.5941	.7096	.8388	.9808	1.143	1.326	1.561	2.179	3.283	.00
.05	.32793	.4130	.5046	.6101	.7252	.8540	.9994	1.166	1.358	1.585	2.203	3.314	.05
.10	.33662	.4223	.5184	.6234	.7400	.8703	1.017	1.183	1.379	1.608	2.229	3.245	.10
.15	.34460	.4320	.5296	.6361	.7542	.8860	1.035	1.204	1.400	1.630	2.255	3.278	.15
.20	.35253	.4422	.5403	.6483	.7678	.9012	1.051	1.222	1.419	1.651	2.280	3.405	.20
.25	.35993	.4510	.5506	.6600	.7810	.9158	1.067	1.240	1.438	1.672	2.305	3.435	.25
.30	.36700	.4595	.5604	.6713	.7937	.9300	1.083	1.257	1.457	1.693	2.329	3.464	.30
.35	.37379	.4678	.5699	.6821	.8060	.9437	1.098	1.274	1.476	1.713	2.353	3.492	.35
.40	.38033	.4755	.5791	.6927	.8179	.9570	1.113	1.290	1.494	1.732	2.378	3.520	.40
.45	.38665	.4831	.5880	.7029	.8295	.9700	1.127	1.306	1.511	1.751	2.399	3.547	.45
.50	.39278	.4904	.5967	.7129	.8406	.9828	1.141	1.321	1.528	1.770	2.421	3.573	.50
.55	.39870	.4978	.6051	.7225	.8517	.9950	1.155	1.337	1.545	1.788	2.443	3.601	.55
.60	.40447	.5045	.6133	.7320	.8625	1.007	1.168	1.351	1.561	1.806	2.465	3.628	.60
.65	.41008	.5114	.6213	.7412	.8729	1.019	1.182	1.366	1.577	1.824	2.486	3.654	.65
.70	.41555	.5180	.6291	.7502	.8832	1.030	1.195	1.380	1.593	1.841	2.507	3.679	.70
.75	.42090	.5245	.6367	.7590	.8932	1.042	1.207	1.394	1.608	1.858	2.528	3.703	.75
.80	.42612	.5308	.6441	.7676	.9031	1.053	1.220	1.408	1.624	1.875	2.548	3.730	.80
.85	.43122	.5370	.6515	.7761	.9127	1.064	1.232	1.422	1.639	1.892	2.568	3.754	.85
.90	.43622	.5430	.6586	.7844	.9222	1.074	1.244	1.435	1.653	1.908	2.588	3.779	.90
.95	.44112	.5490	.6656	.7925	.9314	1.085	1.255	1.448	1.668	1.924	2.607	3.803	.95
1.00	.44592	.5548	.6724	.8005	.9406	1.095	1.267	1.461	1.682	1.940	2.626	3.827	1.00

For all values $0 \leq \tau \leq 1$. $\lambda(0,\tau) = 0$.

SOURCE: Cohen, A. C., Jr. 1961. "Tables for Maximum Likelihood Estimates: Singly Truncated and Singly Censored Samples." *Technometrics*.

TABLE 8. CRITICAL VALUES FOR T_n (ONE-SIDED TEST) WHEN THE STANDARD DEVIATION IS CALCULATED FROM THE SAME SAMPLE

Number of Observations, n	Upper 0.1% Significance Level	Upper 0.5% Significance Level	Upper 1% Significance Level	Upper 2.5% Significance Level	Upper 5% Significance Level	Upper 10% Significance Level
3	1.155	1.155	1.155	1.155	1.153	1.148
4	1.499	1.496	1.492	1.481	1.463	1.425
5	1.780	1.764	1.749	1.715	1.672	1.602
6	2.011	1.973	1.944	1.887	1.822	1.729
7	2.201	2.139	2.097	2.020	1.938	1.828
8	2.358	2.274	2.221	2.126	2.032	1.909
9	2.492	2.387	2.323	2.215	2.110	1.977
10	2.606	2.482	2.410	2.290	2.176	2.036
11	2.705	2.564	2.485	2.355	2.234	2.088
12	2.791	2.636	2.550	2.412	2.285	2.134
13	2.867	2.699	2.607	2.462	2.331	2.175
14	2.935	2.755	2.659	2.507	2.371	2.213
15	2.997	2.806	2.705	2.549	2.409	2.247
16	3.052	2.852	2.747	2.585	2.443	2.279
17	3.103	2.894	2.785	2.620	2.475	2.309
18	3.149	2.932	2.821	2.651	2.504	2.335
19	3.191	2.968	2.854	2.681	2.532	2.361
20	3.230	3.001	2.884	2.709	2.557	2.385
21	3.266	3.031	2.912	2.733	2.580	2.408
22	3.300	3.060	2.939	2.758	2.603	2.429
23	3.332	3.087	2.963	2.781	2.624	2.448
24	3.362	3.112	2.987	2.802	2.644	2.467
25	3.389	3.135	3.009	2.822	2.663	2.486
26	3.415	3.157	3.029	2.841	2.681	2.502
27	3.440	3.178	3.049	2.859	2.698	2.519
28	3.464	3.199	3.068	2.876	2.714	2.534
29	3.486	3.218	3.085	2.893	2.730	2.549
30	3.507	3.236	3.103	2.908	2.745	2.563
31	3.528	3.253	3.119	2.924	2.759	2.577
32	3.546	3.270	3.135	2.938	2.773	2.591
33	3.565	3.286	3.150	2.952	2.786	2.604
34	3.582	3.301	3.164	2.965	2.799	2.616
35	3.599	3.316	3.178	2.979	2.811	2.628
36	3.616	3.330	3.191	2.991	2.823	2.639
37	3.631	3.343	3.204	3.003	2.835	2.650
38	3.646	3.356	3.216	3.014	2.846	2.661
39	3.660	3.369	3.228	3.025	2.857	2.671
40	3.673	3.381	3.240	3.036	2.866	2.682
41	3.687	3.393	3.251	3.046	2.877	2.692
42	3.700	3.404	3.261	3.057	2.887	2.700
43	3.712	3.415	3.271	3.067	2.896	2.710
44	3.724	3.425	3.282	3.075	2.905	2.719
45	3.736	3.435	3.292	3.085	2.914	2.727
46	3.747	3.445	3.302	3.094	2.923	2.736
47	3.757	3.455	3.310	3.103	2.931	2.744
48	3.768	3.464	3.319	3.111	2.940	2.753
49	3.779	3.474	3.329	3.120	2.948	2.760
50	3.789	3.483	3.336	3.128	2.956	2.768

(Continued)

TABLE 8 (Continued)

Number of Observations, n	Upper 0.1% Significance Level	Upper 0.5% Significance Level	Upper 1% Significance Level	Upper 2.5% Significance Level	Upper 5% Significance Level	Upper 10% Significance Level
51	3.798	3.491	3.345	3.136	2.964	2.775
52	3.808	3.500	3.353	3.143	2.971	2.783
53	3.816	3.507	3.361	3.151	2.978	2.790
54	3.825	3.516	3.368	3.158	2.986	2.798
55	3.834	3.524	3.376	3.166	2.992	2.804
56	3.842	3.531	3.383	3.172	3.000	2.811
57	3.851	3.539	3.391	3.180	3.006	2.818
58	3.858	3.546	3.397	3.186	3.013	2.824
59	3.867	3.553	3.405	3.193	3.019	2.831
60	3.874	3.560	3.411	3.199	3.025	2.837
61	3.882	3.566	3.418	3.205	3.032	2.842
62	3.889	3.573	3.424	3.212	3.037	2.849
63	3.896	3.579	3.430	3.218	3.044	2.854
64	3.903	3.586	3.437	3.224	3.049	2.860
65	3.910	3.592	3.442	3.230	3.055	2.866
66	3.917	3.598	3.449	3.235	3.061	2.871
67	3.923	3.605	3.454	3.241	3.066	2.877
68	3.930	3.610	3.460	3.246	3.071	2.883
69	3.936	3.617	3.466	3.252	3.076	2.888
70	3.942	3.622	3.471	3.257	3.082	2.893
71	3.948	3.627	3.476	3.262	3.087	2.897
72	3.954	3.633	3.482	3.267	3.092	2.903
73	3.960	3.638	3.487	3.272	3.095	2.908
74	3.965	3.643	3.492	3.278	3.102	2.912
75	3.971	3.648	3.496	3.282	3.107	2.917
76	3.977	3.654	3.502	3.287	3.111	2.922
77	3.982	3.658	3.507	3.291	3.117	2.927
78	3.987	3.663	3.511	3.297	3.121	2.931
79	3.992	3.669	3.516	3.301	3.125	2.935
80	3.998	3.673	3.521	3.305	3.130	2.940
81	4.002	3.677	3.525	3.309	3.134	2.945
82	4.007	3.682	3.529	3.315	3.139	2.949
83	4.012	3.687	3.534	3.319	3.143	2.953
84	4.017	3.691	3.539	3.323	3.147	2.957
85	4.021	3.695	3.543	3.327	3.151	2.961
86	4.025	3.699	3.547	3.331	3.155	3.966
87	4.031	3.704	3.551	3.335	3.160	2.970
88	4.035	3.708	3.555	3.339	3.163	2.973
89	4.039	3.712	3.559	3.343	3.167	2.977
90	4.044	3.716	3.563	3.347	3.171	2.981
91	4.049	3.720	3.567	3.350	3.174	2.984
92	4.053	3.723	3.570	3.355	3.179	2.989
93	4.057	3.728	3.575	3.358	3.182	2.993
94	4.060	3.732	3.579	3.362	3.186	2.996
95	4.064	3.736	3.582	3.365	3.189	3.000
96	4.069	3.739	3.586	3.369	3.193	3.003
97	4.073	3.744	3.589	3.372	3.196	3.006
98	4.076	3.747	3.593	3.377	3.201	3.011
99	4.080	3.750	3.597	3.380	3.204	3.014
100	4.084	3.754	3.600	3.383	3.207	3.017

(Continued)

TABLE 8 (Continued)

Number of Observations, n	Upper 0.1% Significance Level	Upper 0.5% Significance Level	Upper 1% Significance Level	Upper 2.5% Significance Level	Upper 5% Significance Level	Upper 10% Significance Level
101	4.088	3.757	3.603	3.386	3.210	3.021
102	4.092	3.760	3.607	3.390	3.214	3.024
103	4.095	3.765	3.610	3.393	3.217	3.027
104	4.098	3.768	3.614	3.397	3.220	3.030
105	4.102	3.771	3.617	3.400	3.224	3.033
106	4.105	3.774	3.620	3.403	3.227	3.037
107	4.109	3.777	3.623	3.406	3.230	3.040
108	4.112	3.780	3.626	3.409	3.233	3.043
109	4.116	3.784	3.629	3.412	3.236	3.046
110	4.119	3.787	3.632	3.415	3.239	3.049
111	4.122	3.790	3.636	3.418	3.242	3.052
112	4.125	3.793	3.639	3.422	3.245	3.055
113	4.129	3.796	3.642	3.424	3.248	3.058
114	4.132	3.799	3.645	3.427	3.251	3.061
115	4.135	3.802	3.647	3.430	3.254	3.064
116	4.137	3.805	3.650	3.433	3.257	3.067
117	4.141	3.808	3.653	3.435	3.259	3.070
118	4.144	3.811	3.656	3.438	3.262	3.073
119	4.146	3.814	3.659	3.441	3.265	3.075
120	4.150	3.817	3.662	3.444	3.267	3.078
121	4.153	3.819	3.665	3.447	3.270	3.081
122	4.156	3.822	3.667	3.450	3.274	3.083
123	4.159	3.824	3.670	3.452	3.276	3.086
124	4.161	3.827	3.672	3.455	3.279	3.089
125	4.164	3.831	3.675	3.457	3.281	3.092
126	4.166	3.833	3.677	3.460	3.284	3.095
127	4.169	3.836	3.680	3.462	3.286	3.097
128	4.173	3.838	3.683	3.465	3.289	3.100
129	4.175	3.840	3.686	3.467	3.291	3.102
130	4.178	3.843	3.688	3.470	3.294	3.104
131	4.180	3.845	3.690	3.473	3.296	3.107
132	4.183	3.848	3.693	3.475	3.298	3.109
133	4.185	3.850	3.695	3.478	3.302	3.112
134	4.188	3.853	3.697	3.480	3.304	3.114
135	4.190	3.856	3.700	3.482	3.306	3.116
136	4.193	3.858	3.702	3.484	3.309	3.119
137	4.196	3.860	3.704	3.487	3.311	3.122
138	4.198	3.863	3.707	3.489	3.313	3.124
139	4.200	3.865	3.710	3.491	3.315	3.126
140	4.203	3.867	3.712	3.493	3.318	3.129
141	4.205	3.869	3.714	3.497	3.320	3.131
142	4.207	3.871	3.716	3.499	3.322	3.133
143	4.209	3.874	3.719	3.501	3.324	3.135
144	4.212	3.876	3.721	3.503	3.326	3.138
145	4.214	3.879	3.723	3.505	3.328	3.140
146	4.216	3.881	3.725	3.507	3.331	3.142
147	4.219	3.883	3.727	3.509	3.334	3.144

SOURCE: ASTM Designation E178-75, 1975. "Standard Recommended Practice for Dealing With Outlying Observations."