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Background Ground-Water Quality of the Kirtland Air Force Base Area, Bernalillo County, New Mexico

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Abstract

Background ground-water quality must be known to assess environmental impacts at Sandia National Laboratories and the Inhalation Toxicology Research Institute. Both of these Department of Energy (DOE) facilities are located on Kirtland Air Force Base (KAFB), in Bernalillo County, New Mexico. In this report, maximum background concentrations and other statistical descriptors were established for major ions and for a number of other inorganic ground-water constituents in the KAFB area. Stiff diagrams, Piper diagrams and concentration maps were also prepared, and in combination with the statistical results, used to develop a detailed model of KAFB-area ground-water quality.

Results of this study reveal that most trace constituents, several minor species, and sulfate are characterized by single populations which encompass all ground water in the KAFB area. In contrast, two discrete populations were identified for most major ions, for some minor species, and for a few trace ground-water constituents. These two discrete populations were subdivided into the low and high-TDS hydrochemical facies on the basis of having relatively small or large concentrations of total dissolved solids (TDS).

The low-TDS hydrochemical facies is characterized by relatively small concentrations of total dissolved solids, bicarbonate, alkalinity, chloride; total calcium, potassium, sodium, and magnesium; and total and filtered boron, lithium, and strontium; and relatively low specific conductance. Ground waters representative of this facies are predominantly calcium-bicarbonate waters and underlie the bulk of the KAFB-area.

In contrast, the high-TDS hydrochemical facies is characterized by relatively large concentrations of total dissolved solids, bicarbonate, alkalinity, bromide, chloride, dissolved iron; total calcium, magnesium, potassium and sodium; and total and dissolved boron, lithium, manganese, and strontium; and relatively high specific conductance. Stiff diagrams show that these waters are calcium-sodium-bicarbonate-chloride waters. The high-TDS facies is restricted to the general area near the convergence of the Tijeras, Sandia, and Hubbell Spring Faults, occupying much of the pediment area on KAFB. The high-TDS hydrochemical facies likely represents various mixtures of shallow ground waters with deep waters that are migrating upward along faults.

Elevated salinities of ground-water samples from wells KAFB-10 and CWL-BW3 suggest that liquid-phase contaminants have reached the water table at Technical Area 5 and the Chemical Waste Landfill (CWL). Concentrations of chromium and nickel in ground-water samples collected from CWL-BW3 exceed maximum background values, indicating that ground water monitored by the well is contaminated with these metals probably due to leakage from sources in the CWL area.

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Background Ground-Water Quality of the Kirtland Air Force Base Area, Bernalillo County, New Mexico

1. Introduction

Sandia National Laboratories (SNL) and the Inhalation Toxicology Research Institute (ITRI) are located south of Albuquerque on Kirtland Air Force Base (KAFB), in Bernalillo County, New Mexico. SNL is operated for the U. S. Department of Energy (DOE) by Sandia Corporation, a wholly-owned subsidiary of Martin Marietta Corporation. ITRI is operated for the DOE by the Lovelace Biomedical and Environmental Research Institute. As shown in Figure 1.1, SNL research facilities occupy five technical areas and several remote sites distributed throughout much of the KAFB area; whereas, ITRI encompasses a single site along the southern boundary of KAFB. In this report, the KAFB area refers to KAFB proper, the withdrawn U. S. Forest Service lands east of KAFB, DOE lands within KAFB, and portions of Albuquerque and the Isleta Pueblo lying immediately adjacent to the northern and southern boundaries of KAFB; respectively.

Numerous DOE Environmental Restoration (ER) sites are scattered across the KAFB area. SNL ER sites are depicted in Figures 1.2, 1.3, and 1.4; whereas, ITRI ER sites are shown in Figure 1.5. Solid Waste Management Units and Operable Units corresponding to SNL ER sites are listed in McDonald and Stone (1993; Table 1). At these ER sites, a wide variety of chemicals, hazardous wastes, radionuclides, fuels, explosives, and metals have been or may have been released to the environment.

The New Mexico Environment Department (NMED) entered into an agreement with the DOE in October 1990 (the Agreement in Principle or "AIP") to provide State oversight of DOE waste management and environmental activities. As part of these oversight duties, the present study was commissioned to improve the NMED's understanding of the hydrogeologic system in the KAFB area. Background hydrochemistry must be characterized before environmental impacts at SNL and ITRI can be assessed. However, comprehensive studies of background hydrochemistry have not been completed by either of these DOE facilities.

For a given constituent, background hydrochemistry is herein defined as a population of ground-water data representing natural conditions. Ideally, such a sample population can be conveniently represented by various statistical descriptors, including a concentration limit for maximum background. In this study, ground-water samples were collected from 38 locations in the KAFB area to obtain random, stable, and independent data that are suitable for a statistical evaluation of background conditions. Each sample was analyzed in the laboratory for general chemistry, total and dissolved metals, nitrate plus nitrite, and total phosphorus.

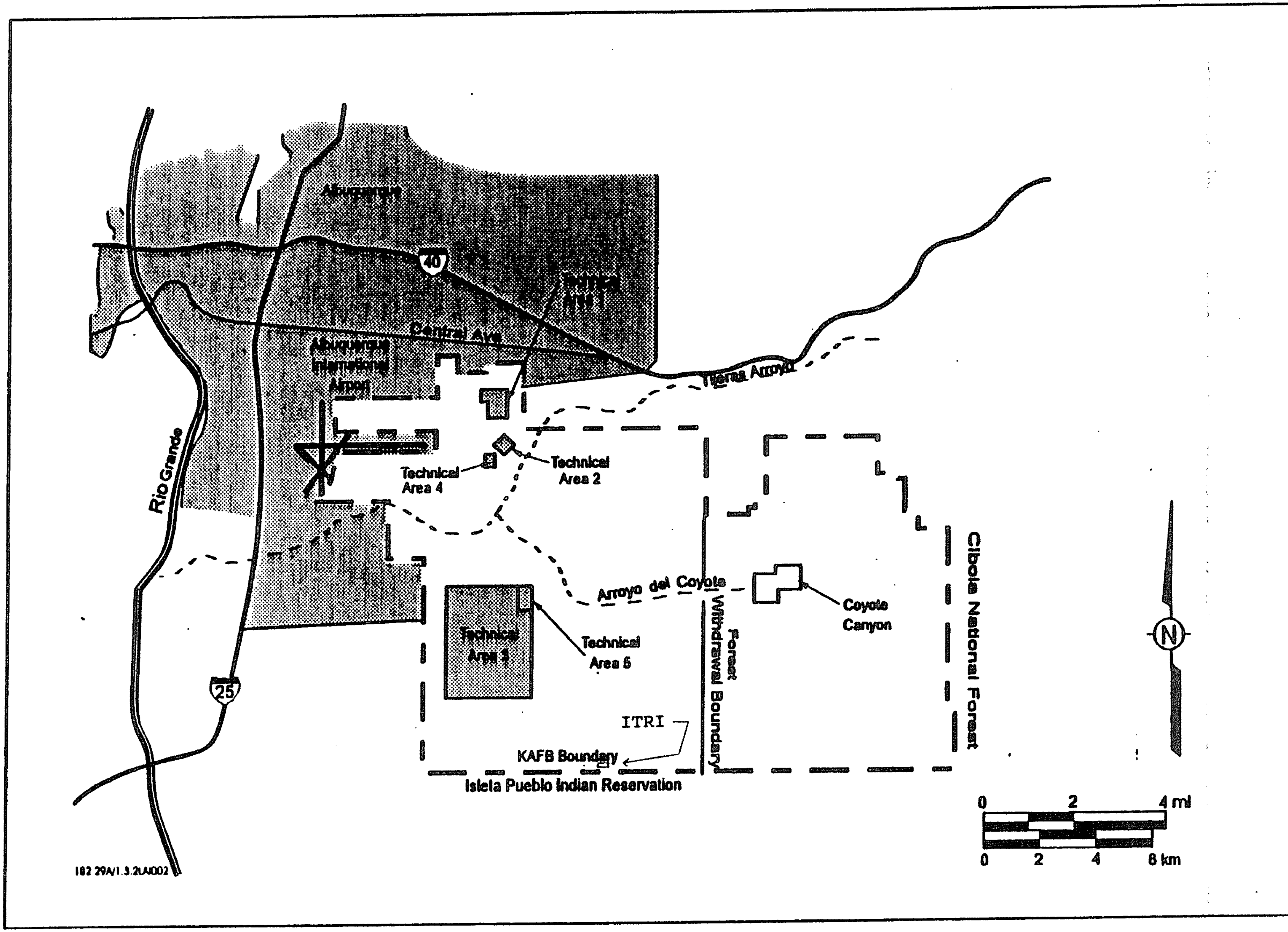


Figure 1.1. Location of Kirtland Air Force Base (KAFB), Sandia National Laboratories' (SNL) Technical Areas 1-5, and the

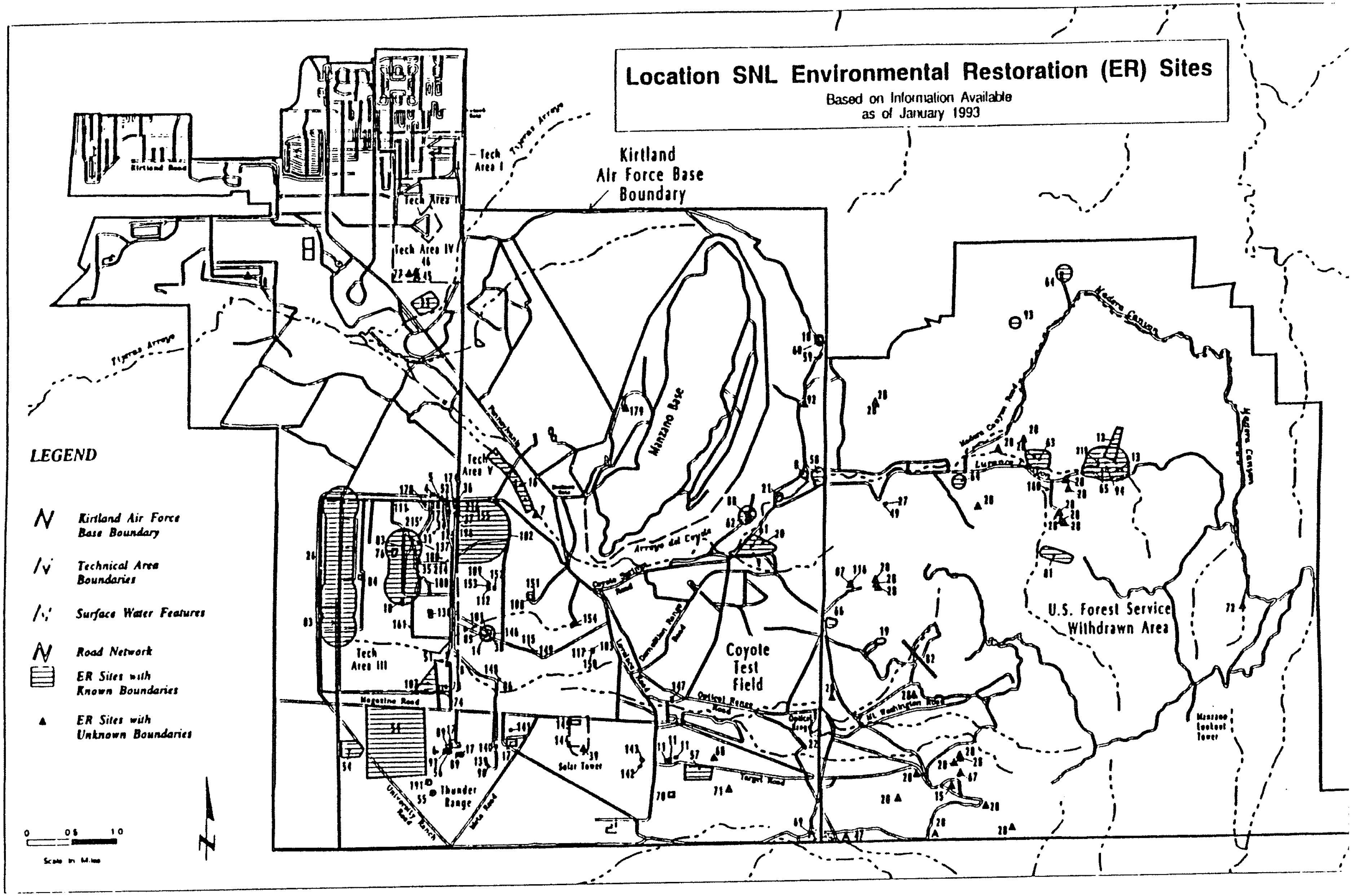


Figure 1.2. Location map of SNL environmental restoration sites, excluding Technical Areas 1 and 2 (from SNL Environmental Restoration Program).

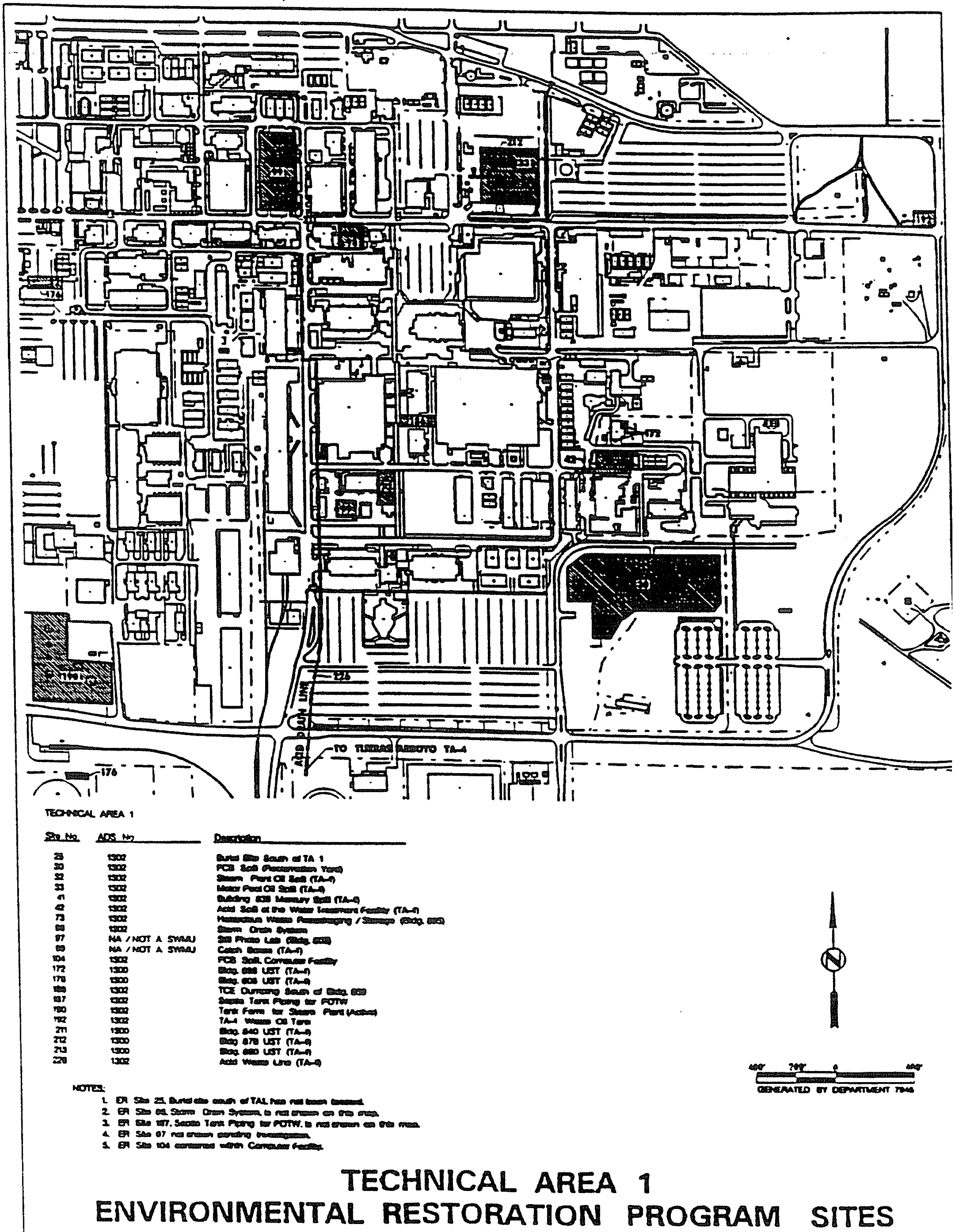


Figure 1.3. Location map of SNL Technical Area 1 environmental restoration sites (from SNL Environmental Restoration Program).

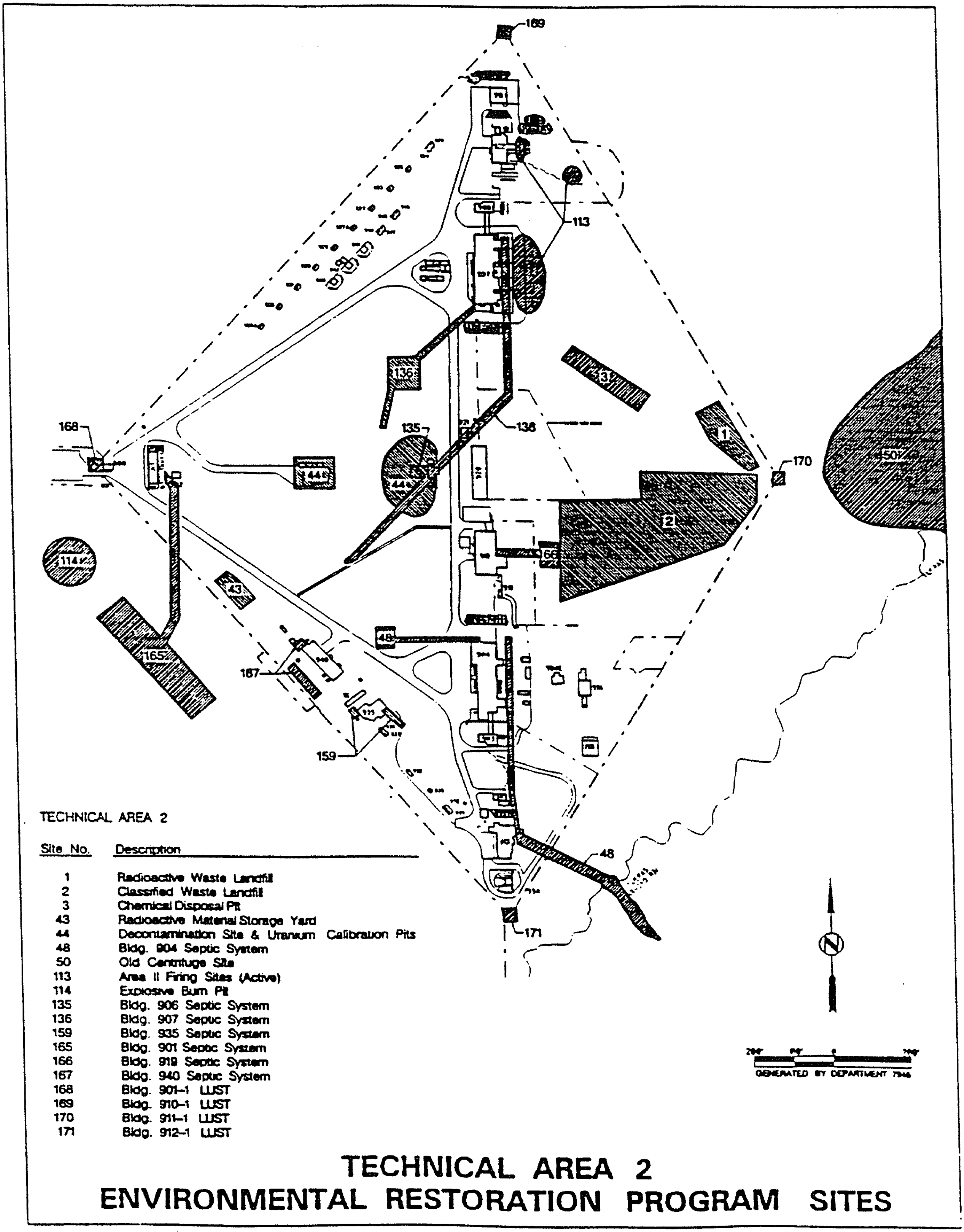


Figure 1.4. Location map of SNL Technical Area 2 environmental restoration sites (from SNL Environmental Restoration Program).

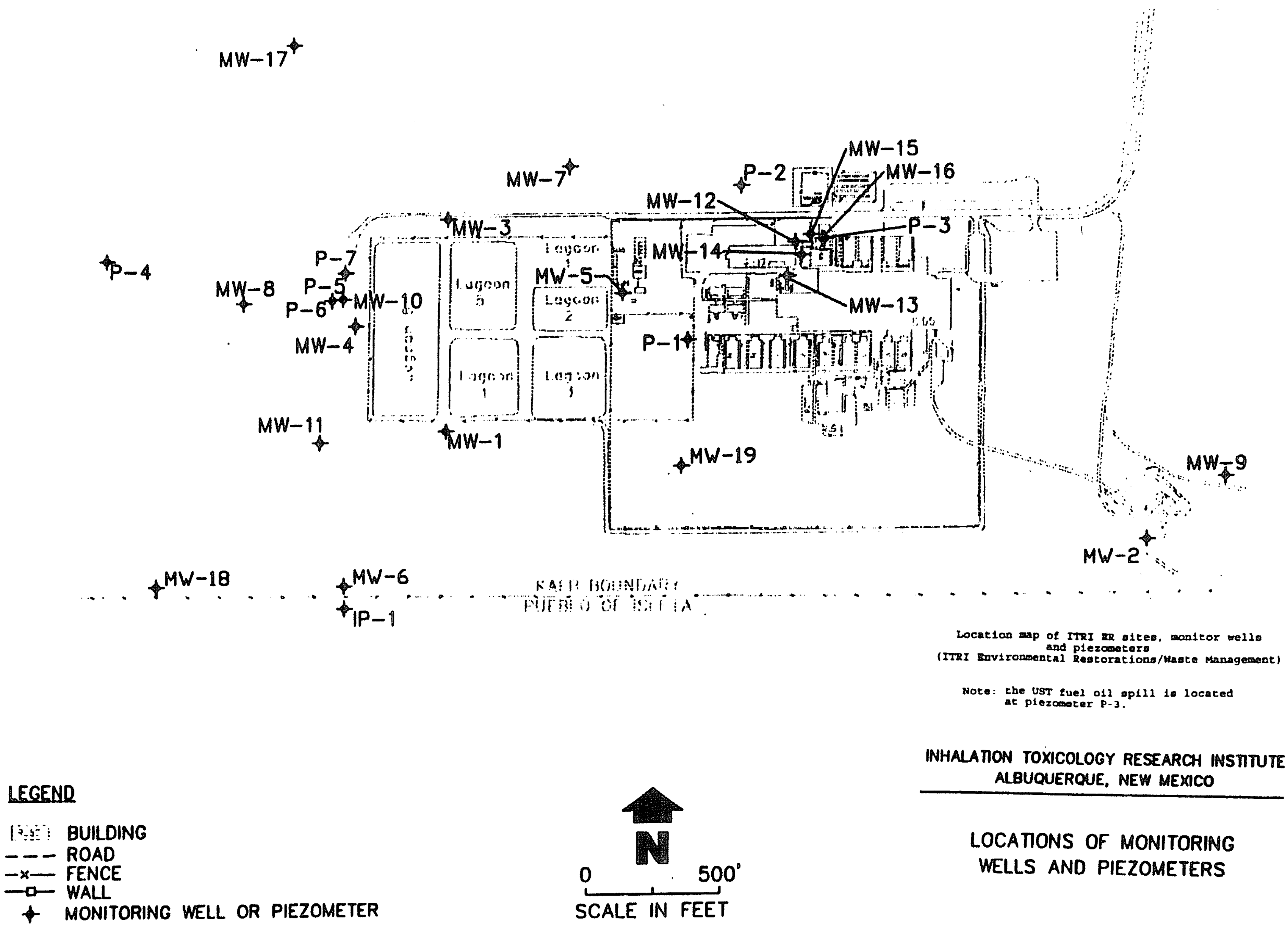


Figure 1.5. Location map of ITRI environmental restoration sites

Field measurements of temperature, dissolved oxygen, pH, and specific conductance were also made and recorded for each sample.

Using both statistical and traditional methods, the authors interpret these ground-water data to establish background hydrochemistry in the KAFB area. Piper diagrams, Stiff diagrams, and concentration maps were prepared, and in combination with the statistical results, used to develop a detailed model of KAFB-area ground-water quality.

Due to their length, the appendices of this report will be distributed only to major stakeholders such as the NMED, DOE, SNL, ITRI, KAFB, the City of Albuquerque, the Isleta Pueblo, the Bureau of Indian Affairs, and the U. S. Environmental Protection Agency (EPA). However, all summary statistics and interpretations of background hydrochemistry are included within the main body of this report. The public is welcome to review the complete set of appendices at the NMED field office at SNL or at the NMED DOE Oversight Program office in Santa Fe.

2. Geologic and Hydrogeologic Setting

2.1 Bedrock Geology of the KAFB Area

The bedrock geology of the KAFB area is relatively complex as mapped by Myers and McKay (1970 and 1976) and as discussed by Reiche (1949). A wide variety of Precambrian igneous and metamorphic rocks are exposed along the foothills and western fronts of the Sandia and Manzanita Mountains (Figure 2.1). These include the Sandia Granite, the Sevillita Rhyolite (actually a metagranite here), the greenstone complex of Reiche (1949); and several other mapped units, including biotite-granite, quartzite, and schist. General stratigraphic relationships of KAFB-area rocks are shown in Table 2.1.

Precambrian rocks in the KAFB area are unconformably overlain by Pennsylvanian-Permian sedimentary rocks which include the Sandia Formation, the Madera Limestone, and the Abo Formation. The Sandia Formation averages about 200 feet in thickness, and consists mainly of clastic sediments. A hard ledge-forming basal conglomerate, often grading upward into a pebbly coarse-grained sandstone, generally forms the base of this unit and makes an excellent marker bed.

The Madera Limestone forms a thick sequence of predominantly carbonate rocks that are exposed over much of the mountainous area of KAFB and adjacent regions. The formation averages about 1100 feet in thickness, and consists mostly of medium to thick beds of hard, cliff-forming grey calcarenite. Individual limestone beds within the unit often contain chert nodules and are typically separated from other calcarenite strata by thin layers of

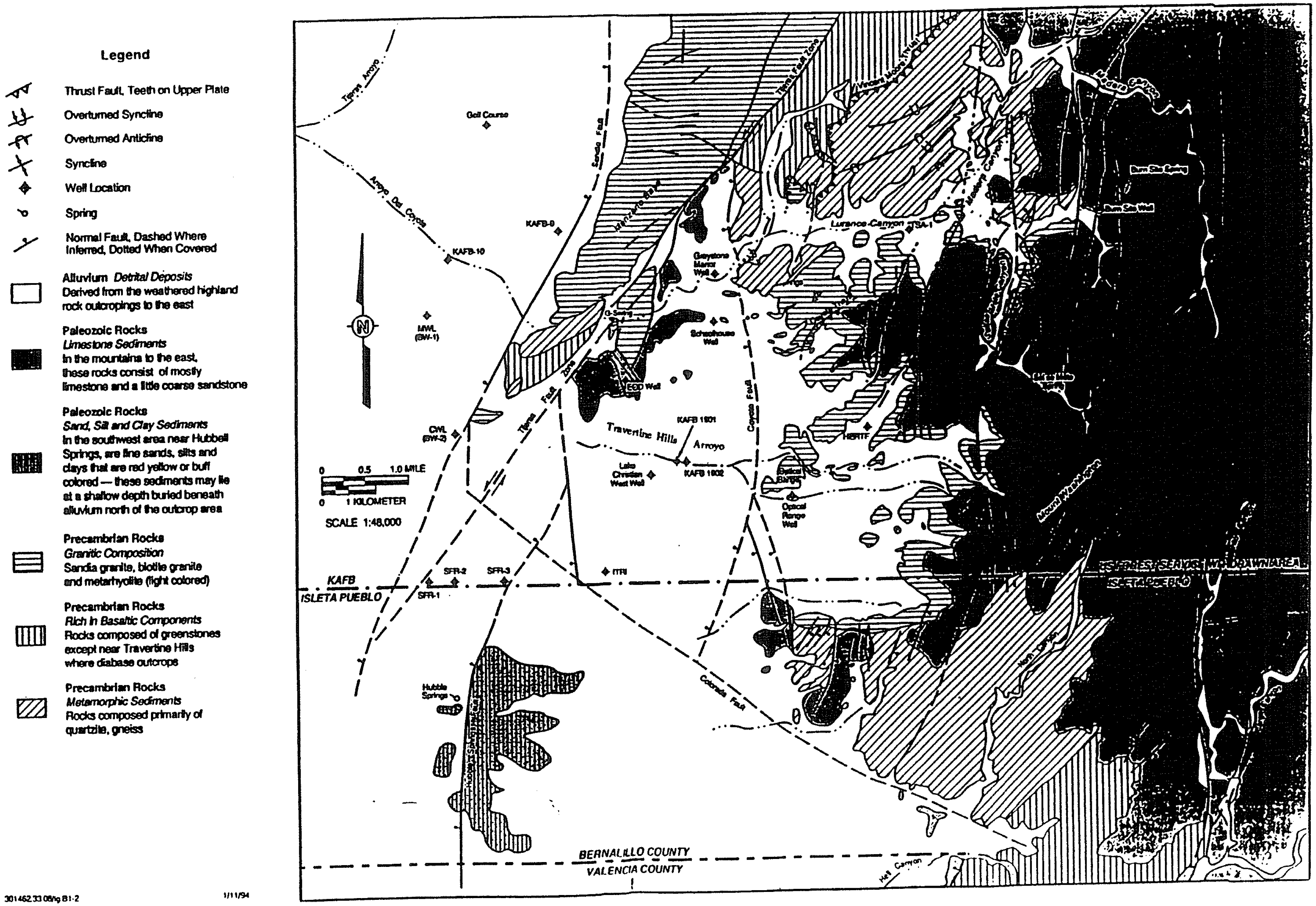


Figure 2.1. Generalized geologic map of part of the KAFB area (from McCord and others, 1994).

calcareous shale. The Madera is locally fossiliferous, containing various marine fauna such as crinoids, brachiopods, and bryozoans. The formation has been subdivided into five members (Myers and McKay, 1976), of which only the lowermost (Los Moyos Limestone) crops out over any appreciable area on KAFB.

Table 2.1

Generalized Stratigraphy of KAFB-Area Rocks

Unit	Age
Abo Formation	Lower Permian
Madera Limestone	Middle Pennsylvanian to Lower Permian
Sandia Formation	Middle Pennsylvanian
Sandia Granite	Precambrian
Biotite granite	Precambrian
Quartzite	Precambrian
Sevillita Rhyolite	Precambrian
Schist	Precambrian
Greenstone of Reiche	Precambrian

Outcrops of the Abo Formation occur on the east side of the Sandia and Manzanita Mountains and immediately south of KAFB on the Isleta Pueblo. In these areas, the Abo consists chiefly of thick, monotonous sequences of thin-bedded to medium-bedded, reddish, brownish, and purplish siltstones and fine-grained sandstones. Sporadic bleached spots throughout the rock mass of individual stratum and along fractures are a characteristic feature of these rocks, as well as occasional thin beds of white to buff-colored sandstones. The Abo Formation has been encountered in boreholes and monitor wells drilled at and near ITRI, and may occur in the subsurface along significant portions of the Hubbell Bench and the pediment areas.

2.2 Structure

Numerous faults occur throughout the KAFB area. Most of these faults trend north or northeast; however, a few trend northwest. In general, the entire sequence of Precambrian and Paleozoic rocks is uplifted and dips towards the east. The Tijeras, Hubbell Spring, Coyote, and Sandia Faults bound major structural blocks (Figure 2.1) along the eastern margin of the Albuquerque Basin. SNL's Sitewide Hydrogeologic Characterization Project is currently investigating these faults and their potential influence on KAFB-area ground water. Results of this investigation show that most, or perhaps all, of these faults affect the hydrochemistry of KAFB-area ground water.

2.3 Hydrogeologic Setting

The KAFB area lies on the east-central margin of the Albuquerque Basin, which is approximately 20 to 40 miles wide and extends 100 miles south along the Rio Grande Rift from the Jemez uplift to the Ladron uplift (Figure 2.2). The Albuquerque Basin is bounded to the east by the Sandia (Sandia/Manzanita Mountains) and Manzano uplifts and to the west by the Lucero and Ladron uplifts. The Rio Grande, a perennial stream, lies about 5 miles west of KAFB and is the basin's most important drainage feature. Alluvium aquifers within the basin are the sole source of water for New Mexico's largest metropolitan area. Due to recent concerns regarding the adequacy of future water supplies, the hydrogeology of the Albuquerque Basin is currently receiving considerable attention by a number of researchers, such as Hawley and Haase (1992), Lozinski and Tedford (1991), Thorn and others (1993), and Lozinski and others (1991).

Quaternary/Tertiary sediments of the Santa Fe Group constitute the principal basin-fill. In the KAFB area, the upper Santa Fe Group consists chiefly of unconsolidated sediments deposited by at least three alluvial fan systems: the Tijeras Arroyo, the Coyote Arroyo, and the informally-named Travertine Hills Arroyo (Figure 2.1). Alluvial fan sediments in the western portions of KAFB overlie and at depth intertongue with axial fluvial deposits of the ancestral Rio Grande. Where saturated, the latter deposits are especially important because they host much of Albuquerque's drinking water supplies. Due to a lack of deep drilling, the subsurface distribution of these ancestral Rio Grande deposits on KAFB is not well understood. However, the importance of their relationship to potential pathways of contaminant migration can not be overstated.

In the KAFB area, the relative proportions of the various lithologic and mineralogic clasts making up the alluvial fan sediments appear to differ across KAFB depending on suspected source areas. Detrital grains within these deposits are typically angular to subrounded, and generally exhibit poor sphericity. Unfortunately, sediments in each principle arroyo in the KAFB area have not been described; this precludes using such information to accurately delineate alluvial fan deposits in the KAFB area.

Thick deposits of coarse gravels and sands are mostly restricted to the canyons and the pediment, and other areas located proximal to the mountain front (such as at ITRI and elsewhere on the Hubbell Bench). Further from the mountains, these coarser sediments grade basinward into poorly-stratified, poorly-sorted deposits of silty fine-grained to medium-grained sands. Most of these finer-grained deposits contain various proportions of thin to thick beds of sandy gravels and sandy silts. Hard cemented gravels (calcretes) are found south of Manzano Base in Arroyo del Coyote (by and downstream from "G"-Spring and Coyote Spring), along the Travertine Hills, in the northeastern portions of the Isleta Pueblo, and in the

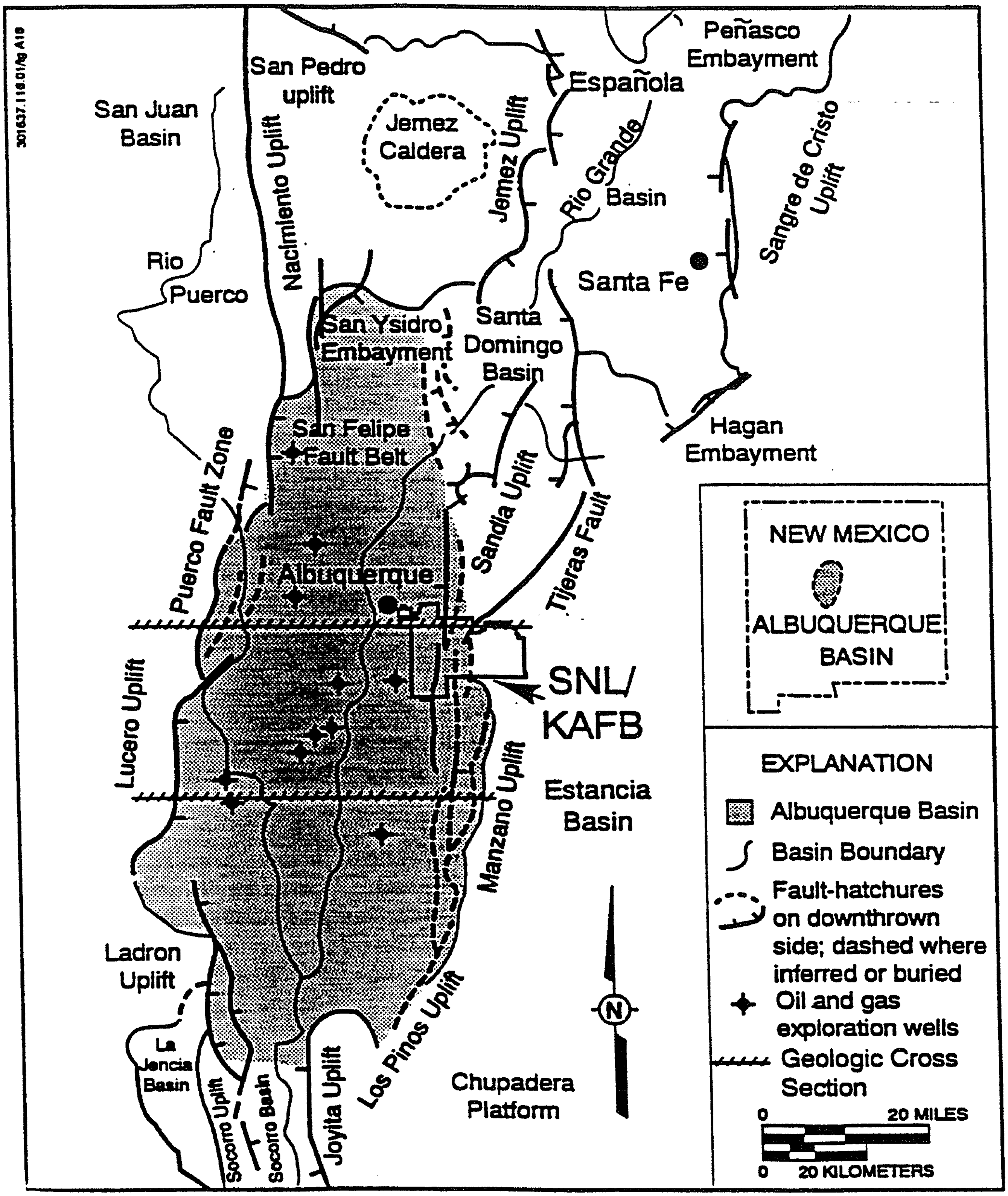


Figure 2.2. Regional tectonic setting of the Albuquerque Basin (from McCord and others, 1993).

subsurface at ITRI. The origin of these calcretes are related to ground-water quality in the KAFB area.

2.4 Ground Water in the KAFB Area

East of the major faults along the pediment and in the canyon areas, depth to ground water averages about 100 feet. In contrast, in the main part of the Albuquerque Basin west of these faults, the water table generally lies at a depth of about 500 to 600 feet. Horizontal hydraulic gradients differ markedly across the KAFB area, as suggested by the generalized potentiometric-surface map shown in Figure 2.3. Water-level data are scarce in the canyons; consequently, hydraulic gradients can not be accurately determined in these areas. Although vertical gradients exist over much of the western portion of the KAFB area, virtually no data exist to characterize them.

Regional ground-water flow is generally in a westerly to northwesterly direction, with a more northerly component near the public-supply wells in and near the northern part of KAFB. Recent work by others shows that a composite cone-of-depression presently extends south from Albuquerque across KAFB and onto the Isleta Pueblo (Thorn and others, 1993).

A number of SNL reports describe KAFB drinking-water production and conclude that changes in regional ground-water flow directions, and decreasing static water levels observed in some environmental monitoring wells are a direct result of production pumping by KAFB and the city of Albuquerque (Hwang and others, 1991; Culp and others, 1992; Culp and others, 1993). Beyond such brief references, the impact caused by Albuquerque drinking-water production hardly receives any further attention. Although KAFB drinking-water production is important, the U. S. Air Force pumps only about 4% of the volume of water produced annually by the city. Thus, ground-water flow in the KAFB area is probably controlled more by the pumping of city wells, rather than by the pumping of KAFB wells.

At least five springs occur in the KAFB area. Coyote, Hubbell, Sol Se Mete, and G-Springs are perennial; whereas, the Burn Site Spring may be intermittent in especially dry years.

3. Surface-Water System in the KAFB Area

The surface-water system in the KAFB area consists of at least five principal arroyos which, when active, recharge ground water in the Albuquerque Basin at areas west of and adjacent to the Sandia and Mazanita Mountains. The Tijeras Arroyo is the largest drainage in the KAFB area, trending west from the mountains to the Rio Grande, and draining approximately 126 mi^2 of watershed (McCord and others, 1994). The upper reaches of the arroyo are fed by Tijeras Creek,

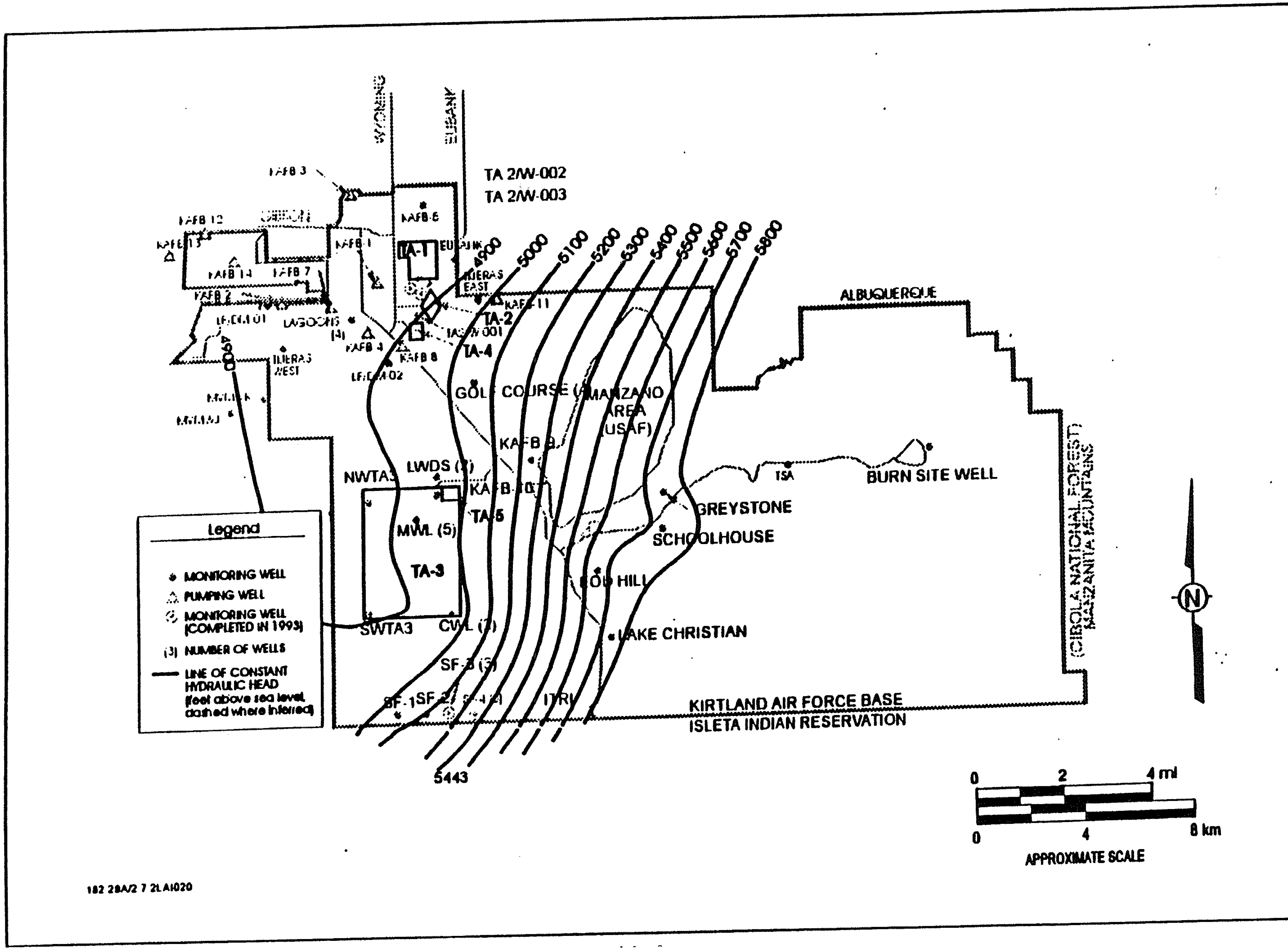


Figure 2.3. Potentiometric surface map of the KAFB area (from McCord and others, 1994). Note that contours drawn through the Manzano Base area (a bedrock high) are not likely correct.

a perennial stream. Work by staff of the U. S. Geological Survey suggests that 95% of the base flow in Tijeras Creek becomes recharge (M. Kernodle, personal communication, 1995). Several SNL ER sites are located along Tijeras Arroyo and are of special concern to the NMED/AIP (e.g. septic systems at Technical Area 2 and the outfall area of the Old Acid Discharge Line). KAFB has installed a number of wells along the arroyo at several locations. Unfortunately, SNL has installed few wells in the Tijeras Arroyo, and none in critical areas near ER sites.

Arroyo del Coyote is the second largest drainage feature in the KAFB area, draining approximately 39 mi^2, including Lurance and Madera Canyons (McCord and others, 1994). Arroyo del Coyote intersects Tijeras Arroyo at a point approximately 0.7 miles southwest of the southwest corner of Technical Area 4. As previously noted by McDonald and Stone (1993), almost no wells have been installed to monitor shallow ground water in the alluvium of the Arroyo del Coyote or its tributaries, even though several SNL ER sites are located along these drainages.

The remaining three arroyos drain smaller areas. Two of these arroyos die out just beyond the pediment in the southern part of KAFB prior to reaching other major arroyos or the Rio Grande. The first of these, the Travertine Hills Arroyo drains the canyons and surrounding highlands east of the Starfire Optical Range (SOR) (McCord and others, 1994). The other arroyo (unnamed) is located east and south of ITRI, and drains the mountain areas near the U. S. Geological Survey's seismic station. The adequacy of ground-water monitoring along these two arroyos is under investigation by NMED/AIP staff.

Finally, the smallest drainage of concern (also unnamed) lies to the east and northeast of Manzano Base. This arroyo drains into Tijeras Arroyo after passing through a residential neighborhood. The abandoned Yates' well (installed circa 1943) is the only existing well in this small channel. Unfortunately, damage to the well prevents the collection of ground-water samples.

4. Background Ground-Water Sampling Locations

Ground-water samples were collected from four springs and 34 wells located on KAFB, in the city of Albuquerque, and on the Isleta Pueblo. The locations of these 38 sampling points are shown in Figure 4.1, as well as the general physiographic areas of the Albuquerque Basin, the Mazanita Mountains, and the Sandia pediment/Hubbell Bench (a pediment is a sloping bedrock surface that is adjacent to a highland, which in places, may be covered by thin veneers of sediments). In this report, the Sandia pediment refers to the bedrock areas on KAFB that extend north of the Hubbell Bench and lie between the Sandia Fault and the mountain front.

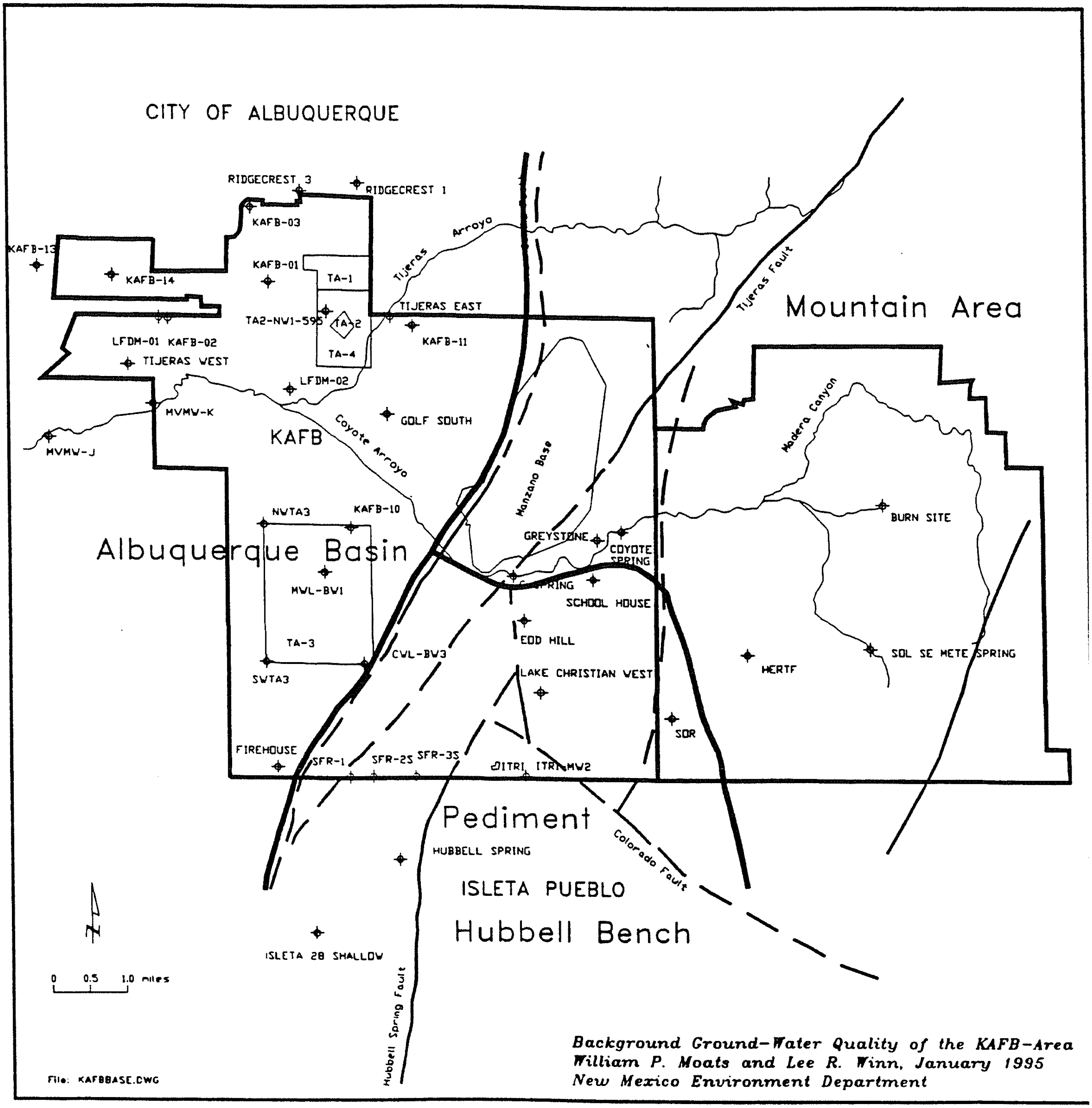


Figure 4.1. Map showing locations of ground-water sampling sites (Phase-1 and Phase-2). The physiographic areas of the Albuquerque Basin, Mazanita Mountains, and the Sandia pediment/Hubbell Bench are also shown.

In the authors' opinion, there are not enough monitor wells and springs in the KAFB area that are outside the influence of contaminated sites to provide adequate coverage for a background investigation. Thus, production wells were sampled as part of this study to fill data gaps. A few of the wells sampled for this study are known to monitor ground waters containing low to relatively high concentrations of inorganic contaminants. Obviously data derived from sample fractions that are representative of contaminated conditions should not be used in a background investigation. Therefore, decisions regarding whether specific data are representative of background hydrochemistry were made on a case-by-case basis following the screening process described in Section 7.1.

Sampling for this study was conducted pursuant to guidance found in *Environmental Sampling Standard Operating Procedures for the New Mexico Hazardous and Radioactive Materials Bureau DOE Oversight Program* and EPA's *Technical Enforcement Guidance Document*. Because of budget constraints, sampling was done in two phases. Phase-1 sites were sampled from April 4 to May 21, 1993; whereas, Phase-2 sampling was conducted from August 30 to October 22, 1993. Sample locations for each phase are specified in Sections 4.1 and 4.2.

Samples were analyzed in the laboratory for total and dissolved metals (Cr, Ni, Fe, Cd, Cu, Co, V, Mn, Zn, Ba, B, Pb, Al, Li, Sr), nitrate plus nitrite as nitrogen, total phosphorus, and general chemistry (calcium, magnesium, sodium, potassium, alkalinity, chloride, bromide, fluoride, sulfate, silica , bicarbonate, carbonate, total dissolved solids). *Dissolved metals* refer to the concentrations of metals in ground-water samples passed through 0.45 μm filters (In this report, the terms *filtered* and *dissolved metals* are considered fungible, and thus, both are used throughout the text). Phase-2 filtered samples for major cations were inadvertently not analyzed.

Temperature, dissolved oxygen, pH, and specific conductance were measured in the field at each sample location. Specific gravity was measured only for Phase-1 samples. Laboratory analytical data are presented in Appendix A of this report; whereas, field measurements are tabulated in Appendix B. Copies of raw analytical data and associated quality-control (QC) data are available for public inspection upon written request at the NMED/DOE Oversight office in Santa Fe.

4.1 Phase-1 Samples

Phase-1 samples were collected in conjunction with those of SNL's Ground-Water Surveillance Task. During Phase-1, SNL chose to collect split-samples for nearly all of the ground-water constituents investigated by this study. Analytical results for SNL's split-samples are included in the tables presented in Appendix C. KAFB-10 could not be purged prior to collecting the various sample fractions from this well. In addition, SNL sampled

KAFB-10 a few days later than the NMED due to problems with monitoring equipment.

All Phase-1 samples were submitted to Analytical Technologies, Incorporated (ATI). Sample locations, dates and times, and corresponding ATI laboratory identification numbers are listed in Table 4.1. Phase-1 field quality-control samples are listed in Table 4.2

Table 4.1

Phase-1 Samples

Well Name	Date	Time	ATI Lab ID#
Coyote Spring	04/12/93	0918	304341
Burn Site Well	04/12/93	1100	304341
Sol Se Mete Spring	04/12/93	1300	304341
Greystone	04/13/93	1025	304345
Hubbell Spring	04/14/93	0945	304360
SWTA3	04/15/93	1150	304373
KAFB-10	04/19/93	1244	304387
MVMW-J	04/22/93	0935	304412
MVMW-K	04/22/93	1239	304412
MWL-BW1	04/28/93	1145	304444
MWL-MW1	04/27/93	1015	304438
MWL-MW3	04/27/93	1300	304438
MWL-MW2	04/26/93	1155	304430
Schoolhouse	04/29/93	0940	304448
Golf Course S.	04/29/93	1345	304448
Tijeras East	05/04/93	1200	305303
LFDM-02	05/05/93	1335	305306
SFR-2S	05/06/93	1130	305311
SFR-1D	05/06/93	1500	305311
CWL-BW3	05/21/93	0931	305360

Field quality control samples EDOC-1 and EDOC-5 are blanks prepared with deionized water obtained from the Scientific Laboratory Division (SLD) of the New Mexico Department of Health. EDOC-2 is a field replicate of MWL-MW2; SFR-2SB is a field replicate of SFR-2S.

Table 4.2

Phase-1 Quality Control Samples

QC Sample	Date	Time	ATI Lab ID#
EDOC-1	04/26/93	0900	304430
EDOC-2	04/26/93	1430	304430
SFR-2SB	05/06/93	1138	305311
EDOC-5	05/21/93	0800	305360

4.2 Phase-2 Samples

Most Phase-2 samples were collected by the NMED without SNL participation. During Phase-2, SNL chose to collect split-samples from NWTA3, LFDM-01, and EOD Hill. These three wells are routinely monitored by SNL's Ground-Water Surveillance Task on a quarterly basis (recently changed to semiannual). SNL's split-sample results for NWTA3, LFDM-01, and EOD Hill are included in the tables in Appendix C. KAFB, the City of Albuquerque, and the Isleta Pueblo elected not to collect split-samples from wells owned by them.

Samples from KAFB and Albuquerque production wells represent untreated ground water obtained from taps installed immediately downstream from the pumps. G-Spring was sampled using a glass beaker as a dipper. ITRI-MW2 was sampled with a dedicated Grundfos™ pump. All other ground-water samples were collected using portable Bennett™ pumps.

Phase-2 samples were submitted to SLD for laboratory analyses. Table 4.3 provides a list of Phase-2 sample locations, sample-collection dates, and corresponding SLD laboratory-request identification numbers. Dissolved oxygen for KAFB-10 was measured a few days later than the reported sampling date due to battery failure of the instrument. Phase-2 field quality control samples are listed in Table 4.4.

Field quality control samples EDOC-6 and EDOC-8 are blanks prepared with deionized water from SLD. EDOC-7 is a field replicate of LFDM-01; EDOC-9 is a field replicate of ITRI-MW2.

4.3 Supplemental Ground-Water Sampling

Supplemental ground-water samples were collected from two wells in support of this investigation (Table 4.5). Because monitor well TA2-NW1-595 had not been sampled prior to October 7, 1993, additional sample fractions for organics and radiochemistry were collected to characterize waste water generated during purging. Sampling of SWTA3 ground water was repeated after discovering appreciable quantities of filtered chromium (the second sampling verified initial results). This unexplained occurrence of filtered chromium at relatively high levels is apparently unique to this well. Supplementary sample results for both monitor wells are included in Appendix D.

Table 4.3
Phase-2 Samples

Well Name	SLD Request Numbers	Date
KAFB-1	059151, 059152, 059153, 059154	08/30/93
KAFB-2	059155, 059156, 059157, 059158	08/30/93
KAFB-3	059159, 059160, 059161, 059162	08/30/93
KAFB-11	059163, 059164, 059165, 059166	09/02/93
KAFB-13	059167, 059168, 059169, 159170	09/02/93
KAFB-14	059171, 059172, 059173, 059174	09/02/93
Firehouse	059175, 059176, 059177, 059178	09/07/93
SOR	062000, 062001, 062002, 062003	09/07/93
HERTF	062004, 062005, 062006, 062007	09/08/93
NWTA3	062008, 062009, 062010, 062011	09/27/93
EOD Hill	062012, 062013, 062014, 062015	09/28/93
LFDM-01	062024, 062025, 062026, 062027	09/29/93
G-Spring	062028, 062029, 062030, 062031	09/30/93
Lake Christian W.	062032, 062033, 062034, 062035	10/04/93
Tijeras West	062036, 062037, 062038, 062039	10/05/93
SFR-3S	062040, 062041, 062042, 062043	10/06/93
TA2-NW1-595	062044, 062045, 062046, 062047	10/07/93
Isleta 28 Deep	062053, 062054, 062055, 062056	10/13/93
Isleta 28 Shallow	062057, 062058, 062059, 062060	10/13/93
ABQ Ridgecrest 1	062061, 062062, 062063, 062064	10/14/93
ABQ Ridgecrest 3	062065, 062066, 062067, 062068	10/14/93
ITRI-MW2	062077, 062078, 062079, 065320	10/22/93

Table 4.4
Phase-2 Quality Control Samples

QC Sample	SLD Request Numbers	Date
EDOC-6	062016, 062017, 062018, 062019	09/29/93
EDOC-7	062020, 062021, 062022, 062023	09/29/93
EDOC-8	062069, 062070, 062071, 062072	10/22/93
EDOC-9	062073, 062074, 062075, 062076	10/22/93

Table 4.5

Supplemental Ground-Water Samples

Well Name	Parameter	SLD Request Numbers
TA2-NW1-595	VOCs, BNAs, RAD[1]	062048, 062049, 062052
SWTA3	Cr, Ni, Fe, Mo	062050[2], 062051[3]

Notes: [1] Gross alpha, gross beta, gamma-spec; sampled 10/07/93
[2] Total metals, sampled 10/06/93
[3] Filtered metals, sampled 10/06/93

4.4 Availability of Historical Ground-Water Data

Historical ground-water data for major ions, nutrients, and total metals are provided in Appendix C. Abundant historical data are available for most sampling locations in the KAFB area for major ions, nitrate plus nitrite, and a few trace metals such as chromium and lead. In contrast, almost no data exist for total phosphorus, aluminum, boron, lithium, and strontium. The few data for boron, strontium, and lithium are especially puzzling, given that these minor constituents may be useful for determining specific ground-water types. Ground-water data for cobalt, vanadium, and zinc are restricted mainly to monitor wells at regulated sites such as the Mixed Waste Landfill and the Chemical Waste Landfill. Historical data for alkalinity and bromide are common only for wells and springs that are included in SNL's Ground-Water Surveillance Task. Analytical results for TDS and silica are generally only available from production wells.

4.5 Aquifer and Well-Construction Information

Selected aquifer and well-construction information for KAFB area wells and springs is provided in Table 4.6.

Table 4.6

Aquifer and Well-Construction Information for KAFB-Area Wells and Springs

Well/Spring	Type	Screened Interval	Sand Pack Interval	Screen Material	Total Depth	Drilling Method	Aquifer
CWL-BW3	M	485.5-505.5	473.3-508?	304SS WR	533	AR	SFG
Burnsite	P	230-350	unknown	unknown	350	unknown	p€qs?
Greystone	P	44-54?	unknown	PVC/STEEL	54?	unknown	SFG?
SWTA3	M	407.2-427.2	395-432.2?	SS WR	467	MR	SFG
KAFB-10	P	495-1044[1]	unknown	STEEL?	1044	MR	SFG?, bedrock at 1025-1044?
MVMW-J	M	200-220	193-225?	PVC	225	HSA?	SFG
MVMW-K	M	275-295	267-300?	PVC	300	HSA?	SFG
MWL-BW1	M	452.2-472.2	443-478?	304SS	478	MR	SFG
Schoolhouse	P	83-107	unknown	STEEL	107?	unknown	IPs?
Golf Course South	M	437-457	383.5-466?	304SS	495	MR	SFG
Tijeras East	M	465-525	358.5-539.5	304SS	571	MR	SFG
LFDM-02	M	378-428	370-450	PVC	450?	MR?	SFG
SFR-2S	M	97-117	74-122?	316SS	162	SONIC	SFG
SFR-1D	M	348-368	304-378?	PVC	418	SONIC & AR	SFG
Coyote Spring	S	---	---	---	---	---	bedrock?
Sol Se Mete	S	---	---	---	---	---	IPs
Hubbell Spr.	S	---	---	---	---	---	SFG?
KAFB-01	P/565	550-1199[2]	unknown	STEEL?	1199	MR	SFG
KAFB-02	P/484	494-1000	unknown	STEEL?	1000	MR	SFG
KAFB-03	P/505	452-900	unknown	STEEL?	900	MR	SFG
KAFB-11	P/705	670-1327	unknown	STEEL?	1327	MR	SFG
KAFB-13	P/480	413-953	unknown	STEEL	1000	MR	SFG?
KAFB-14	P/510	380-1000	unknown	STEEL?	1000	MR	SFG?
Firehouse	P	unknown	unknown	unknown	unknown	unknown	SFG?
SOR	P	160-320?[3]	unknown	PVC?	320?	unknown	p€mr?
HERTF	P	449-500?	unknown	OPEN HOLE	500	unknown	p€mr?
NWTA3	M	434.9-454.9	427.5-461?	SS WR	461	MR	SFG
EOD Hill	M	---	---	OPEN HOLE	212	unknown	IPm
LFDM-01	M	415-465	409-475?	PVC	480	MR?	SFG
G-Spring	S	---	---	---	---	---	bedrock?
L. Christian W.	P	60-72?	unknown	STEEL	72?	unknown	SFG?
Tijeras West	M	337-357	276.5-370.5?	304SS	415	MR	SFG
SFR-3S	M	182-212	155-222	PVC	408	SONIC	SFG
TA2-NW1-595	M	535-595[4]	523-605[4]	PVC	650	SONIC	SFG
Isleta 28 Shallow	M	30-50	30-50	PVC	50	MR	SFG?
Ridgecrest 1	P/653	636-1260	unknown	STEEL	1260	unknown	SFG?
Ridgecrest 3	P/660	620-1436	unknown	STEEL?	1475?	unknown	SFG?
ITRI-MW2	M	168-188	160-188	SS	194?	AR	SFG?

Notes:
All distances in units of feet below ground surface.
TYPE: M = Monitor Well, P = Production Well, P/565 = Production Well with pump set at 565 ft, S = Spring
SCREEN MATERIAL: SS = Stainless Steel, WR = Wire-Wrapped, 304SS = type 304 stainless, PVC = PVC plastic
DRILLING METHOD: AR = air rotary, MR = mud rotary, HSA = hollow- stem auger
AQUIFER: SFG = Santa Fe Group, IPs = Sandia Formation, IPm = Madera Limestone, p€mr = metarhyolite, p€qs = quartzite schist
[1] KAFB-10 screened 495-505, 542-577, 672-682, 700-710, 804-814, 845-875, 900-910, 954-974, 1004-1044
[2] KAFB-01 screened 550-800 and 970-1199
[3] SOR screened 160-180?, 180-200?, 240-260?, 300-320?
[4] TA2-NW1-595 screened 535-555 and 585-595, sand pack at 523-562 and 572-605

5. Quality Control

Phase-1 and Phase-2 quality control samples are listed in Tables 4.2 and 4.4; respectively. The Quality-Assurance (QA) target ranges adopted for this investigation are a precision of ± 20% Relative Percent Difference (%RPD) and an accuracy of 75-125% Recovered (%REC). To support the results of this investigation, historical data were compiled inasmuch as possible for all sampling locations for total metals and general water chemistry (Appendix C). Historical data were obtained from KAFB, SNL, and ITRI environmental reports; and City of Albuquerque, Bureau of Indian Affairs, and NMED files. Except for monitor wells at ITRI, few historical data for filtered metals could be located; thus no effort was made to document these data in this report.

Analytical results for NMED and SNL split-samples are considered to agree closely when they differ by no more than ± 20 %RPD. The same criterion is applied for the comparison of NMED data with historical data. Analytical results which failed to meet the specified QA targets were used in the analysis of background if they agreed closely with SNL split-sample data and/or if they agreed closely with or fell within the range of historical data. The few data failing to meet these criteria were omitted from the analysis of background.

5.1 Phase-1 Data

The majority of ground-water data acquired during Phase-1 fell within acceptable QC lots. Nonetheless, the Phase-1 data presented in Table 5.1 failed to meet the specified QA targets. Decisions to reject specific data are indicated in Table 5.1, as well as reasons for the retention of data. Detections for blanks EDOC-1 and EDOC-2 are listed in Table 5.2.

Although results for total and filtered metals are reported in Table 5.2, both of the blanks were actually prepared using the same unfiltered water. The low values for total alkalinity, nitrate plus nitrite, and bicarbonate are not a concern. Based on analytical results for the environmental samples and the consistency of the above values for boron, iron, lead, and zinc, we can conclude that the deionized water used to prepare these blanks probably contained relatively low concentrations of these metals. Low values for boron and iron seen in Phase-2 blanks support this conclusion.

Table 5.1
Phase-1 Data Failing Quality Assurance Target Ranges

Well/Spring	Parameter	Decision	Decision Codes
Coyote Spring	Fe	Use	1,2,3
Burn Site well	Fe	Use	1
Sol Se Mete Spring	Fe	Reject	---
Hubbell Spring	Fe	Reject	---
Hubbell Spring	Pb	Use	1
SWTA-3	Nitrate	Use	2
SWTA-3	Pb	Use	1
MVMW-J	Cr	Use	1
MVMW-K	Cr	Use	1
MWL-MW2	Cr	Use	1,3
MWL-MW2	Fe	Use	1,3
MWL-MW2	Zn	Use	2
MWL-MW2	Silica	Use	3
Schoolhouse	Zn	Reject	---
Golf Course South	Zn	Reject	---
Tijeras East	Cr	Use	1
SFR-2S	Cr	Reject	---
SFR-2S	Fe	Reject	---
SFR-1D	Cr	Use	1
SFR-1D	Fe	Use	2,3
LFDM-02	Cr	Use	1
CWL-BW3	Fe	Use	3
CWL-BW3	Zn	Reject	---

Decision Codes:
1. Falls near (+- 20 %RPD) or within range of historical data.
2. Agrees well with SNL split (+- 20% RPD)
3. Sample results closest to an acceptable QC lot and generally well above method detection limit

5.2 Phase-2 Data
Ground-water data acquired during Phase-2 met QA target ranges with the exception of fluoride, total dissolved solids, potassium, sodium, zinc, and vanadium. The SLD does not report their laboratory QC data and corresponding QC lot numbers with analytical results for inorganics. Because of this, all SLD data for these constituents were rejected unless they agreed closely with SNL split-sample data and/or historical data. The only exceptions to this rule were for vanadium and zinc where little data are available for comparison; and for fluoride, total dissolved solids, potassium, and sodium from a few wells where no other data exist. Decisions to retain or reject Phase-2 data in accordance with this process are indicated in Table 5.3.

Phase-2 data for vanadium and zinc were accepted as is because:

1. Analytical results for both vanadium and zinc appear to agree with limited historical and SNL data.

2. Duplicate analytical results for zinc and vanadium are close to their respective method detection limits. In general, data falling at concentrations approaching method detection limits commonly resulted in the poorest precision.

3. For vanadium, the 25 %RPD between duplicate samples is not far from the QA target of 20 %RPD.

Detections for Phase-2 blanks, EDOC-6 and EDOC-8, are listed in Table 5.4.

As before, both of the blanks for total and filtered metals were actually prepared with the same unfiltered deionized water. Values for total alkalinity, bicarbonate, potassium, and TDS (for EDOC-8) are relatively low and are thus ignored. The suspect results for fluoride, and TDS for EDOC-6 are likely due to laboratory error. The deionized water used to prepare EDOC-6 and EDOC-8 likely contained low concentrations of boron and iron.

Table 5.2

Detections for Phase-1 Blanks

	Totals (mg/L)	Filtered (mg/L)	MDL (mg/L)
EDOC-1			
Nitrate	0.39	-----	0.06
Zn	0.026	0.025	0.010
Fe	<0.020	0.027	0.020
EDOC-5			
Bicarbonate	2	-----	1
T. Alkalinity	2	-----	1
Nitrate	0.08	-----	0.06
B	0.32	0.31	0.10
Fe	0.039	0.029	0.020
Pb	0.002	0.002	0.002
Zn	0.020	0.017	0.010

Table 5.3

Phase-2 Data Failing Quality Assurance Target Ranges

Well/Spring	Fluoride	TDS	Potassium	Sodium
KAFB-01	1	1	1	1
KAFB-02	1	1	1	1
KAFB-03	1	1	1	1
KAFB-11	1	1	1	1
KAFB-13	1	1	R	1
KAFB-14	1	1	1	1
Firehouse	NHD	NHD	NHD	NHD
SOR	1	1	NHD	1
HERTF	1	NHD	NHD	1
NWTA3	1,2	1	1	1,2
EOD Hill	1	1	1,2	1,2
LFDM-01	1,2	1	R	1,2
G-Spring	1	NHD	1	1
Lake Christ W.	R	1	1	1
Tijeras West	NHD	NHD	NHD	NHD
SFR-3S	NHD	NHD	NHD	NHD
TA2/NW1/595	NHD	NHD	NHD	NHD
Isleta 28 D.	1	1	R	R
Isleta 28 S.	1	1	R	R
Ridgecrest 1	1	1	R	1
Ridgecrest 3	1	1	R	1
ITRI-MW2	R	R	1	1

Decision Codes:
1 = Falls near (+- 20% RPD) or within range of historical data.
2 = Agrees well with SNL split data (+- 20% RPD).
NHD = No historical data available. Data used as is.
R = Rejected data.

Table 5.4
Detections for Phase-2 Blanks

	Totals (mg/L)	Filtered (mg/L)	MDL (mg/L)
EDOC-6			
Bicarbonate	0.3	-----	1
T. Alkalinity	0.3	-----	1
TDS	70	-----	
B	0.1	-----	0.100
EDOC-8			
Bicarbonate	0.12	-----	1
T. Alkalinity	0.09	-----	1
F	2.0	-----	0.1
K	1	-----	
TDS	12	-----	
Fe	0.07	0.05	0.05

6. Distributions of Ground-Water Constituents in the KAFB Area

In most ground-water investigations, the distribution of a sample population for a given constituent is first assumed to be normal, and a test for normality is applied. If an acceptable fit to a normal distribution is not found, then the data are transformed, and an attempt is made to approximate the data to a log-normal distribution. If normality or log-normality cannot be sufficiently demonstrated, nonparametric methods can be employed to describe central tendency, or alternatively, a distribution can be assumed. Fortunately, most statistical inferences are not overly sensitive to the assumed distribution of the underlying population (Scheaffer and Mendenhall, 1975).

Histograms show the number of observations (data points) which fall within arbitrarily chosen intervals. Histograms for each ground-water constituent considered in this study are presented in Appendix E. With the exception of QA-rejected data, all data were used to generate these plots, including any outliers that might be present and any analytical results that may be representative of contamination. Data points having relatively high magnitudes compared to the rest in a given data set were sometimes omitted to improve readability; however, all such omissions are specified on the histograms. Histograms can provide insight as the type and number of distributions that may be present in a given data set.

Normal-probability plots are often used to test sample populations for normality, and to identify the presence of any multimodal populations (log-normal-probability plots are used in the same way). Due to the simplicity of this approach, probability plots were generated for each constituent in an attempt to determine their distribution(s) and to search for the existence of multimodal populations. Results of these efforts were then compared to the histograms.

Distributions could not be approximated with reasonable certainty for trace constituents where most or all of their respective analytical values fell below detection. For any given sample population, greater than 50% of its data was required to exceed the method detection limit before a distribution was accepted. Otherwise the distribution for such a data set was assigned as "unknown".

Results of this investigation show that most trace constituents, several minor constituents, and sulfate are characterized by single populations that encompass all ground water in the KAFB area. Constituents falling within this category are referred to herein as *single-population ground-water constituents*.

In contrast, two distinct populations were identified for most major, for some minor, and a few trace ground-water constituents. These two populations are subdivided on the basis of having relatively high or relatively low total dissolved solids (TDS), and are referred to herein as the *high-TDS* and the *low-TDS hydrochemical facies*; respectively. The spatial distributions of these facies are depicted in Figure 6.1. The extents of these zones are generalized because much of the northern portions of the high-TDS facies, and most of the eastern parts of the low-TDS facies are within the foothills and mountains. Except for alluvium aquifers within the arroyos and occasional springs, shallow ground water is not expected to occur in most of these bedrock areas. Readers should note that the high-TDS facies occurs within the shallow ground-water regime in the KAFB area.

Probability plots for constituents represented by a single population are presented in Appendix F. Similar plots for ground-water species characterized by two populations are presented in Appendix G for the low-TDS facies, and Appendix H for the high- TDS facies. Probability plots showing combined data for the high- TDS and low-TDS facies are included in Appendix I. With the exception of QA-rejected data, all data are included on these probability plots, including any outliers and any analytical results that may be representative of contamination. Data falling below detection are either plotted at half their detection limit, or are not shown on the plots (in the case of the high-TDS facies). Nonetheless, the positions of all data points were accounted for on the plots, even if they are not shown.

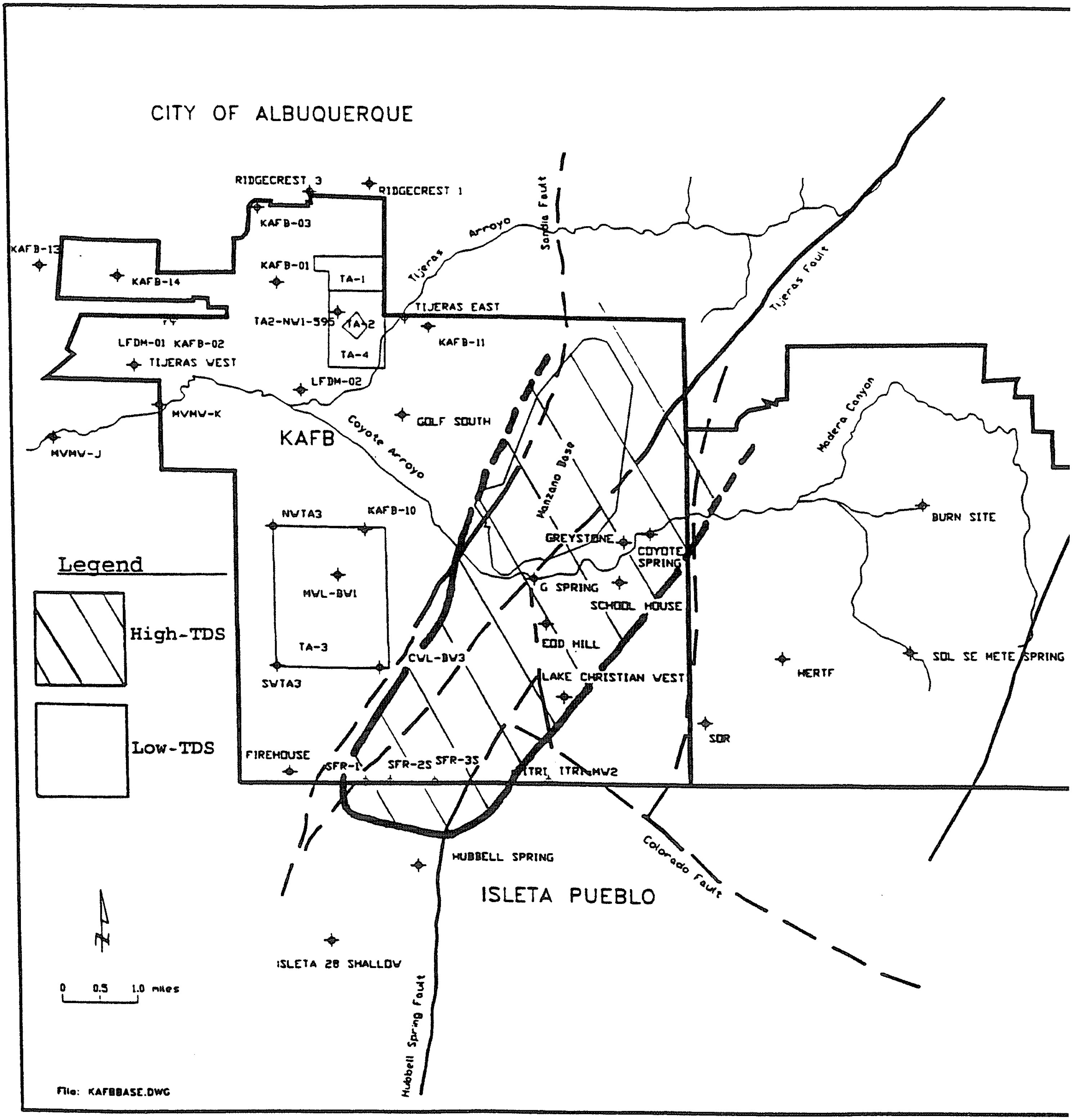


Figure 6.1. Generalized distributions of the low-TDS and high-TDS hydrochemical facies in the KAFB area.

Ground-water constituents in the KAFB area that can be approximated by normal or log-normal distributions are tabulated in Table 6.1.

Table 6.1

Distributions of Ground-Water Constituents in the KAFB Area

Parameter	Distribution	Bimodal Populations
Bicarbonate	normal	yes
Lab Alkalinity	normal	yes
Chloride	normal	yes
Fluoride	log normal	no
Nitrate + Nitrite	log normal	no
Lab pH	normal	no
Sulfate	normal	no
Gravity	normal	no
TDS	normal	yes
Total boron	log normal	yes
Filtered boron	log normal	yes
Total calcium	normal	yes
Total chromium	log normal	no
Total iron	log normal	yes
Total potassium	normal	yes
Total magnesium	normal	yes
Total sodium	normal	yes
Silica	normal	no
Total strontium	log normal	yes
Filtered strontium	log normal	yes
Dissolved oxygen	normal	no
Field pH	normal	no
Field alkalinity	normal	yes
Specific conductance	normal	yes
Temperature	normal	no

Bromide, total aluminum, filtered iron, total and filtered lithium, and total and filtered manganese appear to have bimodal populations as suggested by subsets of data for these constituents that are predominantly above method detection limits. These data subsets also correspond well with sampling points assigned to the high-TDS facies. Thus, these ground-water species were divided into data subsets that are representative of the low-TDS and high-TDS hydrochemical facies.

In most areas, major ions are usually normally distributed; whereas trace constituents are typically log-normally distributed (Hounslow, 1990). These relationships were found to be generally true of low-TDS ground water in the KAFB area.

Future investigations will probably show this to be true also for ground water of the high-TDS facies.

7. Process to Establish Background Water Quality

Background ground-water quality was evaluated in accordance with the procedures presented below. Microbial activity in the ground water was assumed to be insignificant. No attempt was made to identify distinct ground-water populations based on lithologic characteristics or the type of aquifer in which the waters reside.

7.1 Eliminating Data from Background

To ensure a stable sampling process and to maintain consistency of data quality and type, only data obtained by this study were used to determine background hydrochemistry. Although every attempt was made to use all data for each constituent, selected values were eliminated from or retained in the analysis of background hydrochemistry as described below:

1. Data falling outside the specified QA targets were incorporated in the analysis of background if and only if they were indicated as useable in Sections 5.1 and 5.2.

2. Probability plots and histograms were prepared for each constituent to approximate their distributions as either normal or log normal. The distributions of most trace constituents were assigned as "unknown".

3. Based on these plots, data found to be representative of discrete ground-water populations (hydrochemical facies) were treated separately.

4. Outliers were omitted using Grubbs Test (Section 7.2) in an effort to remove data that are representative of known or suspected contaminated conditions, spurious results, or erroneous laboratory results which otherwise passed the QA process. However, no attempt was made to look for and remove outliers from the nine sites representative of the high-TDS facies.

5. Remaining ground-water data were used to determine background hydrochemistry.

7.2 Identification of Outliers

Outliers were identified using Grubbs Test (Taylor, 1990). Grubbs test can be used to make a statistically supported decision concerning retention or rejection of a suspected outlier (Taylor, 1990). For this investigation, a 95% confidence level (5% risk of a false rejection) was chosen. A description of Grubbs Test and an accompanying table are provided in Appendix J. Both extreme high and low data were tested for each constituent.

7.3 Calculation of Background Statistics

Once step 5 of Section 7.1 was satisfied, background descriptors were determined for each inorganic species. Where data sets contain values below detection, Cohen's Method was employed to calculate corrected means and standard deviations (Cohen, 1961; Hounslow, 1990; Appendix K). For a given constituent, all data falling below the highest detection limit (DL_{max}) were assigned the value of < DL_{max} in cases where multiple detection limits were reported by the two laboratories used in this study (except as noted in Table 7.1).

Ground-water constituents that have been corrected by Cohen's Method are listed in Table 7.1. As previously mentioned, the distributions of some trace constituents could not be determined with reasonable certainty. Statistical descriptors for these constituents were calculated assuming that they can be best approximated by log-normal distributions. Previous investigators have found that trace constituents in the natural environment tend to follow log-normal distributions (Hounslow, 1990), which supports this assumption. Data values below a given detection limit were set equal to one-half of that detection limit to facilitate calculations. Upper tolerance limits were not determined for constituents with assumed distributions (except for high-TDS ground water constituents, see Section 8.2). Instead, for these constituents maximum background was set equal to the 95th percentiles of their respective sample populations.

7.4 One-Sided Upper Tolerance Limits

One-sided upper tolerance limits (UTL) were calculated for those inorganic species found to be adequately approximated by normal or log-normal distributions. A UTL is a concentration limit that is constructed to contain a specified proportion (or coverage) of a population at a specified confidence level (or tolerance coefficient). This investigation used the EPA-recommended coverage of 95% and a tolerance coefficient of 95% (Myers and others, 1989). Therefore, 95% of the population is expected to fall below the UTL at a relatively high probability of 95%. Statistically significant evidence of possible ground-water contamination occurs if a given observation exceeds the UTL for that constituent.

The procedure for calculating a UTL is as follows:

Step 1 Calculate the sample mean (X), and sample standard deviation (s).

Step 2 Construct the one-sided UTL as UTL = X + Ks, where K is the one-sided normal tolerance factor (Myers and others, 1989).

The value of K increases with increasing coverage and increasing confidence; whereas, K decreases as sample size increases. A table of K values is provided in Appendix L.

Table 7.1

Ground-Water Constituents Corrected by Cohen's Method

Constituent	Remarks
Bromide	---
Carbonate	All "0" values set to ½ DL
NO3 (1,2)	---
Total P	34 of 35 values are < DL, s undefined
Silica	---
Total Al	---
Filtered Al	---
Total B	---
Filtered B	---
Total Ba	---
Filtered Ba	---
Total Cd	36 of 37 values are < DL, s undefined
Filtered Cd	---
Total Co	37 of 38 values are < DL, s undefined
Filtered Co	---
Total Cr	Values for KAFB-1 and KAFB-3 set at ½ DL
Filtered Cr	Values for KAFB-1, KAFB-2, KAFB-3, & LFDM-01 set at ½ DL
Total Cu	---
Filtered Cu	---
Total Fe	Value for Tijeras West set at ½ DL
Filtered Fe	Tb = 1.44, Set Tb = 1
Total Pb	h = 0.92, Set h = 0.9
Filtered Pb	---
Total Li	---
Filtered Li	Tb = 2.47, Set Tb = 1
Total Mn	---
Filtered Mn	---
Total Ni	h = 0.95, set h = 0.9
Filtered Ni	h = 0.95 & Tb = 2.0, set h = 0.9 & Tb = 1.0
Total V	---
Filtered V	35 of 36 values are < DL, s undefined
Total Zn	---
Filtered Zn	Value for KAFB-11 set at ½ DL

Notes:
NO3 means nitrate plus nitrite
Total P means total phosphorus
DL means detection limit
s means sample standard deviation

8. Descriptors of KAFB-Area Background Ground-Water Quality

As discussed in Chapter 6, two hydrochemical facies were identified in the KAFB area for most major ions, for some minor constituents, and a few trace constituents. Single ground-water populations were identified for most trace constituents, several minor species, and sulfate. Sections 8.1 and 8.2 present statistical descriptors for the various constituents of the low-TDS and high-TDS hydrochemical facies; respectively. Descriptors for single-population ground-water constituents are presented in Section 8.3. Statistical descriptors are important for classifying samples from KAFB-area wells and for interpreting ground-water quality. Those determined by this study are the mean, standard deviation, median, minimum, maximum, 1st and 3rd quartiles, 25th and 75th percentiles (25th% and 75th%), and maximum background (95th percentile or an upper tolerance limit). The number of samples on which these descriptors are based, as well as the numbers of outliers and no-detects are also reported for each constituent.

In the tables of Section 8, the 1st and 3rd quartiles, and the 25th and 75th percentiles bound the middle 50% of each data set. Except for the omission of QA-rejected data, the 25th and 75th percentiles are based on the entire sample population of each constituent. The 1st and 3rd quartiles are based on data sets equivalent to the 25th and 75th percentiles; however, outliers have also been omitted using Grubb's test. Because so few outliers were identified, readers will note little difference between the 1st quartile and 25th percentile, and the 3rd quartile and 75th percentile for most constituents.

8.1 Low-TDS Hydrochemical Facies

Tables 8.1, 8.2, and 8.3 summarize statistical descriptors for the low-TDS facies for inorganic species determined to have normal, log normal, and unknown distributions; respectively. As discussed in Section 12.1, laboratory alkalinities of samples representative of the low-TDS facies should be used with caution. Historical data demonstrate that values for total and filtered concentrations of major cations are essentially equivalent for any given well or spring in the KAFB area. This suggests that the statistical descriptors for total calcium, sodium, potassium, and magnesium (Table 8.1) can be substituted for their filtered counterparts with negligible error.

Table 8.1

Statistical Descriptors for Normally Distributed Constituents of Low-TDS Ground Water in the KAFB Area

Parameter	Number of Samples	Sample Mean (mg/L)	Sample Std Dev. (mg/L)	Sample Minimum (mg/L)	Sample Maximum (mg/L)	Sample Median (mg/L)	Number of Outliers	Number of No-Detects
Chloride	27	24.0	12.8	6.0	54.0	22.0	2	0
Field Alkalinity	28	170.7	52.8	101.0	291.0	169.5	0	0
Lab Alkalinity [1]	29	150.2	53.5	22.0	244.0	140.0	0	0
Bicarbonate	29	166.9	53.9	22.0	277.0	170.0	0	0
Total Dissolved Solids	28	353.0	115.3	170.0	620.0	347.0	0	0
Specific Conductance [2]	28	417.4	150.8	126.0	700.0	426.5	1	0
Total Calcium	29	59.6	20.4	30.0	98.9	56.0	0	0
Total Magnesium	27	11.4	5.4	4.0	22.0	11.5	2	0
Total Sodium	27	33.3	18.0	11.5	79.0	26.7	1	0
Total Potassium	23	3.5	1.4	1.3	6.1	3.0	1	0

Parameter	1st Quartile (mg/L)	3rd Quartile (mg/L)	25th % (mg/L)	75th % (mg/L)
Chloride	13.5	33.0	13.5	37.0
Field Alkalinity	118.0	201.5	117.0	200.0
Lab Alkalinity [1]	105.0	189.0	105.0	190.0
Bicarbonate	125.0	205.0	125.0	207.0
Total Dissolved Solids	251.0	428.0	260.0	425.0
Specific Conductance [2]	313.0	530.0	310.0	550.0
Total Calcium	40.6	73.0	40.0	77.5
Total Magnesium	7.0	15.5	7.0	17.0
Total Sodium	22.3	31.1	22.0	40.0
Total Potassium	2.9	4.3	2.9	4.7

Notes:

(1) Laboratory alkalinity data should be used with caution. See Section 12.1 of this report.

(2) Units for specific conductance are micromhos

Table 8.2

Statistical Descriptors for Log-Normally Distributed Constituents of Low -TDS Ground Water in the KAFB Area

Parameter	Detection Limit (mg/L)	Number of Samples	Sample Mean[1] (mg/L)	Log Sample Std Dev. (mg/L)	Sample Minimum (mg/L)	Sample Maximum (mg/L)	Sample Median (mg/L)	Number of Outliers	Number of No-Detects
Total Boron	0.10	29	0.116	0.354	<0.100	0.400	0.100	0	14
Filtered Boron	0.10	29	0.111	0.347	<0.100	0.400	0.100	0	13
Total Iron	0.05	27	0.065	0.937	<0.050	5.270	0.060	0	11
Total Strontium		29	0.471	0.202	0.200	1.190	0.486	0	0
Filtered Strontium		29	0.465	0.204	0.200	1.140	0.454	0	0

Parameter	1st Quartile (mg/L)	3rd Quartile (mg/L)	25th% (mg/L)	75th% (mg/L)
Total Boron	<0.10	0.20	<0.10	0.20
Filtered Boron	<0.10	0.20	<0.10	0.20
Total Iron	<0.050	0.191	<0.050	0.200
Total Strontium	0.327	0.635	0.320	0.650
Filtered Strontium	0.300	0.600	0.300	0.640

Note:

[1] Equivalent to geometric mean

Table 8.3

Statistical Descriptors for Constituents With Unknown Distributions: Low-TDS Ground Water in the KAFB Area
(Distribution Assumed to be Log Normal)

Parameter	Detection Limit (mg/L)	Number of Samples	Sample Mean[1] (mg/L)	Log Sample Std Dev. (mg/L)	Sample Minimum (mg/L)	Sample Maximum (mg/L)	Sample Median (mg/L)	Number of Outliers	Number of No-Detects
Bromide	0.40	28	0.341	0.172	<0.400	0.700	<0.400	0	18
Filtered Iron	0.05	26	0.032	0.221	<0.050	0.103	<0.050	1	21
Total Lithium	0.10	29	0.051	0.360	<0.100	0.270	<0.100	0	23
Filtered Lithium	0.10	29	0.073	0.159	<0.100	0.180	<0.100	0	24
Total Manganese	0.05	29	0.009	0.570	<0.050	0.173	<0.050	0	26
Filtered Manganese	0.05	29	0.050	Undefined	<0.050	<0.050	<0.050	0	29
Total Aluminum	0.10	27	0.003	1.207	<0.100	0.900	<0.100	2	24

Parameter	1st Quartile (mg/L)	3rd Quartile (mg/L)	25th% (mg/L)	75th% (mg/L)
Bromide	<0.40	0.40	<0.40	0.40
Filtered Iron	<0.050	<0.050	<0.050	<0.050
Total Lithium	<0.10	<0.10	<0.10	<0.10
Filtered Lithium	<0.10	<0.10	<0.10	<0.10
Total Manganese	<0.050	<0.050	<0.050	<0.050
Filtered Manganese	<0.050	<0.050	<0.050	<0.050
Total Aluminum	<0.10	<0.10	<0.10	<0.10

Note:
(1) Equivalent to geometric mean

8.2 High-TDS Hydrochemical Facies

Tables 8.4 and 8.5 summarize statistical descriptors for the high-TDS facies. Distributions were assumed for each ground-water constituent as either normal or log normal, reflecting those determined for their low-TDS counterparts. Background statistics for constituents of the high-TDS facies were calculated by setting data (if any) below detection equal to one-half their respective detection limits. Cohen's Method was not employed to correct the mean and standard deviation in cases where some of the data of a constituent fell below detection limits (which affects only bromide, total aluminum; and total and filtered manganese). Upper tolerance limits were calculated; however, 95th percentile values are also reported for each constituent (Tables 9.4 and 9.5). Because there are so few data for the high-TDS facies, we recommend using the median values for each constituent in lieu of their means, and using the 95th percentile values in lieu of their upper tolerance limits.

Table 8.4

Statistical Descriptors for Normally Distributed Constituents of High-TDS Ground Water in the KAFB Area (Normal Distribution Assumed)

Parameter	Number of Samples	Sample Mean (mg/L)	Sample Std Dev. (mg/L)	Sample Minimum (mg/L)	Sample Maximum (mg/L)	Sample Median (mg/L)	Number of No-Detects
Total Dissolved Solids	9	1021.8	543.3	570.0	2160.0	770.0	0
Bicarbonate	9	520.3	232.9	346.0	951.0	407.0	0
Field Alkalinity	9	747.8	565.7	346.0	2150.0	580.0	0
Chloride	9	199.9	129.6	85.0	450.0	135.0	0
Total Calcium	9	147.3	51.0	91.4	257.0	133.0	0
Total Magnesium	9	44.1	25.4	21.6	104.0	33.5	0
Total Sodium	9	171.2	140.0	71.8	455.0	103.0	0
Specific Conductance(1)	9	1444.4	1089.6	500.0	4000.0	1210.0	0
Total Potassium	9	13.2	13.1	5.3	44.0	6.7	0

Parameter	1st Quartile (mg/L)	3rd Quartile (mg/L)	25th% (mg/L)	75th% (mg/L)
Total Dissolved Solids	686.5	1376.5	700.0	1200.0
Bicarbonate	377.5	695.0	380.0	640.0
Field Alkalinity	384.0	903.0	400.0	880.0
Chloride	118.5	306.0	120.0	250.0
Total Calcium	116.5	172.5	115.0	160.0
Total Magnesium	26.8	55.0	27.0	55.0
Total Sodium	81.1	273.0	80.0	220.0
Specific Conductance(1)	655.0	1870.0	700.0	1750.0
Total Potassium	6.2	18.4	6.0	15.0

Note:
(1) Units for specific conductance are micromhos

Table 8.5

Statistical Descriptors for Log-Normally Distributed Constituents of High-TDS Ground Water in the KAFB Area
(Log-Normal Distribution Assumed)

Parameter	Detection Limit (mg/L)	Number of Samples	Sample Mean[1] (mg/L)	Log Sample Std Dev. (mg/L)	Sample Minimum (mg/L)	Sample Maximum (mg/L)	Sample Median (mg/L)	Number of No-Detects
Bromide	0.40	9	0.754	0.2841	<0.400	2.400	0.800	1
Total Aluminum	0.10	9	0.325	0.8549	<0.10	3.500	0.510	3
Total Boron	0.10	9	0.357	0.2584	0.200	1.100	0.260	0
Filtered Boron	0.10	9	0.370	0.2967	0.180	1.300	0.260	0
Total Iron	0.050	8	3.030	0.7269	0.186	18.000	2.655	0
Filtered Iron	0.050	8	0.490	1.0826	<0.050	17.000	0.518	0
Total Lithium	0.10	9	0.472	0.3827	0.200	2.100	0.310	0
Filtered Lithium	0.10	9	0.463	0.4029	0.200	2.400	0.300	0
Total Manganese	0.050	9	0.134	0.7157	<0.050	0.988	0.210	0
Filtered Manganese	0.050	9	0.101	0.8590	<0.050	0.978	0.190	2
Total Strontium	0.10	9	1.237	0.1540	0.676	2.200	1.300	0
Filtered Strontium	0.10	9	1.204	0.1629	0.648	2.400	1.300	0

Parameter	1st Quartile (mg/L)	3rd Quartile (mg/L)	25th% (mg/L)	75th% (mg/L)
Bromide	0.60	1.02	0.60	0.95
Total Aluminum	<0.10	1.80	<0.10	1.75
Total Boron	0.23	0.59	0.23	0.50
Filtered Boron	0.22	0.64	0.22	0.58
Total Iron	1.147	17.200	1.100	17.300
Filtered Iron	0.064	7.550	0.065	7.000
Total Lithium	0.24	1.24	0.25	1.00
Filtered Lithium	0. 24	1.24	0.25	0.95
Total Manganese	<0.050	0.525	<0.050	0.480
Filtered Manganese	<0.050	0.545	<0.050	0.500
Total Strontium	0.94	1.50	0.98	1.50
Filtered Strontium	0.93	1.38	0.98	1.37

Note:
[1] Equivalent to geometric mean.

Laboratory alkalinity data for samples representative of the high-TDS facies are not reliable (see discussion in Section 12.1 of this report). In addition, the bromide sample from EOD Hill well (< 0.4 mg/L) is notably low in comparison to historical data, and therefore, this particular value is not likely representative of ground water here.

Total iron concentrations can vary widely because of differing amounts of suspended sediments in ground-water samples. Therefore, compared to total iron, filtered iron is the more reliable characteristic trait of the high-TDS hydrochemical facies.

The relatively high concentrations of total, but not filtered, aluminum are confusing, but are probably due to suspended sediments. The authors can offer no other reasonable explanation for this observation. Further study is required to determine if multimodal distributions do indeed exist in the KAFB area for total aluminum.

8.3 Single-population Ground-Water Constituents

Tables 8.6, 8.7, and 8.8 summarize background statistics for inorganic ground-water species characterized by single populations.

Table 8.6

Statistical Descriptors for Normally Distributed Single-Population Ground-Water Constituents in the KAFB Area

Parameter	Detection Limit (mg/L)	Number of Samples	Sample Mean (mg/L)	Sample Std Dev. (mg/L)	Sample Minimum (mg/L)	Sample Maximum (mg/L)	Sample Median (mg/L)	Number of Outliers	Number of No-Detects
Field pH [1]	---	38	6.84	0.51	5.78	8.03	6.85	0	0
Sulfate	5.0	36	63.53	28.36	22.00	140.00	58.50	2	0
Specific Gravity [1]	---	17	1.00	0.00	1.00	1.00	1.00	0	0
Dissolved Oxygen	---	30	5.47	1.98	1.00	9.10	5.80	0	0
Field Temperature [1]	---	38	19.93	3.95	11.00	29.00	20.75	0	0
Silica	0.4	35	20.05	10.17	<0.4	44.50	17.00	1	1

Parameter	1st Quartile (mg/L)	3rd Quartile (mg/L)	25th% (mg/L)	75th% (mg/L)
Field pH [1]	6.50	7.19	6.45	7.20
Sulfate	43.5	79.0	44.0	85.0
Specific Gravity [1]	0.998	0.999	0.998	0.999
Dissolved Oxygen	4.4	6.9	4.4	6.9
Field Temperature [1]	18.5	22.5	18.5	22.5
Silica	13.0	28.2	13.0	29.0

Note:
[1] Units for field temperature are degrees celsius; specific gravity and pH are dimensionless.

Table 8.7

Statistical Descriptors for Log-Normally Distributed for Single-Population Ground-Water Constituents in the KAFB Area

Parameter	Detection Limit (mg/L)	Number of Samples	Sample Mean [1] (mg/L)	Log Sample Std Dev. (mg/L)	Sample Minimum (mg/L)	Sample Maximum (mg/L)	Sample Median (mg/L)	Number of Outliers	Number of No-Detects
Nitrate + Nitrite [2]	0.100	38	1.172	0.727	<0.100	22.000	1.065	0	5
Total Chromium	0.001	36	0.001	0.657	<0.001	0.037	0.001	1	17
Fluoride	0.100	36	0.679	0.303	0.280	2.750	0.570	0	0

Parameter	1st Quartile (mg/L)	3rd Quartile (mg/L)	25th% (mg/L)	75th% (mg/L)
Nitrate + Nitrite [2]	0.74	4.20	0.74	4.20
Total Chromium	<0.001	0.004	<0.001	0.004
Fluoride	0.36	1.26	0.35	1.25

Note:

[1] Equivalent to geometric mean.

[2] Calculated using all data. Not considered to be reliable. See Section 9.4.

Table 8.8

Statistical Descriptors for Constituents With Unknown Distributions: Single-Population Ground-Water Constituents in the KAFB Area (Distribution Assumed to be Log Normal)

Parameter	Detection Limit (mg/L)	Number of Samples	Sample Mean [1] (mg/L)	Log Sample Std Dev. (mg/L)	Sample Minimum (mg/L)	Sample Maximum (mg/L)	Sample Median (mg/L)	Number of Outliers	Number of No-Detects
Total Lead	0.005	37	0.0008	0.628	<0.005	0.0150	<0.005	1	34
Filtered Lead	0.005	38	0.0050	Undefined	<0.005	<0.0050	<0.005	0	38
Carbonate	1.000	37	0.1860	0.854	<1.000	6.0000	<1.000	1	30
Filtered Chromium	0.001	33	0.0004	0.488	<0.001	0.0025	<0.001	4	26
Total Vanadium	0.010	37	0.0065	0.153	<0.010	0.0130	<0.010	1	33
Filtered Vanadium	0.010	36	0.0100	Undefined	<0.010	0.0100	<0.010	2	35
Total Zinc	0.050	34	0.0079	1.214	<0.050	2.5000	<0.050	1	25
Filtered Zinc	0.050	35	0.0101	1.069	<0.050	1.8700	<0.050	0	26
Total Phosphorus	0.090	35	0.0900	Undefined	<0.090	0.0900	<0.090	3	34
Filtered Aluminum	0.100	38	0.0318	0.402	<0.100	0.2000	<0.100	0	34
Total Cadmium	0.001	37	0.0010	Undefined	<0.001	0.0010	<0.001	1	36
Filtered Cadmium	0.001	37	0.0010	Undefined	<0.001	<0.0010	<0.001	1	37
Total Cobalt	0.010	38	0.0100	Undefined	<0.010	0.0100	<0.010	0	37
Filtered Cobalt	0.010	38	0.0100	Undefined	<0.010	<0.0100	<0.010	0	38
Total Copper	0.050	38	0.0500	Undefined	<0.050	<0.0500	<0.050	0	38
Filtered Copper	0.050	38	0.0500	Undefined	<0.050	<0.0500	<0.050	0	38
Total Nickel	0.020	37	0.0087	0.284	<0.020	0.0310	<0.020	1	35
Filtered Nickel	0.020	37	0.0131	0.157	<0.020	0.0270	<0.020	1	35
Total Barium	0.100	38	0.0940	0.246	<0.100	0.2370	<0.100	0	21
Filtered Barium	0.100	38	0.0920	0.242	<0.100	0.3000	<0.100	0	21

Parameter	1st Quartile (mg/L)	3rd Quartile (mg/L)	25th% (mg/L)	75th% (mg/L)
Total Lead	<0.005	<0.005	<0.005	<0.005
Filtered Lead	<0.005	<0.005	<0.005	<0.005
Carbonate	<1	<1	<1	<1
Filtered Chromium	<0.001	<0.001	<0.001	0.002
Total Vanadium	<0.010	<0.010	<0.010	<0.010
Filtered Vanadium	<0.010	<0.010	<0.010	<0.010
Total Zinc	<0.050	0.060	<0.050	0.065
Filtered Zinc	<0.050	<0.050	<0.050	<0.050
Total Phosphorus	<0.09	<0.09	<0.09	<0.09
Filtered Aluminum	<0.10	<0.10	<0.10	<0.10
Total Cadmium	<0.001	<0.001	<0.001	<0.001
Filtered Cadmium	<0.001	<0.001	<0.001	<0.001
Total Cobalt	<0.010	<0.010	<0.010	<0.010
Filtered Cobalt	<0.010	<0.010	<0.010	<0.010
Total Copper	<0.050	<0.050	<0.050	<0.050
Filtered Copper	<0.050	<0.050	<0.050	<0.050
Total Nickel	<0.020	<0.020	<0.020	<0.020
Filtered Nickel	<0.020	<0.020	<0.020	<0.020
Total Barium	<0.10	0.17	<0.10	0.16
Filtered Barium	<0.10	0.15	<0.10	0.15

Note:

[1] Equivalent to geometric mean.

As discussed in Section 12.1 of this report, values of laboratory pH are meaningless; thus, descriptors for laboratory pH were not included in Table 8.6. Special problems were encountered in our analysis of background for nitrate plus nitrite; these are discussed below in Section 8.4.

8.4 Problems with Establishing Background Nitrate plus Nitrite
Analytical results reveal that a number of the wells sampled for this study are contaminated with nitrate plus nitrite. Samples from Golf Course South, MVMW-J, and MVMW-K contain nitrate plus nitrite concentrations which exceed 10 mg/L (the New Mexico Water Quality Control Commission standard for *nitrate as nitrogen* is 10 mg/L. Generally, nitrite is seldom seen at appreciable levels above its detection limit). Based on data obtained from this study, the upper tolerance limit (UTL) for nitrate plus nitrite is 42.267 mg/L, whereas the mean is only 1.172 mg/L (Table 9.7). Further inspection of the data reveals that some of our samples contain essentially no nitrate plus nitrite, whereas several contain concentrations exceeding 2 mg/L. Because of wide variation among the analytical results due to the mixing of data representing contaminated and uncontaminated conditions, the standard deviation and the corresponding UTL are too large. Based on knowledge of nitrate plus nitrite concentrations seen elsewhere in the State, a UTL of this magnitude is not acceptable as representative of maximum background for *uncontaminated conditions*. It is doubtful that maximum background for nitrate plus nitrite exceeds 10 mg/L in the KAFB area.

In conclusion, background hydrochemistry cannot be reliably established in the KAFB area for nitrate plus nitrite using only existing wells. Unless other wells are installed at uncontaminated sites, background conditions for nitrate plus nitrite should be established strictly on a site-specific basis. For now, it is recommended that the mean value of 1.172 mg/L be considered conservatively high for uncontaminated conditions in the KAFB area.

8.5 Constituents with Conservatively High Means
The means reported herein for total and filtered aluminum, barium, cadmium, cobalt, copper, manganese, nickel, lead, and zinc are suspected to be much higher than actual background values for these constituents. This is due to the relatively high detection limits associated with the analyses of these constituents (in general, SLD reported higher detection limits for ground-water data than did ATI). The means for cadmium, cobalt, copper, manganese, and lead were set equal to their respective detection limits in accordance with Cohen's Method (Section 8.3). The means reported herein for these particular metals are especially likely to be much higher than actual background values.

Statistical descriptors for these constituents can be refined in future ground-water studies by using laboratory services capable of reporting with lower detection limits. For now, the means for these constituents should be regarded as conservatively high. The medians, 1st and 3rd quartiles, and the 25th, 75th, and 95th percentiles best describe the background populations of each of these constituents.

8.6 Discussion Concerning KAFB-10 and CWL-BW3

Ground-water samples collected from KAFB-10 and CWL-BW3 contain relatively high concentrations of chloride. This suggests that ground waters monitored by these two wells should be included with the high-TDS facies. However, if anthropogenic activities have caused chloride to become elevated above natural conditions, then ground waters so affected may not be necessarily related to the high-TDS facies. Readers should note that ground-water contamination does exist near both wells. Furthermore, both KAFB-10 and CWL-BW3 lie west of the Sandia Fault, and therefore, outside of the shallow ground-water regime that is characteristic of the high-TDS facies.

As mentioned earlier, it was not possible to purge KAFB-10 prior to sampling. This problem will undoubtedly have some effect on the water quality of any samples retrieved from this well. However, the reader is reminded that Grubb's test was applied to eliminate any extreme data that could have severely influenced the mean, standard deviation, and any other statistical descriptors that are representative of a given constituent. Thus, any errors introduced by the inclusion of KAFB-10 data in the analysis of background hydrochemistry is believed to be negligible.

A comparison of the hydrochemistry of KAFB-10 to those of two adjacent wells (LWDS-MW1 and LWDS-MW2) allows us to decipher which hydrochemical facies is likely present at Technical Area 5. LWDS-MW1 is located approximately 1100 ft east of and hydraulically upgradient of KAFB-10; whereas, LWDS-MW2 is located about 700 ft north-northeast of KAFB-10. LWDS-MW1 is situated between KAFB-10 and the Sandia Fault (the apparent western boundary of the high-TDS facies here). To illustrate our point, analytical results for ground-water samples collected from LWDS-MW1 and LWDS-MW2 by the NMED in March 1994 are listed in Table 8.9.

Based on these data, the hydrochemistry of the sample from LWDS-MW2 matches nicely that of the low TDS-facies. In contrast, the sample collected from LWDS-MW1 contains high concentrations of chloride, similar to that from KAFB-10. However, the LWDS-MW1 sample also contains high levels of total phosphorus and nitrate plus nitrite, suggesting that the elevated chloride is a result of ground-water contamination (from the Liquid Waste Disposal System and/or the Technical Area 5 Seepage Pits). The presence of trichloroethene (TCE) at concentrations of about 12-13 μg/L confirms that ground water in the vicinity of LWDS-MW1 is contaminated.

Table 8.9

March 1994 Analytical Results for Monitor Wells LWDS-MW1 and LWDS-MW2

Constituent	LWDS-MW1	LWDS-MW2
Nitrate + nitrite	8.4	8.0
Total phosphorus	2.3	<0.05
Total dissolved solids	530	330
Chloride	74	14.5
Bicarbonate	268	187
Calcium	61.9	60.3
Potassium	3.6	3.3
Magnesium	18.6	16.8
Sodium	114	43.8
Boron	0.17	0.14
Lithium	0.14	0.12
Strontium	0.634	0.593
Manganese	0.085	<0.010

Note:
All units are mg/L.

Boron, lithium, and strontium are characteristic constituents of both hydrochemical facies that are probably more resistant to the effects of ground-water contamination than some other constituents such as sodium, potassium, chloride, manganese, and total dissolved solids. Concentrations of these constituents in the LWDS-MW1, LWDS-MW2, and KAFB-10 samples occur at levels that are more typical of the low-TDS facies.

Concentrations of boron, lithium, and strontium in the CWL-BW3 sample also fall within the ranges of those of the low-TDS facies. Piper diagrams (see Section 10) show that the ground-water sample from CWL-BW3 is chemically distinct from those of the other wells and springs in the KAFB area. Plots of magnesium, calcium, and bicarbonate versus chloride (Figures 8.1, 8.2, and 8.3) also reveal that this sample is different from those that are representative of the high-TDS facies. As shown on these same plots and Piper diagrams, similar observations appear to be also true for KAFB-10; however, the purging problem and its effect on water quality renders KAFB-10 data less reliable.

The discussion above suggests that ground waters monitored by KAFB-10 and CWL-BW3 should not be included with the high-TDS facies. Background wells drilled at appropriate locations at some distance away from Technical Area 5 and the Chemical Waste Landfill would be helpful to better resolve this issue.

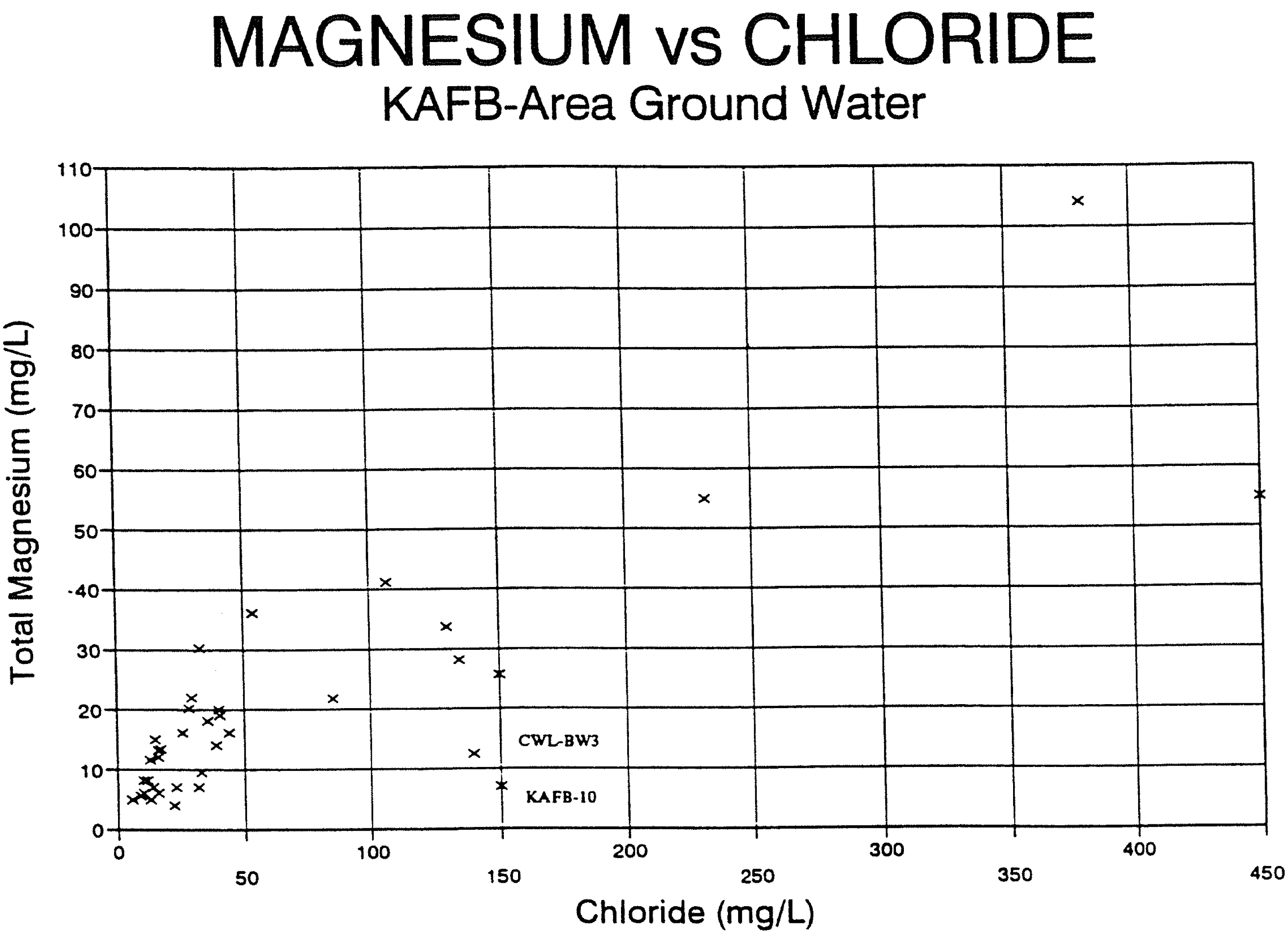


Figure 8.1. Plot of magnesium versus chloride for all ground-water data.

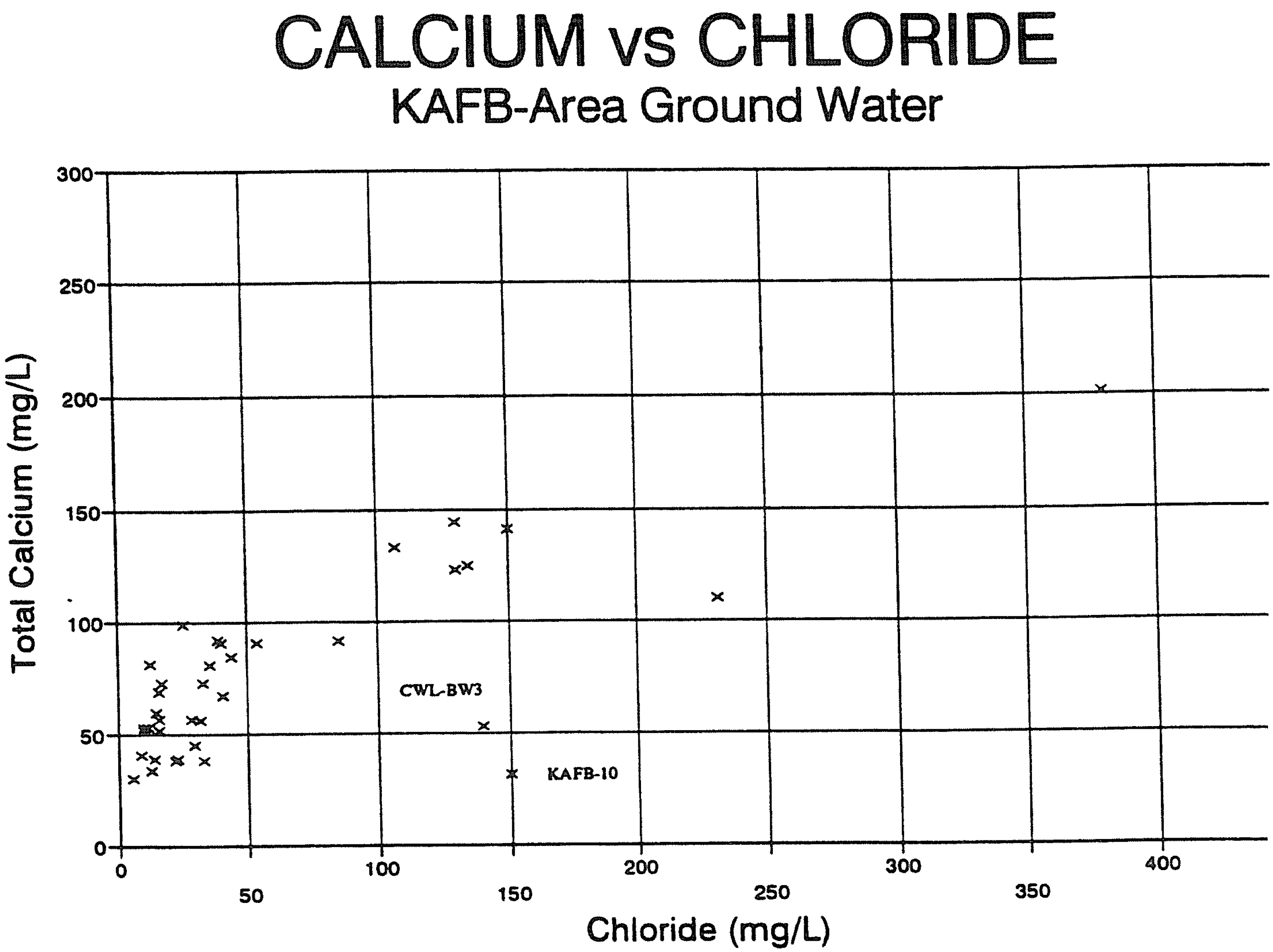


Figure 8.2. Plot of calcium versus chloride for all ground-water data.

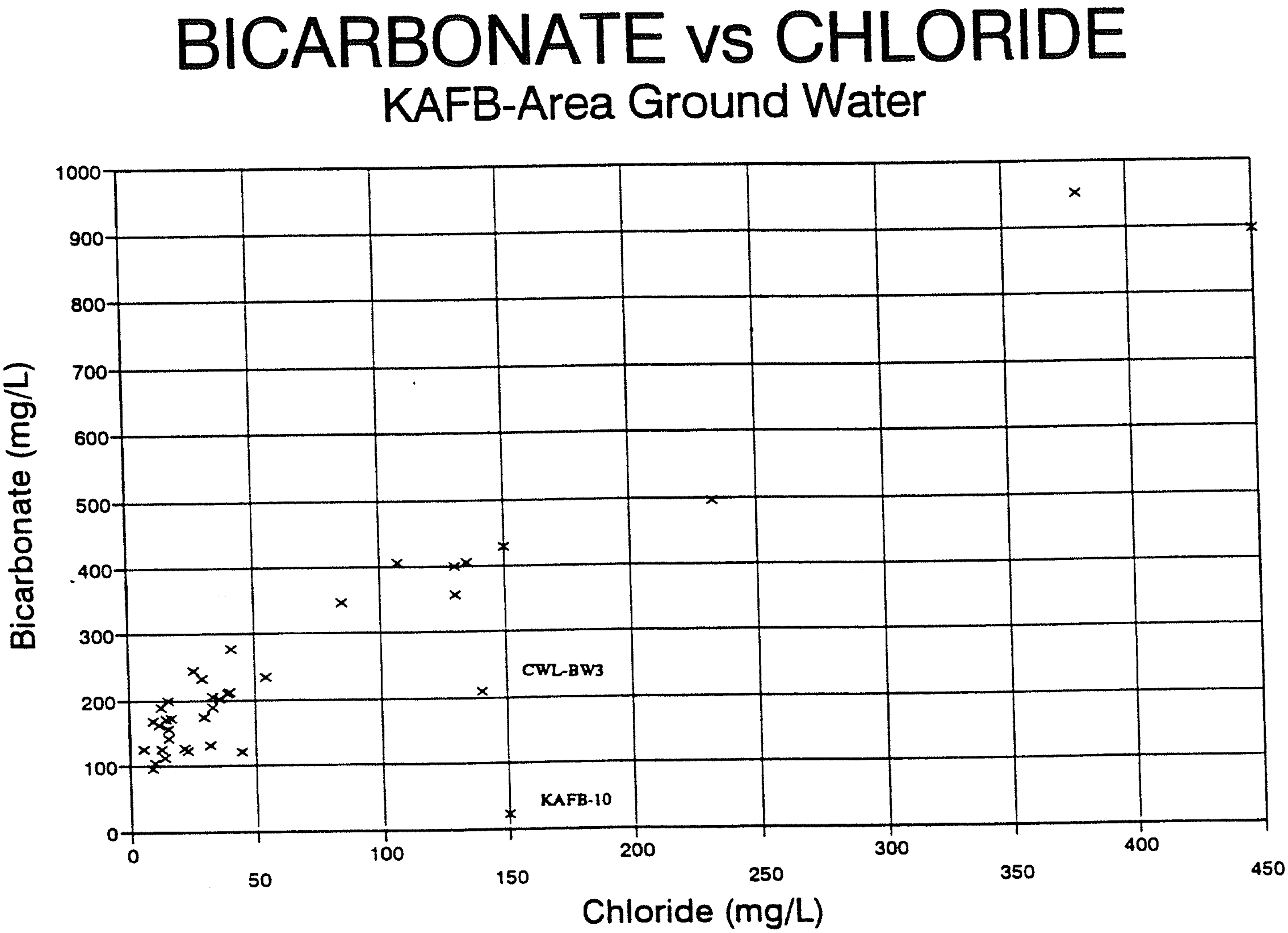


Figure 8.3. Plot of bicarbonate versus chloride for all ground-water data.

9. Maximum Background Hydrochemistry of the KAFB Area

Sections 9.1, 9.2, and 9.3 present maximum background values for the low-TDS facies, high-TDS facies, and single-population ground-water constituents. Maximum background values are important for identifying contamination or suspected contamination at ER sites, for ensuring that no releases of hazardous materials are occurring from current facility operations, and for establishing cleanup standards.

9.1 Low-TDS Hydrochemical Facies

One-sided upper tolerance limits are listed in Tables 9.1 and 9.2 for constituents of the low-TDS facies approximated by normal or log-normal distributions; respectively. Maximum background values for constituents with unknown distributions are set equal to the 95th percentiles of their sample populations (Table 9.3).

9.2 High-TDS Hydrochemical Facies

One-sided upper tolerance limits and 95th percentile values are listed in Tables 9.4 and 9.5; respectively, for constituents of the high-TDS facies. Because there are so few data, it is recommended that the 95 percentile be used in lieu of the UTL for each constituent of the high-TDS facies.

Table 9.1

Upper Tolerance Limits for Normally Distributed Constituents
Low-TDS Ground Water in the KAFB Area

Parameter	Number of Samples	Sample Mean (mg/L)	Sample Std Dev. (mg/L)	Tolerance Factor	UTL (mg/L)
Chloride	27	24.0	12.8	2.263	53.0
Field Alkalinity	28	170.7	52.8	2.249	289.5
Lab Alkalinity [1]	29	150.2	53.5	2.234	269.7
Bicarbonate	29	166.9	53.9	2.234	287.4
Total Dissolved Solids	28	353.0	115.3	2.249	612.3
Specific Conductance [2]	28	417.4	150.8	2.249	756.6
Total Calcium	29	59.6	20.4	2.234	105.1
Total Magnesium	27	11.4	5.4	2.263	23.7
Total Sodium	27	33.3	18.0	2.263	74.0
Total Potassium	23	3.5	1.4	2.329	6.7

Notes:
(1) Laboratory alkalinity data should be used with caution. See Section 12.1 of this report.
(2) Units for specific conductance are micromhos

Table 9.2

Upper Tolerance Limits for Log-Normally Distributed Constituents
Low-TDS Ground Water in the KAFB Area

Parameter	Number of Samples	Sample Mean[1] (mg/L)	Log Sample Std Dev. (mg/L)	Tolerance Factor (mg/L)	Log UTL (mg/L)	UTL (mg/L)
Total Boron	29	0.116	0.354	2.234	-0.145	0.716
Filtered Boron	29	0.111	0.347	2.234	-0.179	0.662
Total Iron	27	0.065	0.937	2.263	0.933	8.570
Total Strontium	29	0.471	0.202	2.234	0.124	1.330
Filtered Strontium	29	0.465	0.204	2.234	0.123	1.327

Note:
[1] Equivalent to geometric mean.

Table 9.3

95th Percentile Values for Low-TDS Ground-Water Constituents in the KAFB Area

Parameter	95th Percentile (mg/L)
Bromide	0.700
Filtered Iron	0.115
Total Lithium	0.220
Filtered Lithium	0.125
Total Manganese	0.100
Filtered Manganese	<0.050
Total Aluminum	3.600

Table 9.4

Upper Tolerance Limits and 95th Percentile Values for Normally Distributed Constituents
High-TDS Ground Water in the KAFB Area
(Normal Distribution Assumed)

Parameter	Number of Samples	Sample Mean (mg/L)	Sample Std Dev. (mg/L)	Tolerance Factor	UTL (mg/L)	95th Percentile (mg/L)
Total Dissolved Solids	9	1021.8	543.3	3.031	2668.5	2250
Bicarbonate	9	520.3	232.9	3.031	1226.2	990
Field Alkalinity	9	747.8	565.7	3.031	2462.4	2217
Chloride	9	199.9	129.6	3.031	592.7	485
Total Calcium	9	147.3	51.0	3.031	301.9	270
Total Magnesium	9	44.1	25.4	3.031	121.1	106
Total Sodium	9	171.2	140.0	3.031	595.5	500
Specific Conductance(1)	9	1444.4	1089.6	3.031	4747.0	4100
Total Potassium	9	13.2	13.1	3.031	52.8	45.5

Note:
(1) Units for specific conductance are micromhos.

Table 9.5

Upper Tolerance Limits and 95th Percentile Values for Log-Normally Distributed Statistics
High-TDS Ground Water in the KAFB Area
(Log-Normal Distribution Assumed)

Parameter	Number of Samples	Sample Mean[1] (mg/L)	Log Sample Std Dev. (mg/L)	Tolerance Factor	Log UTL (mg/L)	UTL (mg/L)	95th Percentile (mg/L)
Bromide	9	0.754	0.2841	3.031	0.738	5.470	2.500
Total Aluminum	9	0.325	0.8549	3.031	2.103	126.765	3.650
Total Boron	9	0.357	0.2584	3.031	0.336	2.168	1.180
Filtered Boron	9	0.370	0.2967	3.031	0.467	2.931	1.340
Total Iron	8	3.030	0.7269	3.188	2.799	629.506	18.700
Filtered Iron	8	0.490	1.0826	3.188	3.142	1386.756	17.500
Total Lithium	9	0.472	0.3827	3.031	0.834	6.823	2.500
Filtered Lithium	9	0.463	0.4029	3.031	0.887	7.709	2.650
Total Manganese	9	0.134	0.7157	3.031	1.296	19.770	1.200
Filtered Manganese	9	0.101	0.8590	3.031	1.608	40.551	1.200
Total Strontium	9	1.237	0.1540	3.031	0.559	3.622	2.040
Filtered Strontium	9	1.204	0.1629	3.031	0.574	3.750	2.480

Note:
[1] Equivalent to geometric mean.

9.3 Single-Population Ground-Water Constituents

One-sided upper tolerance limits are listed in Tables 9.6 and 9.7 for single-population ground-water constituents approximated by either normal or log-normal distributions; respectively. Maximum background values for constituents with unknown distributions are set equal to the 95th percentiles of their sample populations (Table 9.8).

Table 9.6

Upper Tolerance Limits for Normally Distributed Constituents
Single-Population Ground-Water Constituents in the KAFB Area

Parameter	Number of Samples	Sample Mean (mg/L)	Sample Std Dev. (mg/L)	Tolerance Factor	UTL (mg/L)
Field pH [1]	38	6.84	0.51	2.142	7.9
Sulfate	36	63.53	28.36	2.158	124.7
Specific Gravity[1]	17	1.00	0.00	2.486	1.0
Dissolved Oxygen	30	5.47	1.98	2.220	9.9
Field Temperature[1]	38	19.93	3.95	2.142	28.4
Silica	35	20.05	10.17	2.166	42.1

Note:
[1] Units for field temperature are degrees celsius, pH and specific gravity are dimensionless.

Table 9.7

Upper Tolerance Limits for Log-Normally Distributed Constituents
Single-population Ground-Water Constituents in the KAFB Area

Parameter	Number of Samples	Sample Mean[1] (mg/L)	Log Sample Std Dev. (mg/L)	Tolerance Factor	Log UTL (mg/L)	UTL (mg/L)
Nitrate + Nitrite[2]	38	1.172	0.727	2.142	1.626	42.267
Total Chromium	36	0.001	0.657	2.158	-1.503	0.031
Fluoride	36	0.679	0.303	2.158	0.486	3.062

Notes:
[1] Equivalent to geometric mean.
[2] Calculated using all data. Not considered to be reliable. See Section 8.4.

Table 9.8
95th Percentile Values for Single-Population Ground-Water Constituents in the KAFB Area

Constituent	95th Percentile (mg/L)
Total Lead	0.013
Filtered Lead	<0.005
Carbonate	6.500
Filtered Chromium	0.012
Total Vanadium	0.013
Filtered Vanadium	0.012
Total Zinc	2.230
Filtered Zinc	0.603
Total Phosphorus	0.215
Filtered Aluminum	0.170
Total Cadmium	<0.001
Filtered Cadmium	<0.001
Total Cobalt	<0.010
Filtered Cobalt	<0.010
Total Copper	<0.050
Filtered Copper	<0.050
Total Nickel	0.028
Filtered Nickel	0.024
Total Barium	0.200
Filtered Barium	0.200

10. Interpretation of KAFB-Area Ground-Water Quality

As mentioned previously, the primary objective of this study is to improve the NMED's understanding of the hydrogeologic system in the KAFB area. Ground-water quality is one of several vital aspects of any hydrogeologic system. In this chapter, the authors interpret the hydrochemistry of the KAFB area using statistical descriptors from Chapters 8 and 9, Piper diagrams, concentration maps, and Stiff diagrams. Piper diagrams, Stiff diagrams, and concentration maps were prepared to investigate variations in ground-water chemistry, to examine mixing of different waters, and to identify potential ground-water contamination in the KAFB area. Sections 10.1 and 10.2 describe general characteristics of the low-TDS and high-TDS hydrochemical facies. Section 10.3 discusses suspected spatial trends for sulfate, fluoride, and temperature. Finally, Section 10.4 presents evidence supporting our assertion that ground waters monitored by CWL-BW3 and KAFB-10 have been contaminated by historical facility operations.

Piper diagrams were constructed for production wells (Figure 10.1), for monitoring points within the high-TDS facies (Figure 10.2), for monitoring points within the low-TDS facies (Figure 10.3), and for all sampling locations (Figure 10.4). Calculations supporting each Piper diagram are provided in Appendix M. All data, except QA-rejected data, were used to prepare these diagrams including any outliers and any data that may be representative of contamination. Figure 10.4 is similar to three Piper diagrams prepared by McCord and others (1992).

Data used to plot these diagrams were derived from samples collected for this investigation. However, QA-rejected data were replaced with historical data for a few sampling locations (Table 10.1).

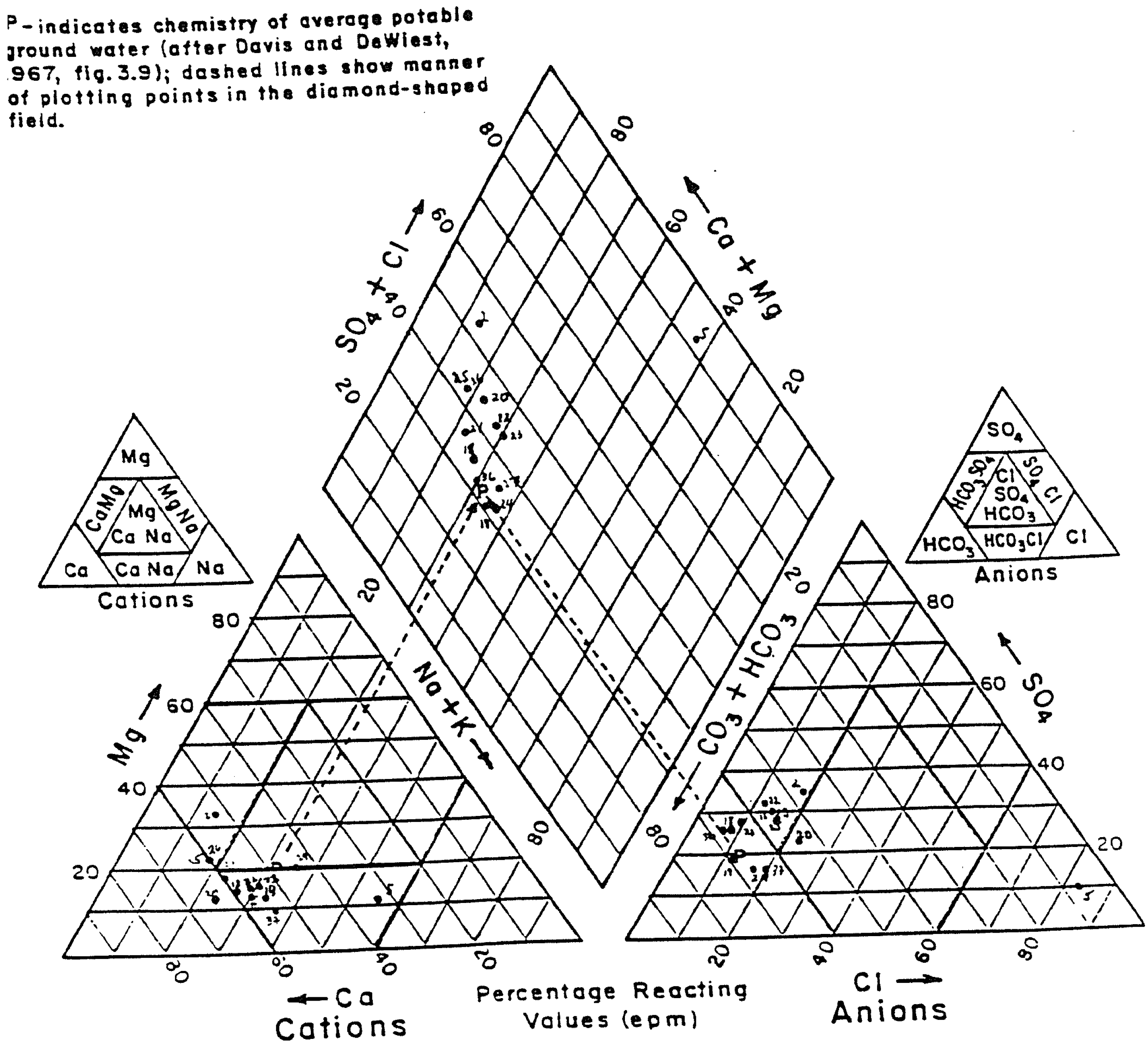
Table 10.1
Historical Data Used to Generate Piper Diagrams

Well ID	Date	Sodium	Potassium
Isleta 28S	03/10/93	16 mg/L	2 mg/L
KAFB-13	08/13/87	--	3.4
LFDM-01	08/06/92	--	2
Ridgecrest 1	09/29/93	--	2.33
Ridgecrest 3	09/29/93	--	3.19

A Piper diagram showing "average" low-TDS and high-TDS ground waters is shown in Figure 10.5.

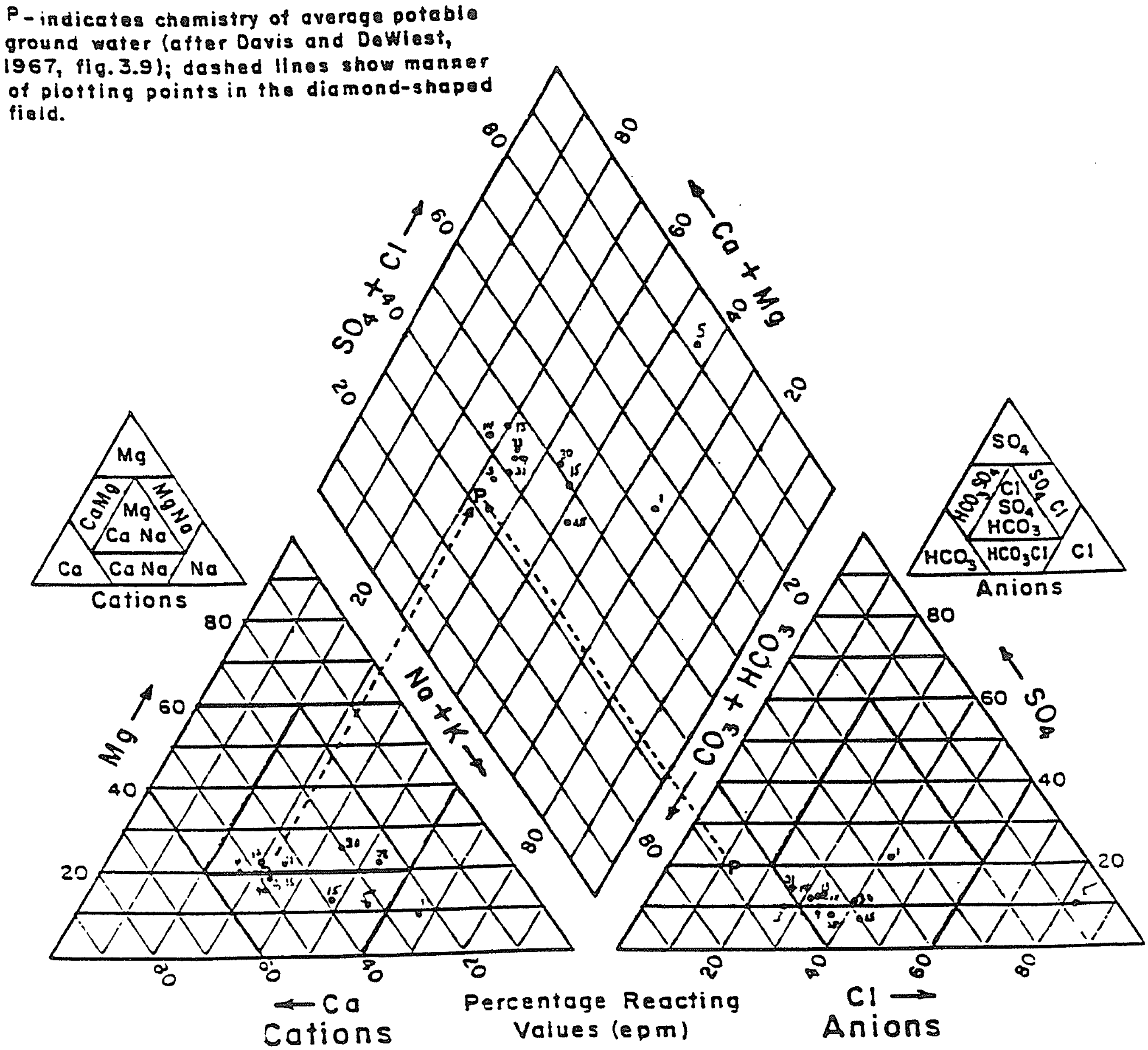
Concentration maps for each inorganic species were also prepared and are presented in Appendix N. The maps were constructed for each constituent using all data, with the exception of QA-rejected data. Therefore, some maps will reflect conditions that are not necessary representative of background hydrochemistry. Major faults in the KAFB area are also shown on each map. Concentration maps are useful for identifying areas with known or potential ground-water contamination, seeing spatial trends in background data, and for identifying areas lacking adequate ground-water monitoring.

Contours were drawn on some maps to illustrate significant spatial trends representing background, and in a few cases, contaminated conditions. Where contoured, the maps are generalized in the sense that shallow ground water is not expected to occur in most



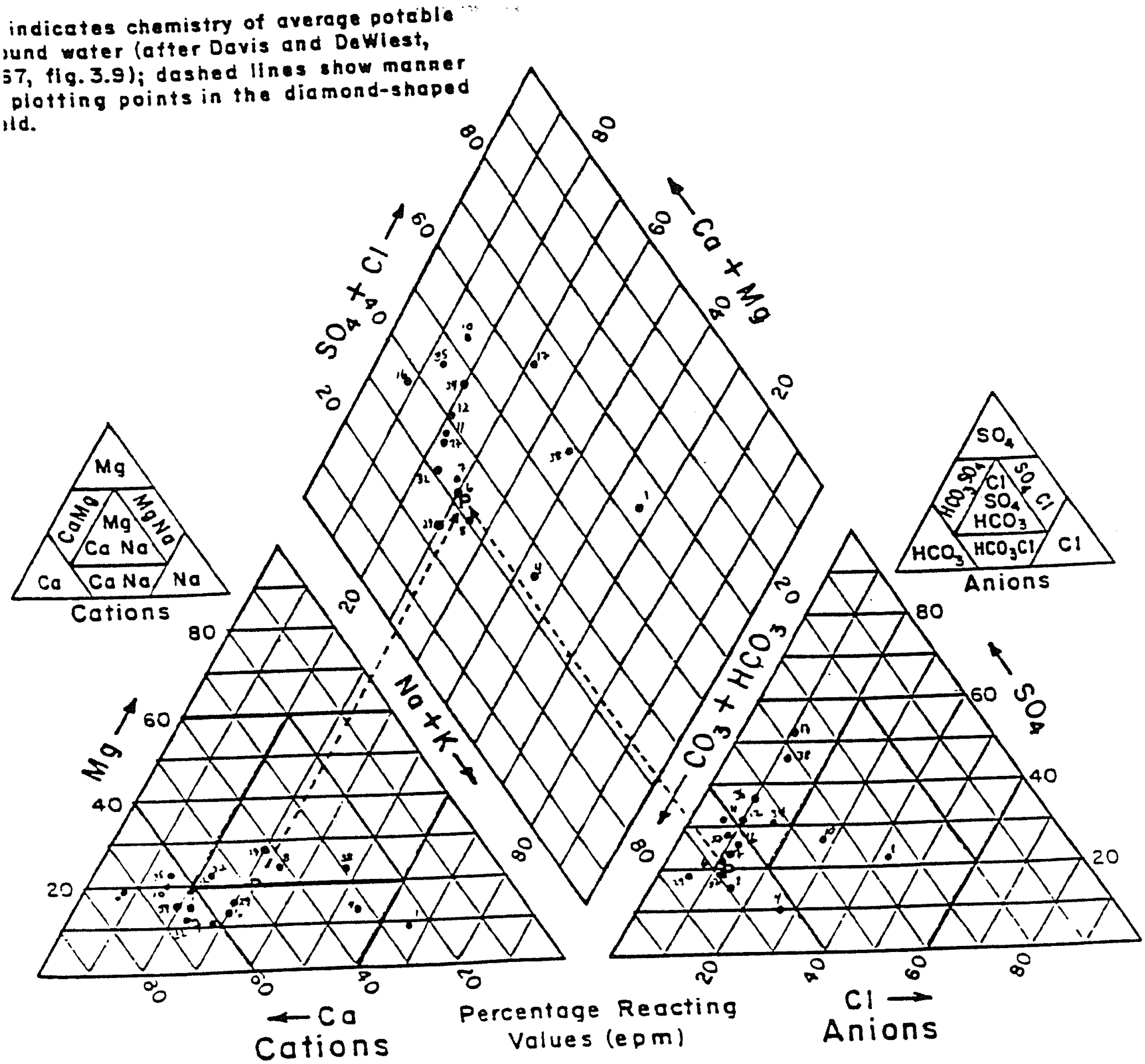
Well #	Well	Well #	Well
2	Burnsite	5	KAFB-10
18	KAFB-1	19	KAFB-2
20	KAFB-3	21	KAFB-11
22	KAFB-13	23	KAFB-14
24	Firehouse	25	SOR
26	HERTF	36	Ridgecrest 1
37	Ridgecrest 3		

Figure 10.1. Piper diagram showing KAFB-area production wells.



Well #	Well	Well #	Well
1	CWL-BW3	3	Greystone
5	KAFB-10	9	Schoolhouse
13	SFR-2S	14	SFR-1
15	Coyote Spring	28	EOD Hill
30	G-Spring	31	Lake Christian West
33	SFR-3S		

Figure 10.2. Piper diagram showing high-TDS ground-water sites, and also wells KAFB-10 and CWL-BW3.



Well #	Well	Well #	Well
1	CWL-BW3	4	SWTA3
6	MVMW-J	7	MVMW-K
8	MWL-BW1	10	Golf Course South
11	Tijeras East	12	LFDM-02
16	Sol Se Mete Spring	17	Hubbell Spring
27	NWTA3	29	LFDM-01
32	Tijeras West	34	TA2-NW1-595
35	Isleta 28 Shallow	38	ITRI-MW2

Figure 10.3. Piper diagram showing low-TDS ground-water sites, excluding production wells.

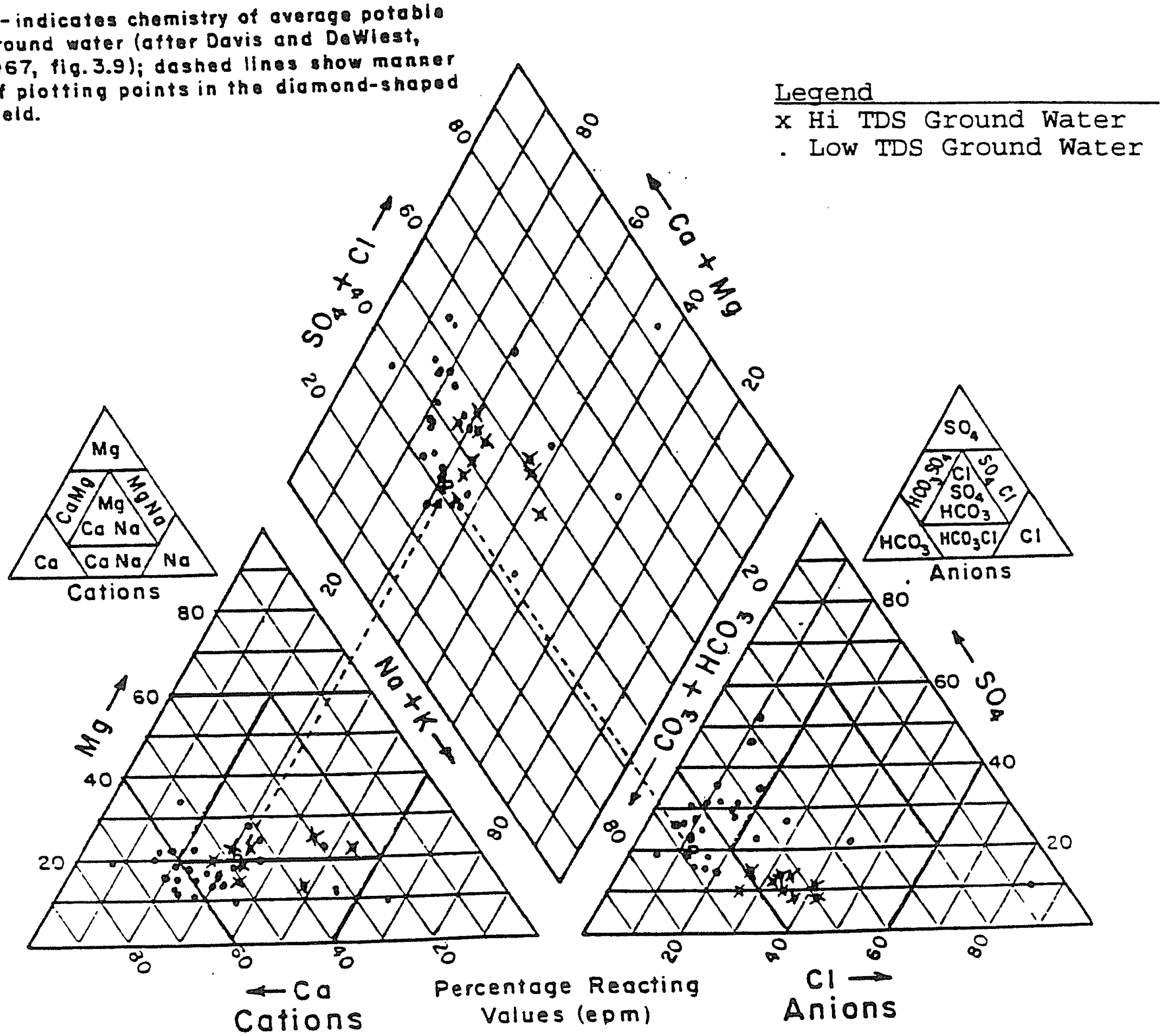


Figure 10.4. Piper diagram showing all KAFB-area wells and springs.

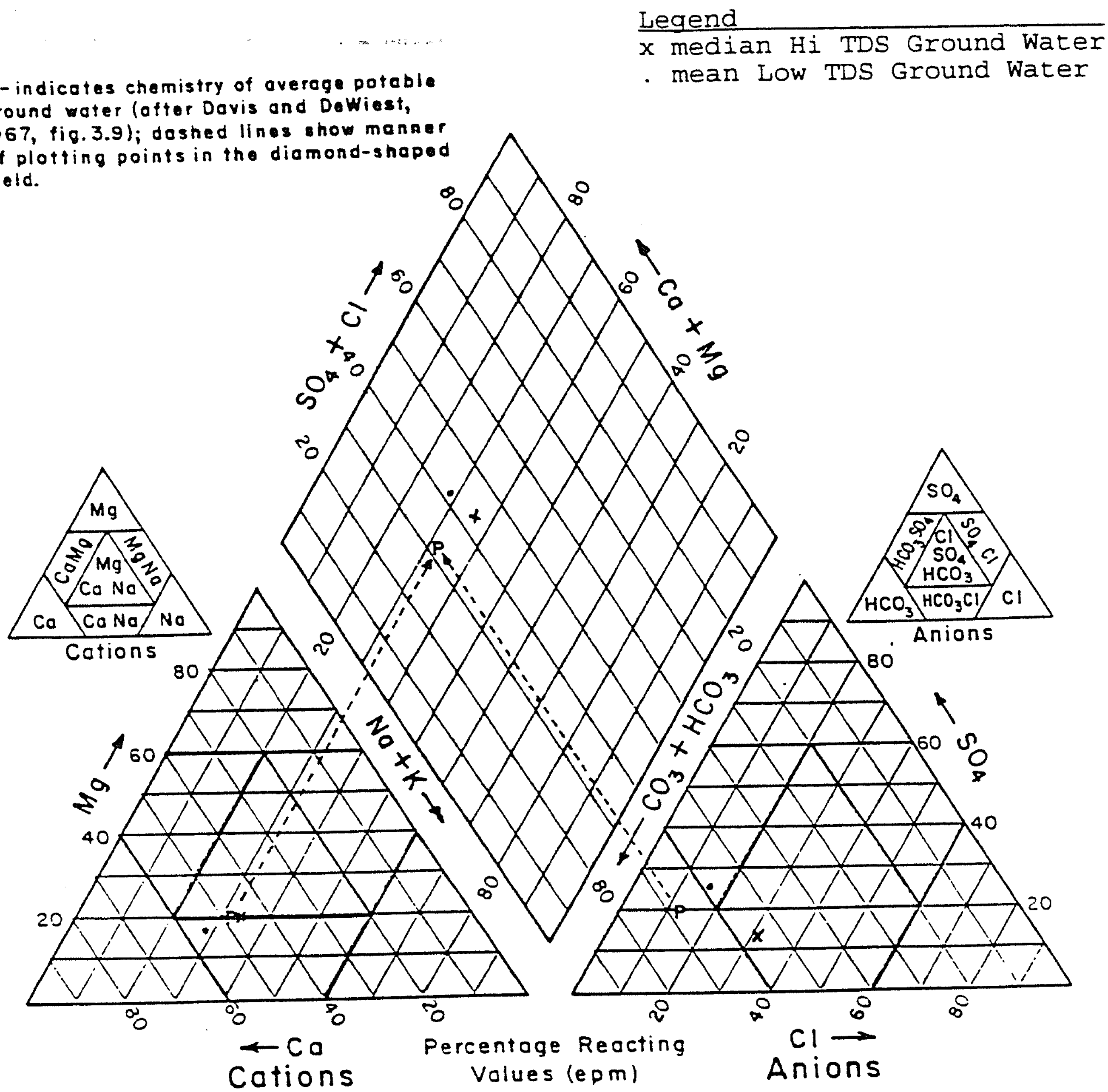


Figure 10.5. Piper diagram showing mean values for low-TDS ground water and median values for high-TDS ground water.

areas where bedrock crops out. Contours reflecting background conditions for the high-TDS facies are shown open to the northeast. However, the northeastern boundary of the high-TDS facies may occur at the surface-water divide (a bedrock high) between the Tijeras and Arroyo del Coyote drainages immediately east of Manzano Base. Wells located further northeast along the Tijeras Fault zone are needed to determine the northern extent of the high-TDS facies.

Stiff diagrams were generated for each sampling location and plotted on a base map of the KAFB area (Plate 1). These diagrams allow the rapid comparison of major ion compositions as a result of their distinctive graphical shapes. Data used to generate the Stiff diagrams are the same as those used to construct the Piper diagrams. The general area of the high-TDS hydrochemical facies is nicely defined by the "fat" Stiff diagrams shown on Plate 1.

10.1 Low-TDS Hydrochemical Facies

Ground water representative of the low-TDS facies contains relatively small concentrations of total dissolved solids, bicarbonate, alkalinity, chloride; total calcium, potassium, magnesium, and sodium; total and filtered boron, lithium, and strontium; and relatively low specific conductance. Stiff diagrams (Plate 1) show that ground water of the low-TDS facies can be generally categorized as calcium-bicarbonate waters. The low-TDS facies underlies the bulk of KAFB area (Figure 6.1).

Piper diagrams (Figures 10.1 and 10.3) suggest that significant differences in ground-water chemistry do not exist between production wells and other monitoring points within the low-TDS facies.

10.2 High-TDS Hydrochemical Facies

Ground water representative of the high-TDS facies contains relatively large concentrations of total dissolved solids, bicarbonate, alkalinity, bromide, chloride; total calcium, magnesium, potassium, and sodium; filtered iron; total and filtered boron, lithium, manganese, and strontium; and relatively high specific conductance. Stiff diagrams (Plate 1) indicate that ground waters of the high-TDS facies can be generally classified as calcium-sodium-bicarbonate-chloride waters. Nine sites fall within the area of the high-TDS facies: Lake Christian West, EOD Hill, South Fence Road 1, South Fence Road 2S, South Fence Road 3S, Greystone, Schoolhouse, G-Spring, and Coyote Spring.

The high-TDS facies is restricted to the general area near the convergence of the Tijeras, Sandia, and Hubbell Spring Faults, occupying much of the pediment area (Figure 6.1). Close association with these structures suggests that the high-TDS facies is formed as deep ground waters flow upward along faults, and mix in the vicinity of the faults with shallow alluvium ground water that is recharged from the mountains. This process probably occurs over much of the pediment area, including along unknown faults buried by thin veneers of sediments. A conceptual model of the origin of the high-TDS facies and its relationship to the low-TDS facies is depicted in the schematic diagram of Figure 10.6.

Depending on how much mixing is taking place, large variability in ground-water chemistry is expected to occur. The authors speculate that in the high-TDS facies, dilution of deep ground waters by shallow recharge waters is impeded because of the relatively small volume of water available within the thin saturated zones of the canyons and pediment areas. However, once high-TDS ground water flows into the main part of the Albuquerque Basin, relatively large volumes of low-TDS waters are available to cause dilution.

The Piper diagram shown in Figure 10.2 illustrates that deep ground waters are responsible for the observed chemistry of the high-TDS facies (especially note EOD Hill well, Coyote Spring and G-Spring). Ground waters of the high-TDS facies contain disproportionately elevated levels of sodium and potassium compared to those of the low-TDS facies (Figures 10.1, 10.2, and 10.3). Because deep ground water tends to be older than shallow ground water, the former typically contains higher concentrations of total dissolved solids and chloride due to longer times of contact with aquifer materials. In addition, deep ground waters are also often enriched in sodium and potassium due to ion exchange of these two elements with calcium (Hem, 1985; Freeze and Cherry, 1979). Cemented gravels in the vicinities of Coyote Spring, G-Spring, and at various locations on the Hubbell Bench have formed as a result of minerals (mainly calcite) being precipitated by deep ground-waters moving upward along faults.

Samples from EOD Hill well, G-Spring, and Coyote Spring probably represent ground water from deep aquifers that have undergone little or no mixing with shallow ground water. Probability plots (Appendix H) support an hypothesis that EOD Hill, G-Spring, and Coyote Spring best represent deep ("parent") ground waters; whereas the Lake Christian West, South Fence Road 1, South Fence Road 2S, South Fence Road 3S, Greystone, and Schoolhouse wells monitor various mixtures of deep waters with shallow ground water. We believe that ground waters at Coyote Spring, G-Spring, and possibly at EOD Hill well are subject to upward vertical gradients, but have no direct proof. However, the water level of Coyote Spring is higher than that of the shallow alluvium aquifer expected to occupy Arroyo del Coyote, strongly suggesting that an upward vertical gradient exists here.

Ground water from G-Spring is chemically similar to that of nearby Coyote Spring, but has lower concentrations of calcium and bicarbonate. It is not possible to sample G-Spring at its discharge point because of a thick growth of salt cedar and other vegetation. We postulate that chemical differences between G-Spring and Coyote Spring may be due to the loss of gases and the

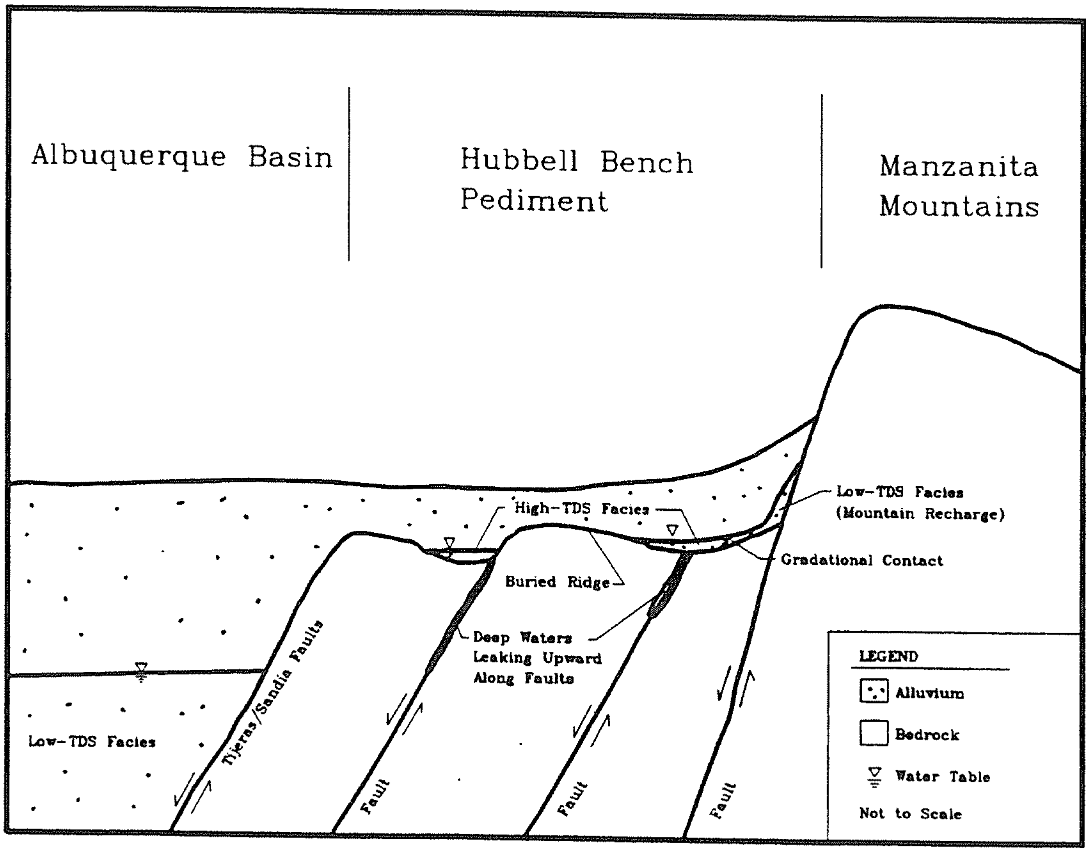


Figure 10.6. Schematic diagram of an east-west cross-section through the KAFB area. A thin veneer of sediments covers bedrock over much of the Sandia pediment/Hubbell Bench area. Deep ground waters flow upward along faults and mix with shallow alluvium ground waters (mountain recharge) to form the high TDS-facies.

Note that ground water can be "channelized" by paleotopography. Intervening buried ridges (that are dry) can separate individual paleochannels that are now occupied by ground water. Eventually, the high-TDS ground waters empty into the Albuquerque Basin, probably by flowing along such paleochannels.

The city pumps its ground water from the Albuquerque Basin.

precipitation of calcium carbonate as the ground water flows downstream from its discharge point.

If two ground waters of different chemistry are mixing, points plotted on a Piper diagram will fall on a straight line between the two sources. The three South Fence Road wells (SFR-1D, SFR-2S, and SFR-3S) are located between the Hubbell and Tijeras Faults on an east-west line and allow us to investigate the possible mixing of two waters within the high-TDS facies. These wells are all screened in alluvium, but at different levels within the aquifer (Table 4.6). The authors speculate that deep ground water is flowing upward along the Hubbell Spring Fault (in the subsurface) somewhere near SFR-3S, and is mixing with shallow ground water as it moves away from the fault. Furthermore, we assume that this deep ground water is similar in chemistry to that of Coyote Spring. Three monitor wells are present at the SFR-3 cluster well site. Although screened deeper, SFR-3T has a static water level that is 75 ft higher than that of any of the other SFR-3 cluster wells. The relatively high static water level in SFR-3T suggests that upward ground-water flow is occurring in this area. The Piper diagram shown in Figure 10.7 suggests that deep ground water in the vicinity of SFR-3S (and the Hubbell Spring Fault) becomes incrementally more sodium-poor as it mixes with shallow ground water from SFR-3S to SFR-1D.

Ground-water samples from the Firehouse well have a distinctly different chemistry compared to those collected from the South Fence Road wells. Unlike the latter, the Firehouse well lies west of the Tijeras and Sandia Faults in the main part of the Albuquerque Basin, which may explain this chemical difference.

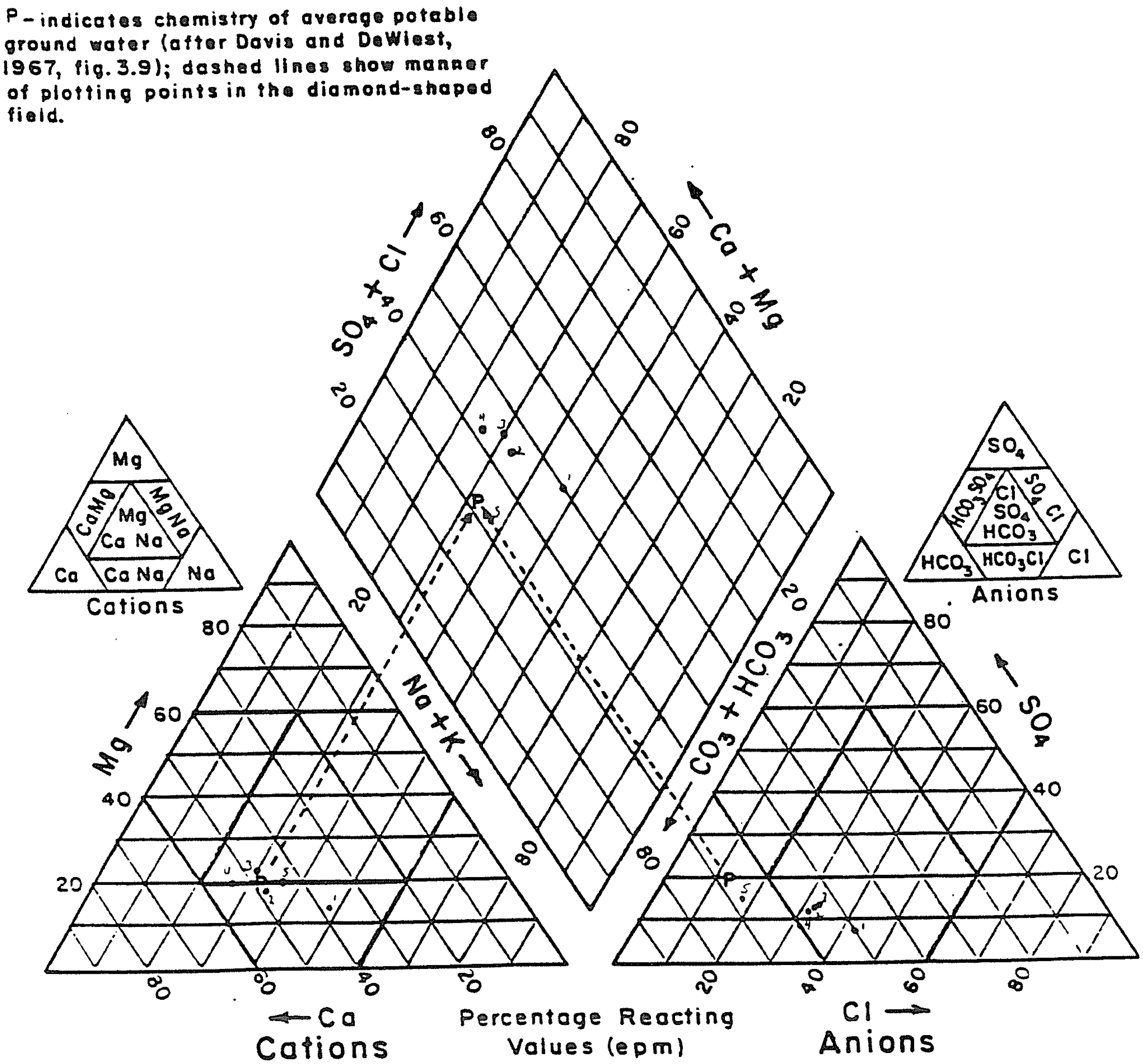
10.3 Suspected Trends for Sulfate, Fluoride, and Temperature

Concentration maps for temperature, fluoride, and sulfate (Appendix N) suggest that water temperature generally decreases, and concentration of sulfate and fluoride generally increases from the northwest to the southeast portions of the KAFB area.

Temperature probably increases to the west due to greater depths of the water table and the natural thermal gradient of the earth. Sulfate may increase to the southeast due to the suspected presence of the Abo Formation underlying much of the Hubbell Bench. The Abo Formation contains gypsum which could account for additional sulfate.

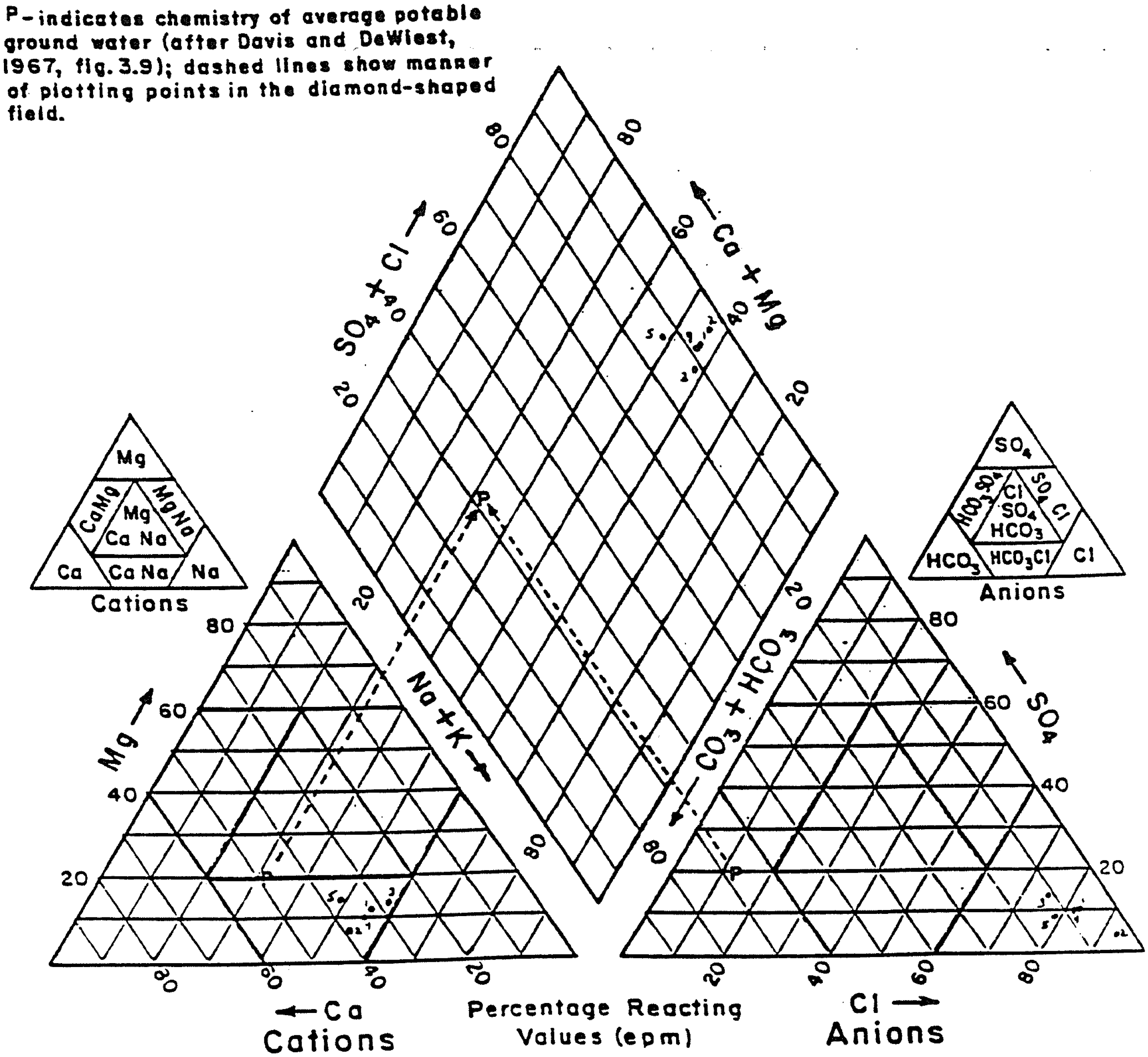
10.4 Contaminated Ground Waters

Figures 10.2 and 10.4 reveal that samples from wells KAFB-10 and CWL-BW3 contain proportionally higher concentrations of chloride and sodium (plus potassium) compared to those collected from the other wells and springs in the KAFB area (see also the discussion in Section 8.6). Historical data from these two wells also show similar saline chemistries (Figures 10.8 and 10.9, Appendix O). The elevated salinities of samples from CWL-BW3 and KAFB-10 suggest



Well #	Well/Spring
1	Coyote Spring
2	SFR-3S
3	SFR-2S
4	SFR-1D
5	Firehouse

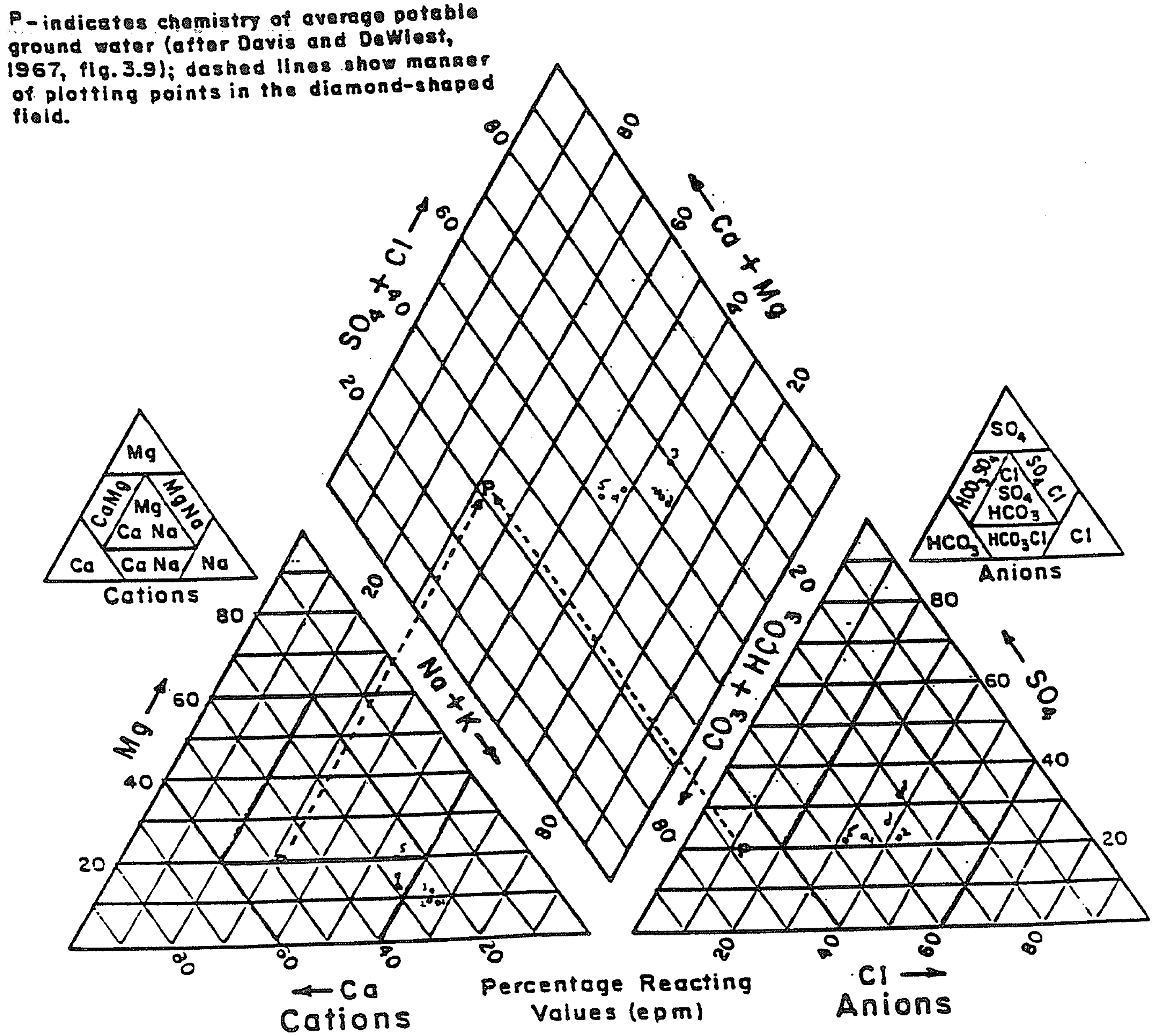
Figure 10.7. Piper diagram of the high-TDS facies showing mixing of deep ground water with shallow ground water from SFR-3S to SFR-1D. The deep ground water is assumed to have a chemistry similar to that of Coyote Spring. Firehouse well is also shown.



KAFB-10

Sample No.	Date Sampled	Data
1	4/93	NMED
2	1/92	SNL
3	7/92	SNL
4	4/91	SNL
5	7/91	SNL

Figure 10.8. Piper diagram showing historical data for production well KAFB-10 (near Technical Area 5).



CWL-BW3

Sample No.	Date Sampled	Data
1	2/93	NMED
2	5/93	NMED
3	1/92	SNL
4	4/91	SNL
5	7/91	SNL

Figure 10.9. Piper diagram showing historical data for monitor well CWL-BW3 at the Chemical Waste Landfill.

that liquid-phase contaminants have been transported to the water table at these locations. Analytical results for chromium and nickel (Appendix A), in comparison to the UTL for chromium (Table 9.7) and the 95th percentile value for nickel (Table 9.8), also indicate that ground water at CWL-BW3 is contaminated probably due to leakage from sources in the CWL area.

11. Comparison of SNL and NMED Background Results

Staff members of SNL's Ground-Water Surveillance Task have been monitoring wells and springs in the KAFB area for several years. Generally, most data reported by SNL are presented only in tabulated form. Previously published work interpreting KAFB-area ground-water quality is limited to three Piper diagrams prepared by McCord and others (1993), and a few sitewide statistics reported by Culp and others (1992).

Culp and others (1992, Tables 7-10 to 7-12), presented analytical results and sitewide statistics for 16 wells and four springs in the KAFB area. Although they listed the maximums, minimums, means, and variances of 12 to 13 ground-water constituents, they provided no specific discussion of them in the text. The means reported by Culp and others (1992) are listed in Table 11.1, along with the results of this investigation for comparison.

For the low-TDS facies, the mean concentrations of magnesium, calcium, potassium, sodium, chloride, bromide, and total alkalinity, are appreciably lower in our results than SNL's. The same relationship exists for nitrate plus nitrite. However, the opposite relationship is generally true for our results for the high-TDS facies.

Culp and others (1992) reported that the chemistry of ground water located east of the major faults is statistically different from that of ground water occurring west of the faults. Applying a Mann-Whitney test at a 90% confidence level, SNL determined that ground-water east of the faults generally has lower values of pH and temperature, and typically has higher values for total alkalinity, chloride, bromide, calcium, and magnesium. It was also determined that statistically significant differences in water quality did not exist for potassium, sodium, fluoride, sulfate, and nitrate plus nitrite (Culp and others, 1992).

In contrast, our data show that bimodal populations exist for sodium and potassium. We did not observe bimodal populations for temperature and pH; but did find strong evidence of the existence of two populations for the other constituents. In addition, the authors differ with SNL regarding the locations of the two ground-water populations. Culp and others (1992) concluded that two ground-water populations are separated by and lie east and west of the faults. In contrast, our study finds that the second population (high-TDS facies) is restricted to areas near the faults, mostly within the pediment area. Finally, although SNL asserts that at least two distinct ground-water populations exist for some constituents, the means summarized in Table 11.1 show that they did not analyze each separately for background ground-water quality.

Table 11.1

Comparison of NMED and SNL Results for Sitewide Statistics

Constituent or Property	SNL 4/91 Mean	SNL 7/91 Mean	SNL 10/91 Mean	NMED Low-TDS Mean	NMED High-TDS Median	NMED Single-Population Mean
pH	7.37	7.58	7.64	-----	-----	6.84
Temperature	17.5	19.1	17.2	-----	-----	19.93
Magnesium	20.2	33.2	27.1	11.4	33.5	-----
Calcium	79.0	86.4	111.9	59.6	133.0	-----
Potassium	5.52	6.54	10.8	3.5	6.7	-----
Sodium	69.7	60.0	59.9	33.3	103.0	-----
Iron	0.10	NS	NS	0.065	2.655	-----
Fluoride	0.58	0.56	0.70	-----	-----	0.679
Chloride	80.8	58.8	92.6	24.0	135.0	-----
Bromide	0.77	0.42	1.05	0.341	0.800	-----
Nitrate/ite	24.0	14.1	16.1	-----	-----	1.172
Sulfate	71.9	46.6	69.1	-----	-----	63.53
Alkalinity	6.10	6.22	7.48	2.8	9.5	-----

Notes:
Units are mg/L except pH, Temperature (°C), and Alkalinity (reported as milliequivalents per liter of bicarbonate). Nitrate/ite = nitrate plus nitrite. NS = not sampled. Dashed lines (-----) = not applicable: NMED results are based on bimodal or single populations depending on specific ground-water constituents. NMED means for iron, fluoride, bromide, and nitrate/ite are geometric means.

Major ionic species can be important as indicators of ground-water contamination. Failure to recognize discrete ground-water populations, especially among major ions, may impair recognition of contaminated sites. For example, our statistical descriptors for chloride (Table 8.1) suggest that impact to ground water has occurred in the vicinity of KAFB-10. However, SNL's results (Culp and others, 1992) suggest exactly the opposite - that no impact to the aquifer has occurred here. Ground-water contamination has been discovered by SNL in well LWDS-MW1, near KAFB-10, which increases confidence in the validity of our work.

12. Additional Discussion

12.1 Field versus Laboratory Measurements of pH and Alkalinity

Although not a primary objective, one purpose of this investigation was to evaluate differences between laboratory and field measurements for pH and total alkalinity of KAFB-area ground water. These efforts were done for the benefit of NMED DOE Oversight Program staff. We do not imply here that either SNL or ITRI have provided unreliable data for these two specific field parameters.

A plot of laboratory pH versus field pH is shown in Figure 12.1. Values of field pH range from about 6.1 to 7.6 pH units. The line on the graph represents the locus of points where laboratory and field pH are equivalent. As demonstrated by this plot, field measurements of pH varied widely from their respective laboratory measurements. The plot shows that pH tends to stabilize to about 8.2 to 8.6 before laboratory measurements are made, regardless of the magnitude of the original field pH. Thus, laboratory pH values are meaningless.

The evaluation of laboratory alkalinity measurements is less straight forward (Figure 12.2). The line on the graph represents the locus of points where laboratory and field alkalinity are equivalent. In general, field alkalinity measurements are higher than laboratory results; however, the differences between them are much less for low-TDS than for high-TDS ground-water samples. Figure 12.2 suggests that laboratory measurements should not be made on ground-water samples suspected of having alkalinities exceeding 400 mg/L. Thus, laboratory alkalinities reported for high-TDS ground-water samples may not be accurate. We recommend that total alkalinity be measured in the field, when possible, for all ground water in the KAFB area.

12.2 Mining Activities and their Effect on Ground-Water Quality

Some faults within the KAFB area host epithermal veins containing fluorite (CaF_2), and subordinate amounts of galena (PbS), barite ($BaSO_4$), calcite ($CaCO_3$), and quartz (SiO_2). All mines in the KAFB area are presently inactive. Except for the Galena King, none of the mines is believed to have had any significant metal or barite production.

Traces of copper mineralization were seen at only a few localities, most notably at the Frustration (northern workings) and the Galena King. Barite and galena are relatively common in the fluorspar veins at the Galena King; elsewhere the two minerals are usually present, but are less abundant. The weak mineralization which characterizes the entire mining district suggests that naturally high metal concentrations should not be typical of KAFB-area ground water. Finally, the small size of the workings, and the fact that the workings are normally dry, suggest that mining activities have had no impact on ground-water quality in the KAFB area.

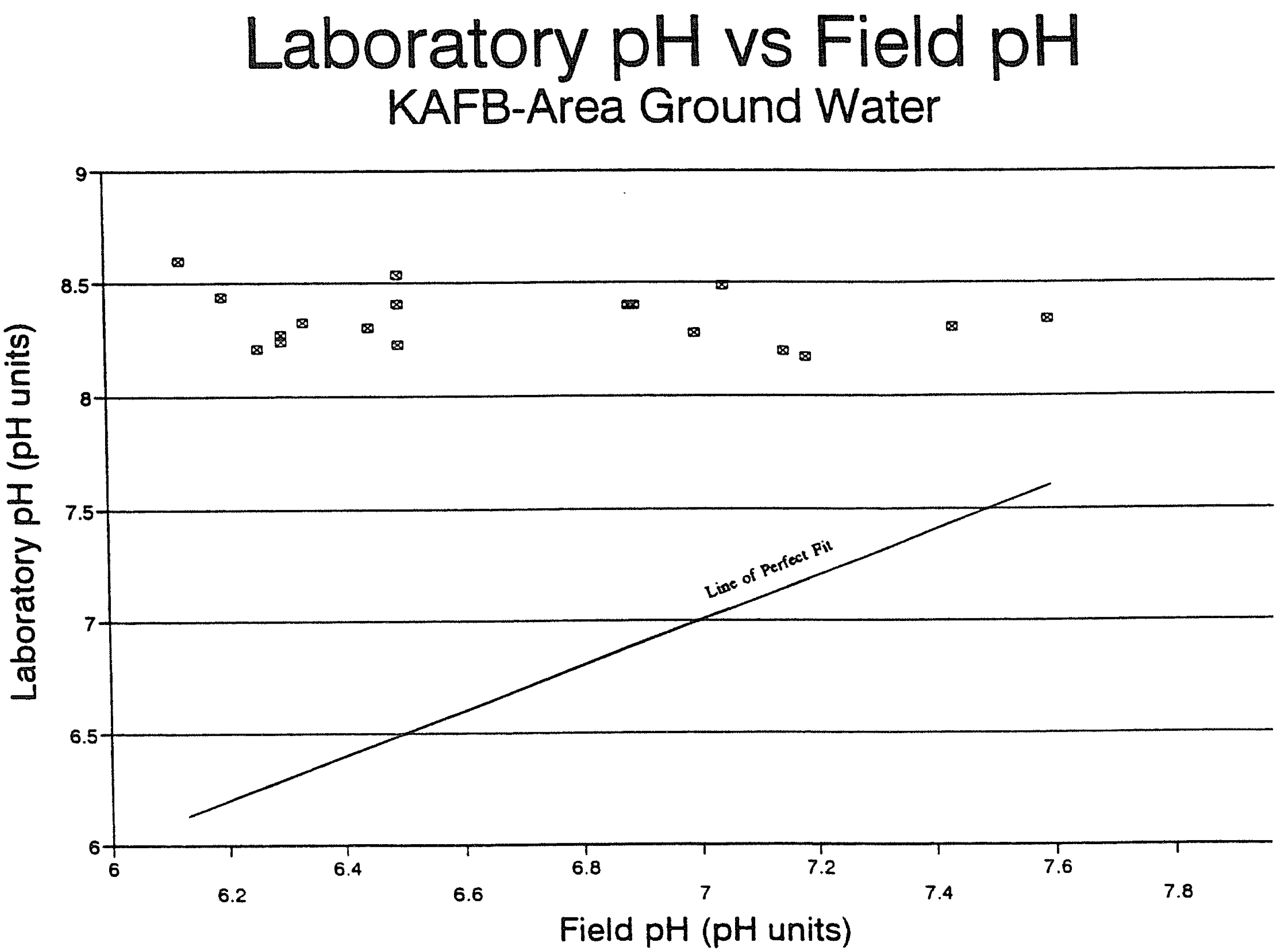


Figure 12.1. Plot of laboratory pH versus field pH.

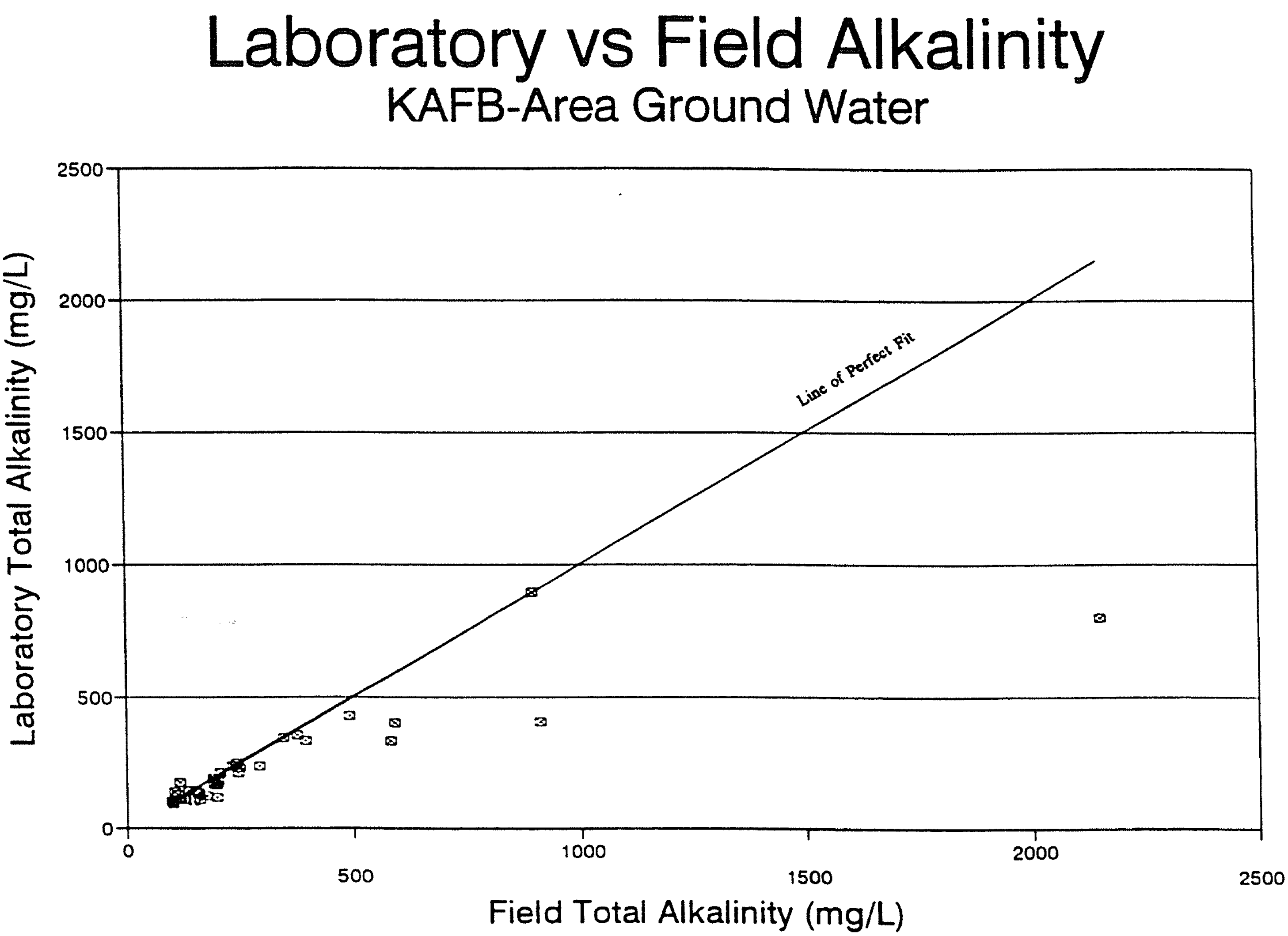


Figure 12.2 Plot of laboratory alkalinity versus field alkalinity.

13. Recommendations for Additional Monitor Wells

As shown in Figure 6.1, few monitor wells exist in the eastern portions (canyon regions) of the KAFB area and the region encompassed by the high-TDS facies. Based on this study, new monitor wells are recommended so that background hydrochemistry can be better established for these areas.

The Yates well, installed in 1943, is the only existing well in the northeastern portion of KAFB. The well is located east of Manzano Base on the edge of an unnamed arroyo, which flows through a residential area and eventually into Tijeras Arroyo. This site is critical for determining the northeastern extent of the high-TDS facies, which could extend a significant distance to the northeast along the Tijeras Fault zone. However, sampling access to the well is blocked by the remnants of a windmill. Information regarding construction and the geologic conditions encountered while drilling the well does not exist. The well is associated with the ruins of the abandoned Yates Ranch, and may be an archaeological feature. If so, rehabilitation of the well might be prohibited by regulatory and statutory requirements intended to protect cultural resources. We recommend that at least one new well be installed in the same arroyo close to the Yates' well to permit investigation of water quality and to facilitate environmental surveillance in this part of KAFB.

Additional wells should also be drilled within and along all of the boundaries of the high-TDS facies to better define its extent, and to acquire more data on background hydrochemistry. As noted above, major ions are often evaluated as indicators of potential ground-water contamination. However, given our present understanding of background conditions, it will be difficult to recognize potential contamination at ER sites that are located within the area encompassed by the high-TDS facies.

The high-TDS facies may extend further east and may occupy more of the Hubbell Bench and the pediment area than is currently recognized. Additional wells should be installed in Coyote Arroyo and its tributaries, along areas west and east of the Travertine Hills, and on the Sandia pediment between the Tijeras/Hubbell Faults and the mountains. To ensure that they are suitable for monitoring background conditions, the wells should not be drilled too close to ER sites. A few wells are also needed on the Isleta Pueblo to better determine the southern extent of the high-TDS facies, which because of geologic factors, may be shifted to the east of the Hubbell Spring Fault and extend much further to the south. It is fortunate that most wells drilled within the high-TDS facies encountered ground water at relatively shallow depths (~100 feet).

Limited data from abandoned production well KAFB-09 suggest that the high-TDS facies may extend just west of the Sandia Fault near

Manzano Base. Like KAFB-10, due to practical reasons, this well can not be purged prior to sampling. A background well to replace KAFB-09 would help to determine if the northwestern boundary of the high-TDS facies indeed extends to the west side of Manzano Base, or if the facies is restricted to the Tijeras Fault zone in this part of the KAFB area.

Deep ground waters may be migrating upward along buried faults in the vicinity of ITRI and adjacent areas on the Hubbell Bench. Recent drilling by the NMED DOE Oversight Program and the facility has shown that the hydrogeologic conditions at the site are more complex than originally believed (personal communication, B. McDonald and W. Stone, 1994). Samples from a few monitor wells at ITRI contain high concentrations of total dissolved solids and chloride, but essentially no nitrate plus nitrite. Results of this study suggests that these specific wells may actually monitor natural high-TDS ground waters that are flowing upward along buried faults. As they flow away from these faults, such waters eventually mix with contaminated ground water from the ITRI sewage lagoons (in effect, naturally diluting the contamination). Cemented gravels encountered in the subsurface reveal that high-TDS ground waters were present at the ITRI site in the geologic past. Future sampling for characteristic traits of the high-TDS facies (e.g. lithium, boron, and strontium) may help to resolve whether these wells monitor natural or contaminated ground water. Additional wells located east of ITRI are recommended to better determine the extent of the high-TDS facies in this part of the KAFB area.

14. Conclusions and Additional Recommendations

In this report, background hydrochemistry is established for major ions and a number of other inorganic constituents in the KAFB area. Maximum background concentrations and other statistical descriptors representing background populations for each constituent were determined. Statistical descriptors are important for classifying samples and for interpreting KAFB-area hydrochemistry. Maximum background values are useful for recognizing the presence of contamination at ER sites, for ensuring that no releases of hazardous materials are occurring from current facility operations, and for establishing cleanup standards. Piper diagrams, Stiff diagrams, and concentration maps were also prepared, and in combination with the statistical results of this study, were used to model hydrochemistry in the KAFB area.

Results of this study reveal that most trace constituents, several minor constituents, and sulfate are characterized by single populations which encompass all ground water in the KAFB area. In contrast, two discrete populations were identified for most major ions, for some minor species, and for a few trace ground-water constituents. These two discrete populations were subdivided into the high-TDS and low-TDS hydrochemical facies on the basis of having either relatively small or large concentrations of total dissolved solids (TDS).

The low-TDS hydrochemical facies is characterized by relatively small concentrations of total dissolved solids, bicarbonate, alkalinity, chloride, calcium, potassium, magnesium, boron, lithium, strontium, and sodium; and relatively low specific conductance. Ground waters representative of this facies are predominantly calcium-bicarbonate waters and underlie the bulk of the KAFB area.

The high-TDS facies is characterized by relatively high concentrations of total dissolved solids, bicarbonate, alkalinity, bromide, chloride, filtered iron; and total and filtered boron, calcium, potassium, lithium, magnesium, manganese, sodium, and strontium; and relatively high specific conductance. Stiff diagrams show that these waters are best described as sodium-calcium-bicarbonate-chloride waters. The high-TDS facies is restricted to the general area near the convergence of the Tijeras, Sandia, and Hubbell Spring Faults, occupying much of the pediment area. The high-TDS facies represents various mixtures of shallow alluvium ground water with deep ground waters that are migrating upward along faults that border and occur within the pediment area.

Other conclusions and recommendations derived from this study are:

1. Sediments in each principle arroyo should be described and characterized. This information can then be used to delineate alluvial fan sediments in the KAFB area.

2. Several SNL ER sites are located along Tijeras Arroyo, Arroyo del Coyote, or along their tributaries; however, SNL has installed few monitor wells in these drainages. Additional monitor wells are needed in these arroyos to better establish background hydrochemistry, and to look for environmental impacts near ER sites. The adequacy of ground-water monitoring along the Travertine Hills arroyo and the unnamed arroyo south of ITRI is under investigation by the NMED/AIP. Replacement of the Yate's well and KAFB-09 should be seriously considered by SNL.

3. Analytical results of ground-water samples from wells CWL-BW3 and KAFB-10 show that the aquifer beneath the Chemical Waste Landfill and Technical Area 5 has been impacted by past facility operations. Based on observations concerning water quality and the fact that the two wells lie outside the shallow ground-water regime in the KAFB area, wells KAFB-10 and CWL-BW3 have not been included with the high-TDS facies. Background wells drilled at appropriate locations at some distance away from Technical Area 5 and the Chemical Waste Landfill would be helpful to better define background hydrochemistry at these two locations.

4. Using only existing wells, background hydrochemistry cannot be reliably established on a sitewide basis for nitrate plus nitrite. The mean value reported herein (1.172 mg/L) is likely conservatively high for uncontaminated conditions in the KAFB area.

5. Elevated salinities of ground-water samples from KAFB-10 and CWL-BW3 suggest that liquid-phase contaminants have reached the water table at Technical Area 5 and the Chemical Waste Landfill. Concentrations of chromium and nickel in ground-water samples collected from CWL-BW3 greatly exceed maximum background values, indicating that ground water monitored by this well is contaminated with these metals probably due to leakage from sources in the CWL area.

6. Total alkalinity should be measured in the field, when possible, for all ground water in the KAFB area. Laboratory alkalinity measurements are not reliable for samples having known or expected alkalinities exceeding 400 mg/L.

7. Mining has had no impact on ground-water quality in the KAFB area.

8. In contrast to work done by SNL, results of this study show that bimodal populations exist for sodium and potassium, but not for pH and temperature. SNL concludes that two ground-water populations are separated by, and lie east and west of the faults. Our study finds that the second population (high-TDS facies) is restricted to areas near major faults, mostly within the pediment area.

15. Acknowledgements

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