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NORTH AMERICAN SPACE OPERATIONS
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Remedial Investigation Report For 903 Pad, Mound, and East Trenches Areas

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NOTICE

All drawings located at the end of the document.

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5.0 SITE HYDROGEOLOGY

This section presents results of hydrogeologic investigations at the 903 Pad, Mound, and East Trenches Areas in the Rocky Flats Plant. The section begins with detailed geologic descriptions of surficial and bedrock materials with emphasis on their hydrologic properties. Geologic descriptions are followed by a discussion of ground-water flow in various materials and their interconnection. The section concludes with a narrative on the nature and extent of ground-water contamination at the 903 Pad, Mound, and East Trenches Areas.

Hydrogeologic and geochemical interpretations are based on information gathered from 35 boreholes and 41 monitor wells completed during the 1986 and 1987 drilling programs. Plate 2-1 shows the locations of all monitor wells at Rocky Flats Plant, and Plate 4-1 presents borehole and monitor well locations at the 903 Pad, Mound, and East Trenches Areas. Appendix A of this report contains excerpts from the RI Work Plan which pertain to this investigation, and Appendix D presents rationale for final borehole and well locations as well as drilling and sampling procedures implemented during the RI. Hydrogeologic data collected during the remedial investigation are presented in Appendix E. This includes geologic logs of all boreholes and wells, well completion data sheets, packer test data sheets and results, slug test data and results, and water level data sheets. Appendix E contains analytical results from soil, ground-water and surface water sampling programs. Quality assurance/quality control (QA/QC) documentation and evaluations for field and laboratory work are provided in Appendix F.

5.1 SURFICIAL GEOLOGY

Surficial materials at the 903 Pad, Mound, and East Trenches Areas consist of the Rocky Flats Alluvium, colluvium, and valley fill alluvium unconformably overlying bedrock (Plate 5-1). All of the study areas are situated on a terrace of Rocky Flats Alluvium which extends eastward from the Plant. A portion of the 903 Pad Area extends south from the terrace toward the South Interceptor Ditch. Colluvium is present on the hillside south of the 903 Pad and East Trenches Areas and on the hillside north of the Mound Area. Valley fill alluvium is present in the drainage of Woman Creek south of the 903 Pad and East Trenches Areas and in the South Walnut Creek drainage north of the Mound Area. Artificial fill was not encountered during site investigations; however, disturbed surficial materials are evident at the Mound Area in the vicinity of the Perimeter Security Zone (PSZ) fence and south of the 903 drum storage site in the 903 pad lip site. Surficial materials at the 903 pad lip site were disturbed by remedial actions at the site.

5.1.1 Rocky Flats Alluvium

The Quaternary Rocky Flats Alluvium is the oldest and topographically highest alluvial deposit at the Rocky Flats Plant; it is pre-Wisconsin in age. The Rocky Flats Alluvium is a series of coalescing alluvial fans deposited by braided streams (Hurr, 1976). The erosional surface (pediment) on which the alluvium was deposited slopes gently eastward truncating the Fox Hills Sandstone, the Laramie Formation, and the Arapahoe Formation at the Rocky Flats Plant. The pediment truncates Arapahoe claystones and sandstones at the 903 Pad, Mound, and East Trenches Areas with an average gradient of 0.02 ft/ft (Plate 5-2).

Buried valleys and ridges eroded into the top of bedrock are present at the base of the Rocky Flats Alluvium (Plate 52). One such paleovalley is located north of the 903 Pad Area along Central Avenue. This paleovalley trends east-northeast along the East Access Road and bends to the southeast just south of well 33-87 (Plate 5-5; Cross Sections H-H',I-I' and Plate 5-6; Cross Section K-K'). Near well 32-87 the paleovalley joins another paleovalley which trends northeast toward well 39-86. The paleoridge east of well 15-87 separates these two paleovalleys. Another paleoridge occurs beneath the northern edge of the Rocky Flats Alluvium terrace east of the Mound Area and north of the East Trenches (Plate 5-4; Cross Section F-F').

The thickness of the Rocky Flats Alluvium in the 903 Pad, Mound, and East Trenches areas ranges from 4.85 feet (BH24-87) to 45 feet (well 40-86). The alluvium is thinnest over the paleoridge along the southern edge of the 903 Pad, and thickest in the paleovalley along the East Access Road (BH44-87, BH54-87, and BH55-87).

Subsequent to deposition of the Rocky Flats Alluvium, eastward flowing streams began dissecting the deposit by headward erosion and lateral planation. All of the alluvium was removed by erosion in the Woman Creek drainage directly south of the 903 Pad, Mound, and East Trenches Areas, and in the South Walnut Creek drainage north of these areas. The result is a terrace of Rocky Flats Alluvium which extends eastward from the Plant between the two drainages.

The Rocky Flats Alluvium consists of a poorly to moderately sorted, poorly stratified, deposit of clays, silts, sands, gravel, and cobbles. Occasional boulders are found locally. Colors of the alluvium vary widely from pale yellowish brown (10 YR 6/2) (GSA Rock Color Chart) to dark yellowish brown (10 YR 4/2). The grain size of the quartzose and granite sands comprising the alluvium are characteristically very fine-grained (3.5 phi) (Jackson, 1970) to medium-grained (1.5 phi). Quartzite and granite gravels, pebbles, and cobbles are predominantly angular to subangular, indicative of materials transported short distances. Occasionally, granite cobbles weathered in place were identified based on the presence of feldspar grains in the sand and gravel matrix.

Calcium carbonate cementation is commonly encountered in the form of caliche in addition to caliche rinds around quartzite gravels and pebbles. Continuous caliche zones were identified and correlated between several boreholes in the Mound and East Trenches Areas (Plate 5-5; Cross Section H-H'). These caliche zones were probably deposited by a fluctuating water table and may represent the seasonal high of the water table.

5.1.2 Colluvium

Colluvial materials are present on the hillside south of the 903 Pad and East Trenches Areas and the hillside north of the Mound and East Trenches Areas. These deposits are generally composed of materials derived from the Rocky Flats Alluvium and claystone bedrock. Colluvium ranges from 3 feet (borehole 11-87A) to 22 feet (well 62-86) in thickness (Plate 5-3; Cross Sections B-B', C-C', D-D' and Plate 5-4; Cross Section E-E').

Colluvium consists predominantly of clay with common occurrences of sandy clay and gravel. Colluvial clay is typically poorly consolidated and ranges from moderate yellowish brown (10 YR 5/4) to dusky brown (5 YR 2/2) in color. Angular to subangular quartzite pebbles are rare, and caliche is commonly present in the clay deposits. The sandy intervals contain moderate yellowish brown (10 YR 5/4), very fine to coarse grained (3.5 phi to 0.5 phi), rounded to subangular quartzose sand. Colluvial materials are poorly to well sorted and generally unconsolidated in the sandy intervals. Gravel lenses if present generally occur at the base of the colluvium directly overlying bedrock (wells 62-86, 63-86, and 12-87BR and borehole BH27-87) as shown on Cross Sections B-B' and C-C' (Plate 5-3).

5.1.3 Valley Fill Alluvium

Valley fill alluvium occurs along the present drainages of Woman Creek and South Walnut Creek. The alluvium is generally gravel with pebbles, cobbles, and some sand. It consists of reworked and redeposited Rocky Flats Alluvium on top of bedrock. Valley fill alluvium thicknesses ranges from 5.8 feet (well 66-86) to 8.8 feet (well 64-86).

The unconsolidated valley fill alluvium in the Woman Creek drainage consists of poorly to moderately sorted, angular to subangular granite and quartzite cobbles, pebbles, and gravels in a dark yellowish brown (10 YR 4/2) to light brown (5 YR 5/6) sandy matrix. Some dusky yellowish brown (10 YR 2/2) silty clay was also found in well 65-86. Sand grains range in size from fine-grained (2.5 phi) to coarse-grained (0.5 phi).

Valley fill alluvium in the South Walnut Creek drainage is typically finer grained than that along Woman Creek. Alluvium encountered in wells 34-86, 35-86, and 36-86 consists of grayish olive (10Y 4/2) to dark yellowish brown (10YR 6/2) poorly consolidated silty clay with traces of sand, gravel, and cobbles. Dark yellowish brown (10YR 4/2) unconsolidated granitic gravel with pebbles and cobbles was also encountered at the base of the valley fill alluvium in well 36-86 (1.2 feet).

5.2 BEDROCK GEOLOGY

The Cretaceous Arapahoe Formation underlies surficial materials at the 903 Pad, Mound, and East Trenches areas. Sixteen wells have been completed in various zones within the bedrock during the 1987 drilling program. The Arapahoe Formation consists of fluvial claystones with interbedded lenticular sandstones, siltstones, and occasional lignite deposits. Contacts between these lithologies are both gradational and sharp.

5.2.1 Arapahoe Formation Claystones

Claystone was the most frequently encountered lithology of the Arapahoe Formation immediately below the Quaternary/Cretaceous contact. Weathered bedrock was encountered directly beneath surficial materials in all of the boreholes and well. Weathered bedrock extends 10 (well 31-87BR) to 58 feet (well 36-87BR) below the alluvium/bedrock contact. Unweathered bedrock occurs between 36 (well 22-87BR) and 58 feet (well 40-86) below ground surface.

The weathered claystones are olive gray (5 Y 3/2) with extensive brown, green, red, and yellow mottling. This zone is generally consolidated, exhibits blocky structure, and contains abundant carbonaceous debris and lignite stringers. Iron oxide concretions and caliche are often encountered and the interval is characterized by mild to intense fracturing.

The unweathered claystone is typically grayish black (N 2/0) to olive gray (5 Y 3/2) and exhibits very little mottling and mild fracturing. Like the weathered claystone, the unweathered, consolidated claystone also has a blocky texture and contains abundant carbonaceous debris. Sandy intervals are common within the claystone and generally consist of very fine-grained (3.5-3.0 phi), rounded quartzose sand grains. Abundant fossils (mainly leaves and plant fragments) were encountered in the Arapahoe Formation claystones.

Fracturing was identified at various depths during the drilling of 18-87BR, 22-87BR, and 30-87BR. Vertical, horizontal, and 45^{0} fractures were encountered. Calcareous deposits were found in the fractures described in 18-87BR, and slickensides were found in 31-87BR at 79.2 to 81.60 feet. Fractured zones are not continuous between wells and are not considered an important conduit for ground-water flow.

5.2.2 Arapahoe Formation Sandstones

Saturated sandstones were found in wells 9-87BR, 12-87BR, 23-87BR, and 25-87BR directly below surficial materials (subcropping), and in wells 62-86, 11-87BR, 14-87BR, and 36-87BR near the alluvium/bedrock contact. Bedrock wells 41-86, 16-87BR, 18-87BR, 20-87BR, 22-87BR, 28-87BR, 30-87BR, and 31-87BR are completed in deeper saturated sandstones. Presented below is a discussion of the Arapahoe sandstones encountered during drilling at the 903 Pad, Mound, and East Trenches Areas.

Sandstones of the Arapahoe Formation in the remedial investigation areas are pale yellowish brown (10 YR 5/6) to olive gray (5 Y 3/2), fine to medium-grained (3.0-1.5 phi) quartzose sands with approximately 10% lithic fragments. The sand grains are rounded to subrounded and are generally well sorted. The sandstones are poorly to moderately cemented, commonly exhibit cross-bedding (well 22-87BR), and often contain silty and clayey intervals.

Very dense calcareous sandstone lenses were encountered during the drilling of 13-87BRA, 16-87BR, 18-87BR, 20-87BR, 22-87BR, 34-86, and 40-86. In addition, calcareous mudstone was found in 22-87BR, and a conglomerate with a calcareous cementation was observed in 31-87BR. The mudstone, calcareous sandstone, and conglomerate contained abundant organic fragments and effervesced when hydrochloric acid was applied. These calcareous units may indicate a near shore fluvial to shallow marine environment of deposition. These intervals are very thin (0.1 to 4.5 feet) and discontinuous.

Siltstones were also encountered in the Arapahoe Formation during drilling. They are dark greenish gray (5 GY 4/1) to dark gray (N 3/0) in color and generally contain some fine-grained sand (3.0 phi). These siltstones are very similar in lithology to the sandstones described above.

Cross sections throughout the area are presented in Plates 5-3, 5-4, 5-5 and 5-6 to show stratigraphic correlations of the lithologies encountered during the drilling program. Cross section locations are shown on Plate 4-1. The Arapahoe sandstones are generally lenticular and somewhat discontinuous; however, some correlations are shown on Plates 5-3 through 5-6.

Based on the correlation of the base of sandstone in wells 9-87BR and 16-87BR Cross Section A-A' (Plate 5-3), bedrock is dipping approximately 7 degrees to the east (assuming a north-south strike). This dip is consistent with that calculated for sandstones in the 881 Hillside Area (Rockwell International, 1987b) and for other sandstones encountered in the 903 Pad, Mound, and East Trenches Areas.

Specifically, the subcropping sandstone in well 23-87BR correlates with a thin sandstone in the upper portion of well 18-87BR at a 7 degree dip (Plate 5-4; Cross Section G-G'), and the subcropping sandstone in well 25-87BR correlates with the near surface sandstone in well 36-87BR with a 7 degree dip (4 degree apparent dip on Cross Section F-F' on Plate 5-3). Wells 12-87BR and 11-87BR also appear to be completed in the same sandstone. However, well 11-87BR is located nearly along strike south of 12-87BR (Plate 5-3, Cross Section B-B').

5.3 GROUND-WATER FLOW

Ground water occurs in surficial materials (Rocky Flats Alluvium, colluvium, and valley fill alluvium) and in Arapahoe sandstones at the 903 Pad, Mound, and East Trenches Areas. These two hydraulically connected flow systems are discussed separately below.

5.3.1 Ground Water in Surficial Materials

Recharge/Discharge Conditions

Ground water is present in the Rocky Flats Alluvium, colluvium, and valley fill alluvium under unconfined conditions. Recharge to the water table occurs as infiltration of incident precipitation and as seepage from ditches and creeks. In addition, retention ponds along South Walnut Creek and Woman Creek probably recharge the valley fill alluvium.

The shallow ground-water flow system is quite dynamic, with large water level changes occurring in response to precipitation events and stream and ditch flow. Hurr (1976) describes the rapid response of water levels in wells completed in Rocky

Flats Alluvium to surface flows in irrigation ditches. Similarly, between mid-April and September, 1986, water levels in wells 1-86 and 4-86 (completed in valley fill alluvium) dropped more than four and eight feet, respectively. Based on water levels from wells 1-86, 2-86, 42-86, 43-86, 64-86, 65-86, and 66-86 (Appendix E) alluvial water levels are highest during the spring and early summer months of May and June. Water levels in these wells decline during late summer and fall, and some of the wells go completely dry at this time of year.

Ground-water Flow Directions

Ground-water flow in the Rocky Flats Alluvium is generally from west to east following the buried topography on top of claystone bedrock. Plate 5-7 presents the potentiometric surface in surficial materials measured on 1 December, 1987. Because of the bedrock highs beneath the Rocky Flats Alluvium in the East Trenches Area, ground-water flow is diverted either toward the paleovalleys or off the edge of the Rocky Flats terrace. Water diverted toward the paleovalleys flows northeast following the trend of the valleys. Ground water flowing toward the terrace edges emerges as seeps and springs at the contact between the alluvium and claystone bedrock (contact seeps), is consumed by evapotranspiration, or flows through colluvial materials following topography toward the valley fill alluvium. Once ground water reaches the valley fill alluvium, it either flows down-valley in the alluvium, is consumed by evapotranspiration, or discharges to the creek. During the driest periods of the year, evapotranspiration can consume so much water that there is no flow in either the colluvium or the valley fill alluvium.

Saturated thickness in surficial materials varied from 0 (well 63-86) to 9 feet (well 17-87) on 1 December, 1987. Plate 5-7 shows an area of little to no saturation in the Rocky Flats Alluvium and colluvium west and south of the 903 Pad Area. The absence of alluvial ground water in this area is due to either:

1) discharge of ground water to overland flow where bedrock is exposed at or near the surface;

2) discharge of ground water to the atmosphere as evaporation from the capillary fringe and as transpiration from phyreatophytes; or

3) recharge to subcropping bedrock sandstones from alluvial ground water.

Moisture content of surficial materials in these areas of little to no saturation is below saturation. Wells completed in these areas have been dry, and boreholes in the area also indicate unsaturated conditions. Hurr (1976) and Rockwell International (1986a) found similar areas of little to no saturation in surficial materials.

Ground-water Flow Rates

Hydraulic conductivity values were developed for surficial materials from drawdown-recovery tests performed on 1986 wells during the initial Phase II site characterization (Rockwell International, 1986a) and from slug tests performed on select 1986 and 1987 wells during the 1987 remedial investigation. Results of these tests are summarized in Table 5-1. Data, analyses, and results for each of these tests are presented in Appendix E.

There is a wide variability in the hydraulic conductivity results from drawdown-recovery versus slug tests performed on wells completed in Rocky Flats Alluvium. However, each test was performed on a different well so no comparison can be made between tests for a given well. There is good agreement between drawdown-recovery and slug test performed on well 35-86 (completed in South Walnut Creek valley fill alluvium). The data presented in Table 5-1 are thus considered

TABLE 5-1

HYDRAULIC CONDUCTIVITY VALUES FOR SURFICIAL MATERIALS

WELL	SLUG TEST RESULT (cm/sec)	DRAWDOWN RECOVERY RESULT* (cm/sec)
Rocky Flats Alluvium		
39-86	--	4×10^{-5}
41-86	--	9×10^{-5}
42-86	5×10^{-2}	---
17-87	6×10^{-5}	---
32-87	1×10^{-3}	---
Geometric Mean:	1×10^{-3} cm/sec (1035 ft/year)	6×10^{-5} cm/sec (62 ft/year)
Woman Creek Valley Fill		
56-86	---	2×10^{-3}
65-86	---	3×10^{-3}
68-86	---	5×10^{-5}
Geometric Mean:		7×10^{-4} (724 ft/year)
South Walnut Creek Valley Fill		
35-86	1×10^{-4} cm/sec (103 ft/year)	9×10^{-5} cm/sec (93 ft/year)

* Rockwell International, 1986a

reliable at this time, but further hydraulic conductivity testing should be performed on old and new wells to correlate test results.

Hydraulic conductivity values for the Rocky Flats Alluvium ranged from a geometric mean of 6 X 10-5 centimeters/second (cm/sec) (62 ft/year) for 1986 drawdown-recovery tests to a geometric mean of 1 X 10-3 cm/sec (1,035 ft/year) for 1987 slug tests (Table 5-1). The geometric mean for all tests is 4 X 10-4 cm/sec (418 ft/year). Based on an average horizontal gradient of 0.02 ft/ft, an assumed effective porosity of 0.1 and a mean hydraulic conductivity of 418 ft/year, the average ground-water velocity in the Rocky Flats Alluvium is 84 ft/year.

Hydraulic conductivity values from drawdown-recovery tests for the Woman Creek valley fill alluvium ranged from 5 X 10-5 cm/sec (52 ft/year) to 2 X 10-3 cm/sec (2069 ft/year) with a geometric mean of 7 X 10-4 cm/sec (724 ft/year). No slug tests were performed on wells completed in Woman Creek valley fill. Using the same gradient and effective porosity as for the Rocky Flats Alluvium and a mean hydraulic conductivity of 724 ft/year, the average ground-water velocity in Woman Creek valley fill is 145 ft/year.

South Walnut Creek valley fill is less conductive than that along Woman Creek based on lithologic descriptions and hydraulic conductivity tests (Table 5-1). The drawdown-recovery test performed on well 35-86 in 1986 indicated a hydraulic conductivity of 9 X 10-5 cm/sec (93 ft/year), and the 1987 slug test result for the same well was 1 X 10-4 cm/sec (103 ft/year). Using a mean conductivity of 9.5 X 10-5 cm/sec (98 ft/year), an effective porosity of 0.1 and an average gradient of 0.02 ft/ft, the average flow velocity in South Walnut Creek valley fill is 20 ft/year.

The average ground-water flow velocities calculated for various surficial materials assumes the materials are fully saturated year-round. However, as discussed above portions of the Rocky Flats Alluvium, colluvium, and valley fill alluviums are not saturated during the entire year. Thus, contaminants in the shallow flow system cannot actually move at the velocities calculated for each of the surficial materials.

5.3.2 Bedrock Ground-water Flow System

Recharge Conditions

The majority of ground-water flow in the Arapahoe Formation occurs in the lenticular sandstones contained within the claystones. Ground-water recharge to sandstones occurs as infiltration from alluvial ground water where sandstones subcrop beneath the alluvium and by leakage from claystones overlying the sandstones.

There is a strong downward gradient between ground water in surficial materials and bedrock. This has been demonstrated previously at the Plant by Hurr (1976), Rockwell International (1986a), and Rockwell International (1987a), and is again demonstrated by data from new wells at the 903 Pad, Mound, and East Trenches Areas. Table 5-2 presents vertical hydraulic gradients calculated for alluvial/bedrock well pairs 34-86 and 35-86, 40-86 and 41-86, 15-87 and 16-87BR, 19-87 and 20-87BR, 24-87 and 25-87BR, 32-87 and 31-87BR, 33-87 and 34-87BR, and 35-87 and 36-87BR. Vertical gradients range from 0.31 between wells 35-86 and 34-86 to 1.05 between wells 41-86 and 40-86.

TABLE 5-2

VERTICAL GRADIENTS

WELL	ELEVATION OF POTENTIOMETRIC SURFACE & DATE	WATER LEVEL DIFFERENCE (ft)	ELEVATION OF SCREENED INTERVAL	ELEVATION OF SATURATED INTERVAL MIDPOINT	SEPARATOR THICKNESS (ft)	DOWNWARD VERTICAL GRADIENT
40-86	5,836.46 (11/26/86)	72.21	5,853.25-5,829.73	5,833.10	68.91	1.05
41-86	5,908.67 (11/26/87)		5,936.13-5,895.33	5,902.00		
40-86	5,838.91 (12/1/87)	64.68	5,853.25-5,829.73	5,834.32	65.14	0.99
41-86	5,903.59 (12/1/87)		5,936.13-5,895.33	5,899.46		
15-87	5,952.44 (12/1/87)	66.93	5,965.09-5,948.83	5,950.64	94.07	0.71
16-87BR	5,885.51 (12/1/87)		5,869.06-5,844.06	5,856.56		
19-87	5,958.07 (12/1/87)	96.88	5,964.48-5,956.33	5,957.20	100.79	0.96
20-87BR	5,861.19 (12/1/87)		5,860.84-5,851.99	5,856.42		
24-87	5,944.74 (12/1/87)	7.73	5,954.29-5,944.19	5,944.47	18.23	0.42
25-87BR	5,937.01 (12/1/87)		5,941.41-5,915.46	5,926.24		
32-87	5,906.68 (12/1/87)	53.87	5,910.09-5,899.54	5,903.11	78.11	0.69
31-87BR	5,852.81 (12/1/87)		5,834.36-5,815.61	5,825.00		

TABLE 5-2
(CONTINUED)
VERTICAL GRADIENTS

WELL	ELEVATION OF POTENTIOMETRIC SURFACE & DATE	WATER LEVEL DIFFERENCE (ft)	ELEVATION OF SCREENED INTERVAL	ELEVATION OF SATURATED INTERVAL MIDPOINT	SEPARATOR THICKNESS (ft)	DOWNWARD VERTICAL GRADIENT
33-87	5,926.25 (12/1/87)	37.78	5,930.27-5,925.27	5,925.76	81.31	0.47
34-87BR	5,888.47 (12/1/87)		5,847.92-5,840.97	5,844.45		
35-87	5,940.27 (12/1/87)	23.05	5,945.86-5,940.01	5,940.14	38.68	0.60
36-87BR	5,917.22 (12/1/87)		5,929.24-5,885.69	5,901.46		
35-86	5,903.14 (12/1/87)	12.62	5,904.34-5,897.60	5,900.37	40.17	0.31
34-86	5,890.52 (12/1/87)		5,866.20-5,854.19	5,860.20		

Ground-water Flow Directions

Flow within individual sandstones is from west to east based on the correlations between wells 9-87BR and 16-87BR (Plate 5-3) and between wells 25-87BR and 36-87BR (Plate 5-4). Wells 9-87BR and 16-87BR are completed in the same sandstone, with 16-87BR downdip and downgradient of well 9-87BR. (Plate 5-3). Ground water in well 9-87BR is unconfined, but confined conditions exist in well 16-87BR. The horizontal gradient between these wells is 0.09 ft/ft. Wells 25-87BR and 36-87BR are also completed in the same sandstone, with well 36-87BR downgradient of 25-87BR. The horizontal gradient between these wells is 0.03 ft/ft, which is in good agreement with published regional values for the Arapahoe Aquifer (Robson and others, 1981a)

Ground-water Flow Velocities

Hydraulic conductivity values for Arapahoe sandstones were estimated from drawdown-recovery tests performed in 1986, slug tests performed in 1987, and packer tests performed in 1986 and 1987. Table 5-3 summarizes results of these tests. Data, analyses, and results of each test are presented in Appendix E.

Hydraulic conductivity values from drawdown-recovery and slug tests are in good agreement; however, packer test results are approximately two orders of magnitude less than results from the other two test methods. Hydraulic conductivity values from drawdown-recovery tests ranged from 2 X 10-5 cm/sec (21 ft/year) to 8 X 10-5 (83 ft/year) with a geometric mean of 4 X 10-5 (41 ft/year), and slug test results ranged from 2 X 10-6 cm/sec (2 ft/year) to 3 X 10-3 cm/sec (3,103 ft/year)

TABLE 5-3

HYDRAULIC CONDUCTIVITY TEST RESULTS FOR ARAPAHOE SANDSTONES AT THE 903 PAD, MOUND, AND EAST TRENCHES AREAS

WELL NO.	SLUG TEST RESULT (cm/sec)	DRAWDOWN RECOVERY TEST RESULT (cm/sec)	GEOMETRIC MEAN OF PACKER TEST RESULT FOR SCREENED INTERVAL (cm/sec)
3-86	----	8×10^{-5}	----
34-86	1×10^{-3}	2×10^{-5}	----
62-86	6×10^{-6}	----	----
9-87BR	3×10^{-3}	----	----
14-87BR	2×10^{-5}	----	----
16-87BR	2×10^{-6}	----	3×10^{-7}
20-87BR	----	----	1×10^{-7}
22-87BR	----	----	2×10^{-6}
23-87BR	2×10^{-4}	----	----
25-87BR	2×10^{-3}	----	----
31-87BR	2×10^{-6}	----	----
34-87BR	1×10^{-5}	----	----
36-87BR	1×10^{-3}	----	----
Geometric Mean:	8×10^{-5} (83 ft/year)	4×10^{-5} (41 ft/year)	4×10^{-7} (0.4 ft/year)

with a geometric mean of 8 X 10-5 cm/sec (83 ft/year). Packer test results ranged from 1 X 10-7 cm/sec (0.1 ft/year) to 2 X 10-6 cm/sec (2 ft/year) with a geometric mean of 4 X 10-7 cm/sec (0.4 ft/year).

The maximum horizontal ground-water flow velocity in sandstone would be 25 ft/year using a hydraulic conductivity of 83 ft/year, an average horizontal gradient of 0.03 ft/ft, and an assumed effective porosity of 0.1. The minimum flow velocity would be 0.1 ft/year using a hydraulic conductivity of 0.4 ft/year and the same gradient and effective porosity. Using a maximum horizontal gradient of 0.09 ft/ft, a maximum hydraulic conductivity of 83 ft/year, and an effective porosity of 0.1, the horizontal ground-water velocity in a sandstone could be up to 75 ft/year. Ground water moving through the sandstone units can only move as far as the sandstone extends, however. Thus, ground-water flow through any given unit is limited by the continuity of the sandstones. Further investigations are needed to determine the extent of subcropping sandstones encountered to date at the 903 Pad, Mound, and East Trenches Areas.

5.4 GROUND-WATER CHEMISTRY

This section describes the extent and nature of ground-water contamination associated with the 903 Pad, Mound, and East Trenches Areas. With the exception of Hazardous Substances List (HSL) organics whose presence in ground water necessarily implies contamination, the concentrations of chemical constituents are compared to background concentrations to assess whether they signify ground-water contamination. However, because chemical constituents elevated above background, particularly major ion concentrations, may also be attributed to natural variation in alluvial and bedrock geochemistry, the inorganic chemistry of the ground water at various monitor wells is further examined to define patterns that suggest contaminant sources and migration pathways.

With the exception of the monitor wells installed for this investigation, four quarters of analytical results (when available) are examined in this evaluation. The four quarters include the last quarter of 1986 (initial Phase 2 site characterization results) and the first three quarters of 1987. Only initial sampling results exist for the new RI wells, and data are not yet available for many of these wells. Table 5-4 lists the analyses performed on ground-water samples.

5.4.1 Background Ground-water Quality

Data from alluvial and bedrock monitor wells located west of the plant were evaluated to estimate background ground-water quality for radionuclides, metals, and inorganics. Many of these wells are located downgradient or within the West Spray Field (SWMU 168) or downgradient of the Ash Pits (SWMU 133) which may bias interpretation of background ground-water quality. Therefore, concentration ranges for each analyte are examined for each background well to qualitatively assess whether the SWMUs are impacting ground-water quality with respect to the analyte. If an impact is apparent, then the data are excluded in determining the background range for that analyte. Also an "outlier", a concentration of an analyte for a given well that is inconsistent in magnitude with the other concentrations reported over time for the well, is excluded in determining the background range for the analyte. An outlier may be due to laboratory error in analysis, a data reporting error, or field contamination of the sample. It may also reflect wide natural variations in concentration for the analyte. However, outliers at the high end of the range are not included in establishing background conditions to be conservative in the analysis of

TABLE 5-4

GROUND-WATER AND SURFACE WATER SAMPLING PARAMETERS

FIELD PARAMETERS
pH
Specific Conductance
Temperature
Dissolved Oxygen*

INDICATORS
Total Dissolved Solids
Total Suspended Solids*

METALS**
Hazardous Substances List - Metals
Beryllium
Calcium
Chromium (hexavalent)
Iron
Lithium
Magnesium
Manganese
Potassium
Sodium
Strontium
Zinc

ANIONS
Carbonate
Bicarbonate
Chloride
Sulfate
Nitrate

ORGANICS
Hazardous Substances List - Volatiles***
Oil and Grease

RADIONUCLIDES
Gross Alpha
Gross Beta
Uranium 233, 234, 235, and 238
Americium 241
Plutonium 239
Strontium 90
Cesium 137
Tritium

TABLE 5-4

GROUND-WATER AND SURFACE WATER SAMPLING PARAMETERS (CONTINUED)

* For surface water samples only
** Dissolved metals for ground-water samples, total and dissolved metals for surface water samples
*** Ground-water samples from the first, second, and third quarters of 1987, and all surface water samples were analyzed for only 9 of the HSL volatiles. These volatiles are the chlorinated solvents historically detected in the ground water and are as follows: PCE, TCE, 1,1-DCE, 1,2-DCA, t-1,2-DCE, 1,1,1-TCA, 1,1,2-TCA, CCl_4 and $CHCl_3$.

contamination at the 903 Pad, Mound, and East Trenches Areas. Many of the outliers at the high end of the range are from the initial Phase 2 site characterization data.

5.4.1.1 Background Alluvial Ground-water Quality

Data from monitor wells 10-81, 49-86, 50-86, 51-86, 55-86, and 56-86 were used to assess background conditions for alluvial ground-water quality. Well 55-86 is the only well upgradient of all SWMUs. All other wells are within or downgradient of the West Spray Field. Well 56-86 is also downgradient of the Ash Pits (SWMU 133). Analytical data are presented in Appendix F, and a summary of background ranges for radionuclides, metals, and inorganics is presented in Table 5-5.

Radionuclides

Although a rigorous statistical analysis of the data has not been performed, plutonium, americium, and uranium-235 concentrations in background alluvial ground water appear to approach 0 pCi/l. Since concentrations are less than the two standard deviation error terms, it is assumed these concentrations are within the random variations around a mean concentration that is generally below analytical detection limits. These concentrations are considered "non-detected".

For reasons unknown, uranium 234 and uranium 238 were at higher concentrations during the initial CEARP Phase 2 site characterization relative to that observed for the first three quarters of 1987. These uranium isotopes ranged from 1 to 12 pCi/l (error term generally 10 - 15% of the mean value) for all the wells in 1986. These uranium isotopes were "non-detectable" during the third quarter of 1987,

TABLE 5-5
BACKGROUND ALLUVIAL
GROUND-WATER QUALITY

METALS

Element	Concentration Range (mg/l)
Antimony	.060U
Arsenic	.001U
Barium	.047-.190
Beryllium	.005U
Cadmium	.005U
Cesium	.1U
Chromium	.002U-.027
Cobalt	.05U
Copper	.02U-.026
Lead	.005U-.05
Manganese	.01U-.547
Mercury	.0002U
Molybdenum	.1U
Nickel	.04U-.08
Selenium	.005U
Silver	.01U
Strontium	0.02U-.20
Thallium	.002U
Vanadium	.005U-.047
Zinc	.005U-0.09

RADIONUCLIDES

Plutonium, Americium, Uranium-235	Below MDA
Uranium-234	Below MDA-3.5(.9)
Uranium-238	Below MDA-4(.9)

MAJOR IONS

Ion	Concentration Range (mg/l)
Calcium	12-36
Magnesium	2-8
Potassium	.010-5
Sodium	8-21
Bicarbonate	ND-130
Carbonate	ND-120
Chloride	.7-19
Nitrate	ND-1.2
Sulfate	3.5-31
Total Dissolved Solids	115-269

with only a total of 8 detectable concentrations for both uranium 234 and uranium 238 over the first and second quarter for all the wells. The detectable concentrations ranged from .61 to 4 pCi/l. At well 55-86, first quarter uranium 234 and uranium 238 concentrations were 1.5(0.9) and 2.2(0.8) pCi/l, respectively. These isotopes were not detected in subsequent quarters at this well. Because of the detection of uranium 234 and uranium 238 in 55-86 at levels of the same magnitude as seen for other wells west of the plant, it is concluded that the occurrence of low levels of "detectable" uranium 234 and uranium 238 are within the random variation of background values. Excluding all 1986 initial site characterization data as outliers, uranium 234 as high as 3.5(.9) pCi/l (second quarter 1987, well 49-86), and uranium 238 as high as 4(0.9) pCi/l (second quarter 1987, well 49-86) will be considered background levels.

Metals

There were several metals that were either not detected or detected at below Contract Laboratory Program (CLP) required detection limits in samples from wells west of the Plant. These metals are antimony (0.06U), arsenic (0.001U), cadmium (0.005U), molybdenum (0.1U), selenium (0.005U), silver (0.01U), and thallium (0.002U). The values in parentheses represent the CLP contract required detection limits milligrams per liter (mg/l) which will be considered the upper background concentration limit for these elements. A "U" after the value indicates the analyte concentration is below the CLP required detection limit.

Beryllium (0.005U), cobalt (0.05U), cesium (0.1U), and mercury (0.0002U) were each present above detection limits only once in all the samples collected from the wells west of the Plant. The concentrations detected were 0.011mg/l (1986 initial Phase 2), 0.1mg/l (1986 initial Phase 2), 0.360 mg/l (1986 initial Phase 2), and 0.003

mg/l (second quarter 1987) for beryllium, cobalt, cesium, and mercury, respectively. These are considered outliers and the upper background concentration limit will be set at the contract required detection limits.

Barium occurred in a concentration range of 0.047 to 0.14mg/l in well 55-86. Concentration ranges for this element in other wells west of the Plant always overlapped this range and the peak concentration was only 0.19mg/l. Therefore, the barium background concentration range is established as 0.047 - 0.19 mg/l.

Strontium occurred in a concentration range of 0.11 to 0.15 mg/l in well 55-86. Strontium ranged from non detected (0.02U) to 0.20 mg/l in the other wells west of the Plant for the four quarters of data examined. Concentrations were typically what was observed for well 55-86. Therefore the background range for strontium is established as 0.02U - 0.20 mg/l.

Manganese showed the highest variation in concentration ranging from not detected (0.01U) to 0.55 mg/l. The highest concentration occurred for well 55-86 (1986 site characterization), and generally the higher concentrations reported were in the 1986 data. However, the entire range will be used as the background range since manganese has been observed to fluctuate widely in time in samples from wells across the entire Plant.

Lead was generally not detected (0.005U) but infrequently and randomly occurred above detection limits in the wells in the range 0.01 - 0.05 mg/l. Therefore, the background range is established as 0.005U - 0.05 mg/l.

Only once was copper detected above the contract required detection limit (0.02U). The concentration was only 0.026 mg/l, therefore the background range is established as 0.02U - 0.026 mg/l.

Like lead, chromium was generally not detected (0.002U) but infrequently and randomly occurred above detection limits in the wells in the range 0.009 - 0.136 mg/l. The second to highest concentration was 0.027 mg/l rendering the 0.136 concentration an outlier. Therefore the background concentration range for chromium is established as 0.002U - 0.027 mg/l.

Nickel was generally not detected (0.04U) but there were three above detection limit occurrences of 0.03, 0.07, and 0.08 mg/l, all from different wells. Therefore the background concentration range for nickel is established as 0.04U - 0.08 mg/l.

Vanadium also was generally not detected (0.005U) but there were five random above detection limit occurrences of 0.027, 0.024, 0.032, 0.047, and 0.8 mg/l. Eliminating 0.8 mg/l as an outlier establishes the background range at 0.005U - 0.047 mg/l.

Zinc was frequently detected above detection limits (0.005U) occurring throughout the range 0.02 - 0.09 mg/l. The highest concentration was observed for well 55-86. Therefore the background concentration range for zinc is established as 0.005U - 0.09 mg/l.

Calcium ranged from 22 - 34 mg/l for 55-86, and data from other wells showed ranges that all overlapped this range. Therefore the entire range of 12 - 36 mg/l is used to establish the background range for calcium.

Like calcium, magnesium ranged from 4 - 6 mg/l in 55-86, and data from other wells showed ranges that overlap this range. Therefore, the entire range of 2 - 8 mg/l is used to establish the background range for magnesium.

Potassium was detected once at 5 mg/l in well 55-86, the highest observed concentration, but it generally is lower and frequently non-detectable. Therefore the range for background potassium concentrations is 0.01U - 5 mg/l.

Sodium ranged from 8 - 13 mg/l in well 55-86, and with the exception of wells 56-86 (range 18-22) and 49-86 (range 27-29), the sodium ranges of other wells overlapped this range. Therefore excluding wells 55-86 and 49-86 from establishing background concentrations for sodium because of potential impacts from SWMUs, the background sodium concentration range is 8 - 21 mg/l.

Bicarbonate and carbonate ranged from non detectable to 130 mg/l and 120 mg/l for bicarbonate and carbonate, respectively. Because small changes in pH can cause large changes in the relative concentration of bicarbonate and carbonate, and there is no apparent impact of SWMUs on the concentrations of these ions, non-detectable to the respective maximum concentrations has been established as the background ranges for these ions.

Chloride occurred in a range from 0.7 - 8 mg/l in well 55-86. Only well 49-86 (range 24 - 31) had a chloride concentration range that did not overlap this range. Therefore, using all the data except data for 49-86, the background chloride concentration is established as 0.7 - 19 mg/l.

Nitrate concentrations were in a range of non-detected to 1.2mg/l in well 55-86. The range of nitrate values for well 55-86 is established as the background range, since nitrate concentrations were often significantly elevated above this range in many wells within and downgradient of the west spray field.

Sulfate ranged from 22 - 27 mg/l in 55-86, and with the exception of well 56-86 (range 15-19) the sulfate ranges in other wells overlap this range. However, because the concentrations of sulfate were somewhat lower in 56-86, the entire data set is used to establish the background sulfate concentration range of 3.5 - 31 mg/l.

5.4.1.2 Background Bedrock Ground-water Quality

Unlike alluvial ground water, the bedrock ground-water quality should not be impacted by the SWMUs present west of the plant area because of the claystone separation of bedrock sandstones from alluvium. It is therefore a simpler task to establish background conditions by only having to recognize outliers. However, the bedrock wells west of the Plant, wells 46-86, 48-86, 52-86, and 54-86, are completed in sandstones of the Laramie Formation while bedrock wells in potentially contaminated areas east of the plant are completed in sandstones of the Arapahoe Formation. Geochemical differences that may exist in these sandstones render data interpretation more difficult. Table 5-6 presents background bedrock ground-water quality.

Radionuclides

As with the background alluvial ground-water quality, plutonium, americium, and uranium 235 concentrations not discernible from 0 pCi/l are established as background for bedrock ground water. There was one occurrence of plutonium at 1.8(1.3) pCi/l, but this has been excluded as an outlier.

TABLE 5-6

BACKGROUND BEDROCK GROUND-WATER QUALITY

METALS

Element	Concentration Range (mg/l)
Antimony	.06U
Arsenic	.001U
Barium	.06-.15
Beryllium	.005U
Cadmium	.005U
Cesium	.1U
Chromium	.002U-.015
Cobalt	.05U
Copper	.02U-.05
Lead	.005U-.030
Manganese	.01-.22
Mercury	.0002U-.0003
Molybdenum	.1U
Nickel	.04U
Selenium	.002U
Silver	.01U
Strontium	.14-.87
Thallium	.002U
Vanadium	.005U-.03
Zinc	.005U-.05

RADIONUCLIDES

Plutonium, Americium, Uranium-235	Below MDA
Uranium-234	Below MDA-6.6(1.8)
Uranium-238	Below MDA-7.5(1.7)

MAJOR IONS

Ion	Concentration Range (mg/l)
Calcium	9-110
Magnesium	1-22
Potassium	1-8
Sodium	22-47
Bicarbonate	9-318
Carbonate	ND-257
Chloride	1-24
Nitrate	ND
Sulfate	ND-66

Uranium 234 was often non discernible from 0 pCi/l, but it also occurred at 2.4(1.3), 1.8(.8), 4(1.4), 3.9(1.6), 19(6), and 6.6(1.8) pCi/l throughout the wells over time. Excluding the 19(6) value as an outlier, concentrations of uranium 234 below 6.6(1.8) are considered to be within background limits.

Uranium 238 also was often non discernible from 0 pCi/l but did occur at 4.4(1.5), 140(30), 1.2(.6), 2.3(1.0), 7.5(1.7) pCi/l throughout the wells over time. Excluding the 140(30) value as an outlier, concentrations of uranium 238 below 7.5(1.7) are considered to be within background limits.

Metals

Antimony, arsenic, beryllium, cadmium, cesium, cobalt, molybdenum, nickel, selenium, silver, and thallium were not detected above the CLP contract required detection limits. Therefore, the detection limits represent the highest concentrations that could be considered background level for these elements.

The ranges observed for manganese (0.01U-0.22mg/l), barium (.06-.15 mg/l), and strontium (.14-.87 mg/l) are established as background ranges for these elements as their concentrations are uniformly distributed throughout the ranges.

Mercury, lead, chromium, zinc, and vanadium were generally non-detectable but infrequently occurred at low levels. Thus the upper limit of the background concentration range is established at their maximum concentrations observed (0.0003mg/l mercury, 0.03 mg/l lead, 0.015mg/l chromium, 0.03mg/l vanadium, and 0.05 mg/l zinc).

Copper frequently occurred at detectable levels in the range 0.01-0.05 mg/l; however, there was one occurrence of copper at 0.132mg/l. Treating this high value as an outlier, the background range for copper is established as 0.02U-0.05mg/l.

All major ion concentration ranges observed have simply been used as the background ranges, because the sample concentrations occurred uniformly throughout the ranges. The only exception is nitrate where there was one occurrence of nitrate at 18.4 mg/l which has been treated as an outlier, i.e. nitrate was otherwise not detected in bedrock ground water.

5.4.2 903 Pad, Mound, and East Trenches Ground-water Chemistry

Volatile organic (VOC) contamination and possibly strontium and major ion contamination of ground water exists from multiple sources at the 903 Pad, Mound and East Trenches Areas. There may also be some trace metal contamination of ground water at a few locations. The elevated major ion and strontium concentrations observed in some instances appear to represent contamination but in others may only reflect natural geochemical variations in ground water. Together with the hydrogeologic data, the major ion data have been used to classify ground-water inorganic chemistry in order to assess potential sources of contamination, alluvial ground-water flow patterns, interconnection of bedrock sandstones, and the recharge of bedrock sandstones by alluvial ground water.

Radionuclide contamination of ground water is not apparent from the data. The only indication of elevated radionuclides is 1986 data (wells 2-71, and 42-86), and first quarter 1987 data (well 40-86). Otherwise all radionuclide concentrations are within background levels as defined in the previous section. At well 2-71 1986 data indicate plutonium, americium, uranium 234, and uranium 238 concentrations to be 32(3), 4.4(2.3), 30(5), and 33(5) pCi/l, respectively. These concentrations are significantly elevated relative to background. However, subsequent sampling and analysis from the first three quarters of 1987 indicate background levels for these radionuclides. The same scenario applies to well 42-86 where 1986 data indicate uranium 234 and uranium 238 to be 9.8(1.1) and 11(1) pCi/l, respectively. At 40-86, a bedrock well, only first quarter 1987 data exist for radionuclides. This one time sampling and analysis shows americium and uranium 234 to be 1(.7) and 10(2) pCi/l. The reason for these high concentrations of radionuclides is unknown, but regardless, all the other data tend to not support ground-water radionuclide contamination. Further ground-water sampling and analysis is required to firmly conclude the absence of radionuclide contamination in the ground water.

5.4.2.1 903 Pad Alluvial Ground-water Chemistry

Organic contamination of alluvial ground water occurs east of the 903 drum storage site at well 15-87 and south of the site at wells 1-71 and 2-71. Organic contamination was not observed further south at well 64-86 located in the Woman Creek valley fill alluvium, and well 63-86 located between 2-71 and 64-86 has always been dry.

In general, the types and concentrations of VOCs present in the ground water at 1-71 and 2-71 vary widely over time with no apparent seasonal pattern. It does appear however that the type of organic contamination present in ground water at 15-87, 1-71, and 2-71 is different at each location. For example, only CCl_4, TCE, and PCE were detected at 15-87 while generally all the VOCs analyzed for were detected at 1-71 and 2-71. At 15-87, PCE was 900 microgram per liter (ug/l), a concentration at 1-71 and 2-71. At 15-87, PCE was 900 micrograms per liter (ug/l), a concentration significantly exceeding those observed at 1-71 and 2-71. At 1-71 and 15-87, CCl4 was 1405 and 4080 ug/l, respectively, but has never been greater than 40 ug/l at 2-71. TCE occurred at a concentration of 9440 ug/l at 2-71 but was present at concentrations only ranging from 510 to 691 at wells 1-71 and 15-87. This data, together with the inorganic data tend to support the conclusion that contamination arises from three separate sources.

Ground water at wells 15-87 and 1-71 appear to have a similar inorganic composition. Calcium is notably elevated, somewhat more in 15-87 (127 mg/l) than at 1-71 (range 74-86 mg/l). Chloride is elevated, again somewhat more in 15-87 (57 mg/l) than at 1-71 (range 16-22 mg/l). Nitrate is also elevated in both 15-87 (9 mg/l) and 1-71 (range 4-20 mg/l). Barium is slightly elevated and similar in concentration in both wells occurring as high as 0.30 mg/l, and strontium is elevated and similar in concentration in both wells occurring in a range of 0.45-0.58 mg/l. Unlike the ground water at 15-87 and 1-71, ground water at well 2-71 has notably high sodium (range 135-221 mg/l), chloride (164-320 mg/l excluding a low value of 2.3), and sulfate (range 97-150 mg/l excluding a low value of 2.5 mg/l). At wells 15-87 and 1-71, sodium ranged from 10-21 mg/l and sulfate ranged from 16-22 mg/l. Barium and strontium were similar in concentration to that observed for 15-87 and 1-71. This data supports the contention that the source of contamination at 2-71 is different from those at 15-87 and 1-71.

Farther to the south, ground water at 64-86 and 65-86 also had high concentrations of sodium and sulfate similar to that observed at 2-71, but they had chloride concentrations only ranging from 38-70 mg/l. High sodium and sulfate values are characteristic of the alluvial ground water downgradient of the 881

Hillside Area. Upgradient of the 881 Hillside Area in well 68-86, these major ion concentrations are lower than those in wells 69-86 and 2-71. This suggests either the 881 Hillside Area or the 903 Pad Area, or both contribute the sodium and sulfate in wells 64-86 and 65-86. Regardless, it is clear that VOCs have not migrated to these wells from any source.

Aside from strontium, selenium was notably elevated in 2-71, and other metals were infrequently elevated in some of the wells. Selenium ranged from 0.018-0.036 mg/l at 2-71, and the only other detection of selenium was 0.015 mg/l at 1-71 (1986 investigation) and 0.009 mg/l at 65-86 (1986 sampling). Other 1986 elevated metals were cobalt at 0.17 and 0.11 mg/l for 1-71 and 2-71, respectively, molybdenum and silver at 0.19 and 0.02 mg/l, respectively for 2-71, and mercury and antimony at 0.002 mg/l and 0.078 mg/l, respectively for 65-86. These metals were not detected in subsequent sampling of the wells and therefore the significance of this data is unknown. The one time sampling of 64-86 in the first quarter of 1987 showed nickel to be 0.44 mg/l. Without further data, the significance of this nickel concentration is also unknown at this time. Therefore, selenium and strontium are the only metals apparently elevated in alluvial ground water in the vicinity of the 903 Pad. Possibly elevated strontium is pervasive while elevated selenium is confined to the ground water near well 2-71. Further investigation is necessary to determine whether strontium and selenium are actually elevated or result from natural geochemical variations. It should be noted that there is no known source of either metal from Rocky Flats operations. Further downgradient in the Woman Creek valley fill alluvium at 66-86, all metals and major ions in the ground water were at or slightly above their respective background levels. VOCs and nitrates were not detected. It is hypothesized that the ground water at this location predominantly represents seepage from Pond C-2.

In Section 4.0, it is postulated that there are three sources of soil contamination (and presumably ground water) at the 903 Pad Area. These sources are the 903 drum storage site [release of bis(2-ethylhexyl)phthalate), Trench T-2 (release of solvents, particularly TCE), and the reactive metal destruction site (release of solvents, particularly CCl_4 and PCE)]. The alluvial ground-water data support this conclusion but modify the understanding of the types of contaminants released.

The high TCE concentrations in well 2-71 do indicate a release from Trench T-2 as stated above. However, high CCl_4 concentrations occur at both wells 15-87 and 1-71, and ground-water contamination at well 15-87 cannot reflect a release from the reactive metal destruction because of its upgradient location. Because of the types of waste that may have leaked at the 903 drum storage site, it is postulated that CCl_4 and PCE (major contaminants in well 15-87) are released by the 903 drum storage site. These contaminants also migrate toward well 1-71, but the occurrence of several other volatiles in the soils and ground water at this location suggest a release is also occurring from the reactive metal destruction site. The lower PCE concentrations in well 1-71 relative to that in well 15-87 is not understood at this time. Also, this absence of solvents in soils from boreholes between the 903 drum storage site and well 1-71 is not understood. Well 12-87BR is completed in a subcropping sandstone; the high TCE value indicates the sandstone that in 2-71.

5.4.2.2 903 Pad Bedrock Ground-water Chemistry

VOCs were detected in bedrock ground water at 12-87BR, 11-87BR, and 14-

87BR. The highest contamination was observed at 12-87BR where TCE and PCE were 3570 and 43 ug/l, respectively. Well 12-87Br is completed in a subcropping sandstone, and the high TCE value indicates the sandstone is recharged by alluvial ground water similar to that in 2-71. At 11-87BR, $CHCl_3$, CCl_4, TCE, and PCE were 71, 560, 595, and 22 ug/l, respectively. However, a split of the sample contained only CCl_4 (430J) and TCE (590). Since well 11-87BR is completed in the same sandstone as 12-87BR, it too is apparently being recharged by ground water containing TCE. In addition, it appears to be receiving water from the 903 drum storage site based on the presence of CCl_4. At 14-87BR, two samples and one split sample provided $CHCl_3$, CCl_4, and TCE concentration ranges of 14-23, 160-404, and 47-109 ug/l, respectively; however, TCE was not detected in the split sample. Based on the presence of CCl_4 in well 14-87BR and the orientation of the sandstone unit, it appears that this sandstone subcrops in the 903 Pad Area.

The major ion chemistries of the bedrock ground water in wells at the 903 Pad Area do not show much similarity. To summarize, key major ion and strontium concentrations are as follows (units mg/l):

Well	Ca	Na	Cl	SO4	NO3	Sr
9-87BR	69	9	4	27	3.0	0.26
16-87BR	26	61	4	77	1.6	0.22
12-87BR	35	213	60	198	1.3	0.26
11-87BR	117	51	73	71	ND	0.96
14-87BR	408	96	30	41	1.6	2.7
(2-71	96	221	269	165	5.6	0.85)
(1-71	80	19	16	18	6.4	1.2)

Based on stratigraphic relationships and organic contamination as described above, bedrock sandstones at 12-87BR and 11-87BR are recharged by alluvial water similar to that at 2-71, and the sandstone at 14-87BR is recharged by alluvial water similar to that at 1-71. Inorganic data presented above do not support this hypothesis except between wells 12-87BR and 2-71. However, geochemical changes occur as water flows through the various bedrock sandstones which may explain these differences.

5.4.2.3 Mound Alluvial Ground-water Chemistry

The most notable characteristic of alluvial ground water at the Mound Area is the high VOC contamination in well 1-74, which is completed in the mound site. At well 43-86 to the west, CCl_4 and TCE were present at only 6 and 8 ug/l respectively during the first quarter of 1987, but were not detected during the second quarter (only 2 quarters of data exist for this well). Closer in to 1-74 at well 17-87, all the VOCs were detected except 1,1,2-TCA, 1,1-DCA, and 1,1-DCE. The maximum VOC concentration was PCE at 150 ug/l. However, at 1-74 all the VOCs except 1,1,2-TCA were detected, and the highest PCE and TCE concentrations in ground water anywhere on Plant site have been reported at this location. Data from 1985 through the third quarter of 1987 show the following changes in TCE and PCE concentration over time: TCE - 970, 2,200, 7,000, 2,400, 8,000, 18,000, 114, and 6B ug/l; PCE - 6,700, 16,000, 120,000, 25,000, 80,000, 528,000, 115, and 5U ug/l. Clearly the third quarter concentrations represent outliers. Furthermore, three different laboratories analyzed the samples and the laboratory which reported the highest value (528,000 ug/l) did not meet all the requirements of the QA/QC Plan. Thus, these data are considered qualitative, and it can only be concluded that significant TCE and PCE contamination exist in the alluvial ground water near well 1-74. The other VOCs were detected at low concentrations, the maximum concentration being 90 ug/l for 1,1-DCE.

The major ion chemistry of the alluvial ground water at the Mound Area is similar to that observed in 903 Pad Area at wells 15-87 and 1-71. Calcium and chloride are moderately elevated above background, while sodium, magnesium, and sulfate are at or slightly above their respective background levels. Nitrate was elevated at 43-86 and 1-74 occurring in a range of 5-10 mg/l (excluding the high value of 45 mg/l at 1-74). Nitrate was within background levels at 17-87 occurring at 0.79 mg/l.

As for the metals, strontium was elevated in all the wells ranging in concentration from 0.32-0.83mg/l, and copper, nickel, and zinc were significantly elevated at well 17-87. Their respective concentrations were 0.42, 0.68, and 2.5 mg/l. Zinc was also elevated at 1-74 during the second and third quarter of 1987 occurring at 0.34 and 0.20 mg/l, respectively.

The similarity in major ion chemistry for ground water at the 903 Pad and Mound Areas is consistent with the hydrogeologic data showing alluvial ground water flow moving from west to east across both of these areas. The source of the low level organic contamination at 43-86, if contamination actually exists at this location, may be the 903 drum storage site. The source of the low level organic contamination and metals contamination at 17-87 may be Trench T-1 (SWMU 108) which is located adjacent to this well.

5.4.2.4 Mound Bedrock Ground-water Quality

Wells 23-87BR,and 20-87BR are the bedrock wells in the Mound Area. VOCs were not detected in either well. Major ions and metals were within background levels at well 23-87BR, and data are unavailable for well 20-87BR at this time. It is tentatively concluded that bedrock ground-water contamination does not exist at the Mound Area.

5.4.2.5 East Trenches Alluvial Ground-water Chemistry

Alluvial ground water at the East Trenches Area contains moderately high concentrations of VOCs at the west end of the area. These concentrations decrease to the east, and there is no VOC contamination as far downgradient as wells 39-86 and 67-86. The same VOCs (CCl_4, TCE, and PCE) were detected in wells 3-74 and 42-86; however, VOC concentrations were higher at 42-86. CCl_4 ranged from 750-4835 ug/l in well 42-86 while at 3-74 it ranged from 280-2885 ug/l. PCE ranges at 42-86 and 3-74 were 152-320 and 345-1080 ug/l, respectively, and TCE ranged from 110-1400 and 218-400 ug/l in wells 42-86 and 3-74, respectively. The higher VOC concentrations in well 42-86 relative to those in 3-74 may be due to the location of 42-86 downgradient of the 903 Pad and Mound Areas as well as the northern East Trenches Area. Well 3-74 is downgradient of the northern East Trenches Area but is likely not impacted by the 903 Pad and Mound Areas because of the ground-water divide south of this well (Plate 5-7).

The same VOCs were detected in well 22-74 as in 42-86 but at generally an order of magnitude less concentration. This well is completed in both the alluvium and bedrock, and dilution of the VOCs by bedrock ground water is postulated. As background strontium concentrations are higher in bedrock ground water compared to alluvial ground water, this contention is supported by the observed higher strontium levels in 22-74 (range 0.81-1.1 mg/l) relative to the 42-86 range (0.31-0.57 mg/l).

As mentioned, these VOCs are present in alluvial ground water southeast of this area but at more dilute concentrations. At 7-74 VOCs were generally not detected but were occasionally present as high as 150 ug/l (CCl4). The highest VOC concentration at 32-87 was PCE at 95 ug/l. At 41-86, PCE was the only detected VOC occurring at 160 and 11 ug/l during the first and third quarters of 1987. VOCs are not present in ground water at wells 39-86 and 67-86.

Major ion chemistry for ground water at all the wells as far east as 32-87 is similar to that observed for the Mound Area and east of the 903 Pad Area. This includes elevated nitrate concentrations in the 1-10 mg/l range. This is consistent with the hydrogeologic data showing alluvial ground-water flow from west to east across the 903 Pad, Mound and East Trenches Areas. At 41-86, sulfate is significantly elevated relative to just west of this location which may be due to the spray irrigation of sewage treatment plant effluent at this location.

Except for the occurrence of mercury at 0.013 mg/l at 42-86 during the third quarter of 1987, all metals except strontium were within background levels. Strontium ranged from 0.31-0.68 mg/l for all samples from these wells collected over time (excluding well 22-74 which was previously discussed). The one high mercury concentration is treated as an outlier, and no environmental significance is tied to this data.

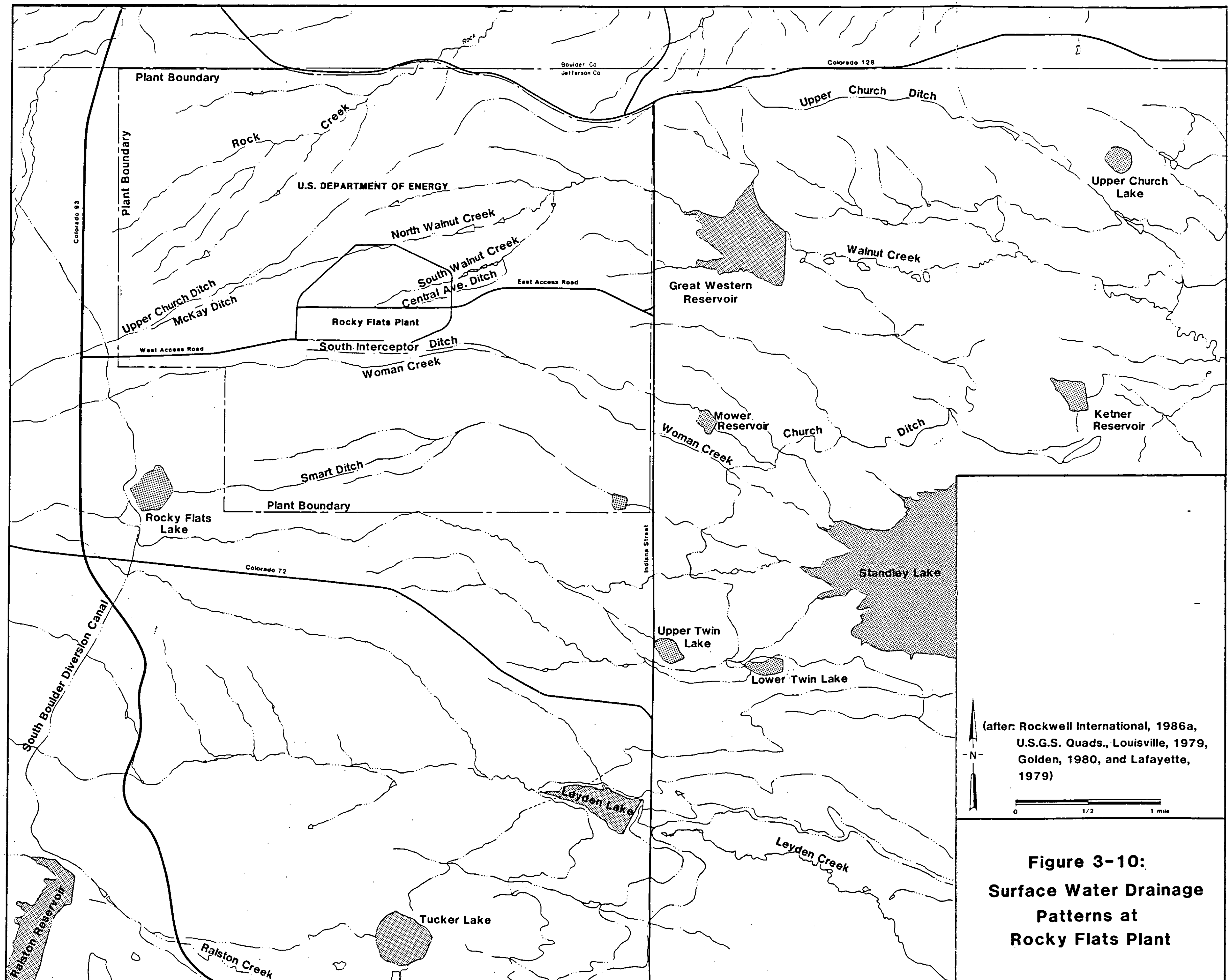
5.4.2.6 East Trenches Bedrock Ground-water Quality

VOC contamination of bedrock ground water in the East Trenches Area is uncertain at this time. VOC concentrations as high as 528 ug/l (PCE) were detected at 25-87BR; however, sample splits with another laboratory did not show VOCs in the water. There were estimated concentrations of 1,1,2-TCA (3J) and PCE (2J) at 31-87BR, and PCE occurred at 130 ug/l in 40-86BR during the second quarter of 1987. VOCs were otherwise undetected at any time at 40-86BR. Further sampling and analysis is necessary to ascertain whether bedrock ground water at the East Trenches Area is contaminated with VOCs.

As summarized below, the major ion chemistry is different for the ground water at each well (units mg/l):

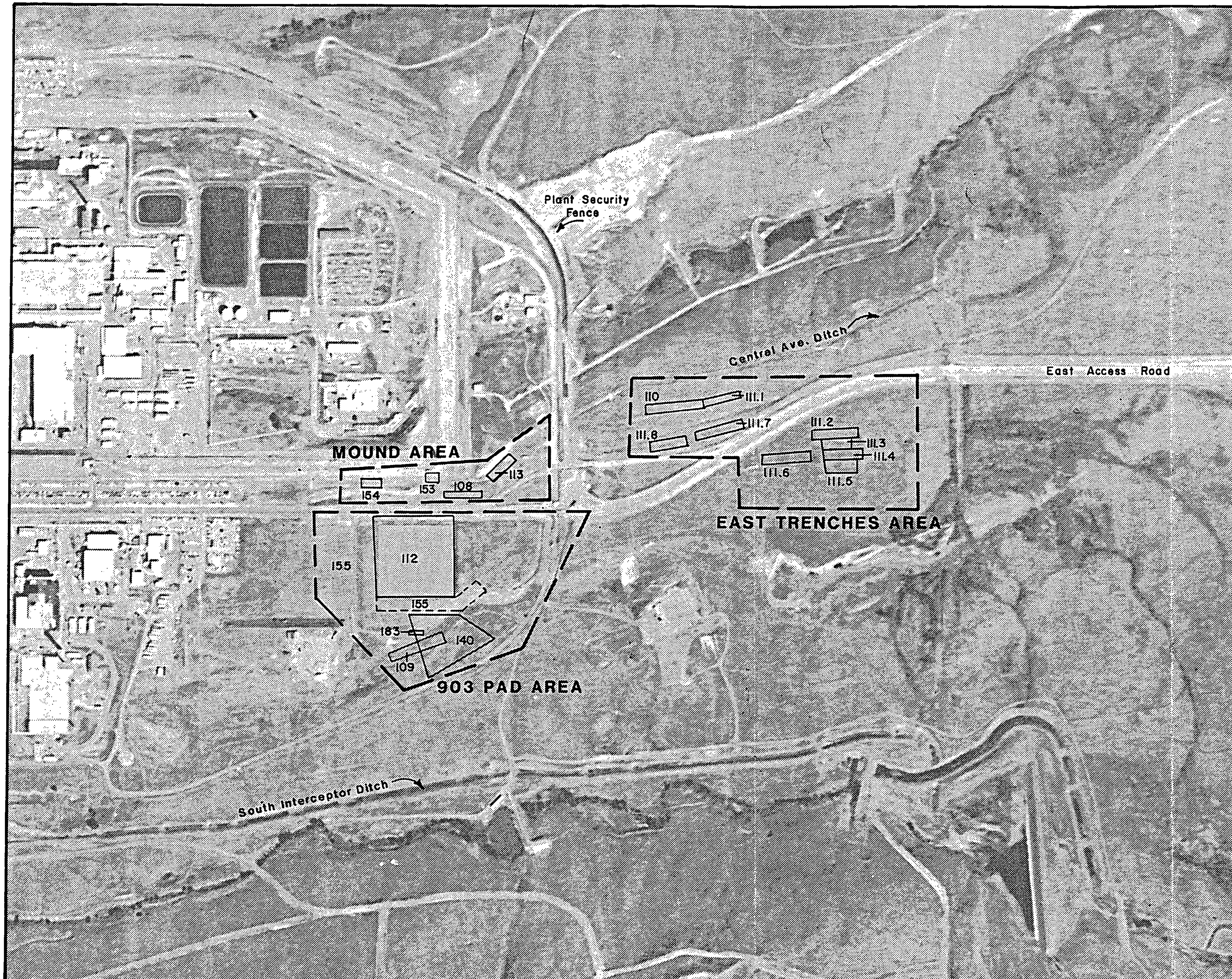
Well	Ca	Na	Cl	SO4	NO3
25-87BR	116	12	30	52	7.6
31-87BR	15	79	10	125	ND
40-86BR	153	135	15	390	1.4

The major ion chemistry at 25-87BR is similar to the alluvial ground water chemistry at 3-74 and 42-86, indicating the sandstone at 25-87BR is recharged by alluvial water. Geologic data support this hypothesis.



(after: Rockwell International, 1986a, U.S.G.S. Quads., Louisville, 1979, Golden, 1980, and Lafayette, 1979)

Figure 3-10: Surface Water Drainage Patterns at Rocky Flats Plant



N

EXPLANATION:

Location of Solid Waste Management Unit

Location of Areas of Interest Within Solid Waste Management Unit

101 Solid Waste Management Unit Reference Number (Rockwell International, 1986a)

NOTES:

1) Base map photo-enlarged from aerial photography of Rocky Flats Plant taken May 20, 1986.

2) The locations of the solid waste management units have been located as accurately as possible, based on information available prior to 1987 remedial investigation.

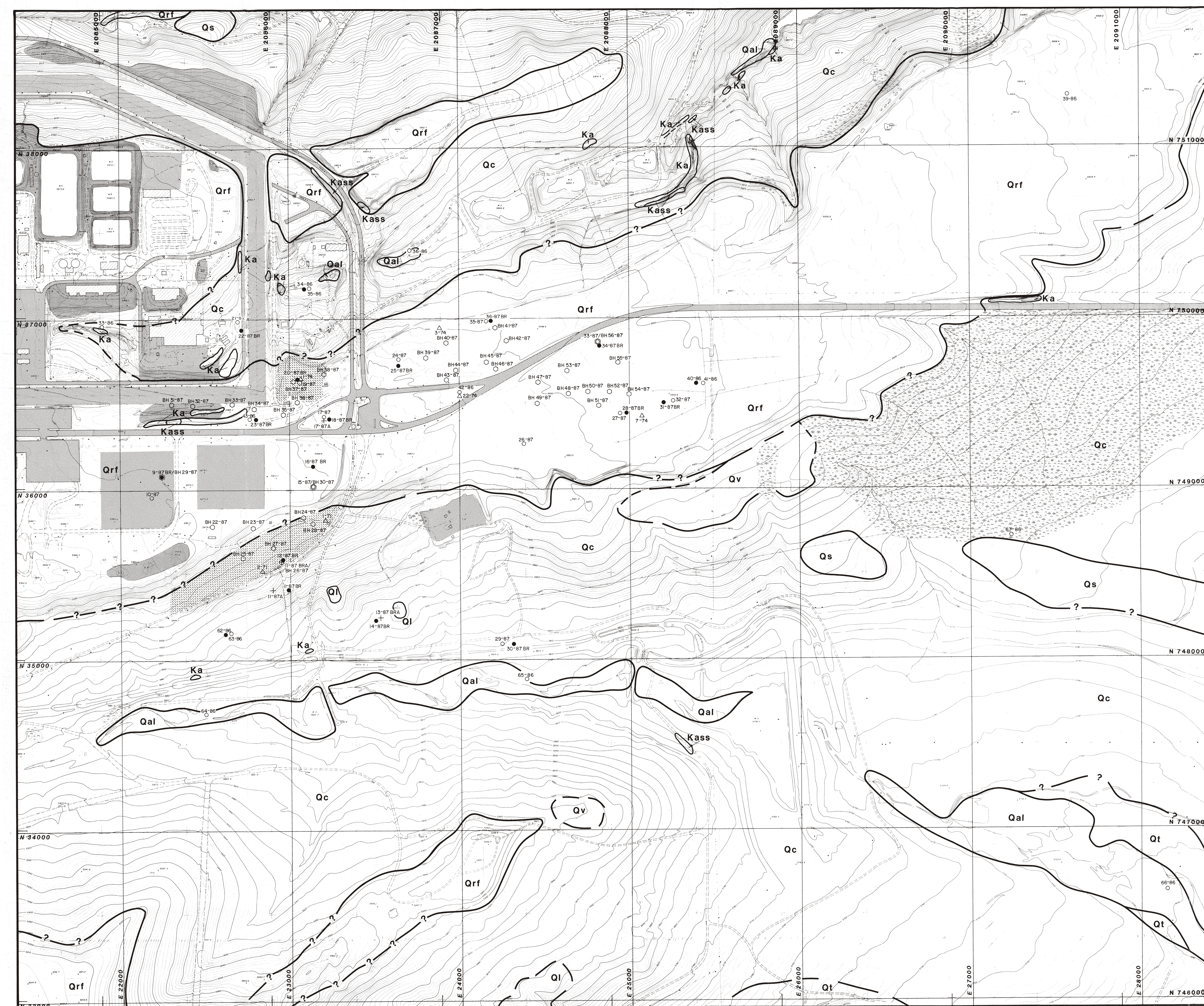
Modifications to these locations as a result of on-going studies and future site characterization will be made as required.

1" = 500'

0 500' 1000'

Figure 2-3: Remedial Investigation Area Locations and Associated Solid Waste Management Units

December 31, 1987



EXPLANATION

Contact

Dashed where approximately located, queried where inferred.

- Artificial Fill
- Phreatophytes
- Pavement or Gravel
- Disturbed Ground

Quaternary

- Qal Recent Valley Fill
- Ql Landslide
- Qc Colluvium
- Qt Terrace Alluvium
- Qs Slocum Alluvium
- Qv Verdos Alluvium
- Qrf Rocky Flats Alluvium

Cretaceous

- Kass Arapahoe Formation, Sandstone
- Ka Arapahoe Formation, Claystone

- ○ 4-87 Alluvial Monitor Well
- ● 5-87BR Bedrock Monitor Well
- △ 1-74 Pre-1986 Monitor Well
- + 7-87 BRA Abandoned Hole
- ⬡ BH 11-87 Borehole

N

Contour Interval = 2'
Scale: 1" = 200'
200' 0' 200' 400'

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Plate 5-1

903 Pad, Mound, East Trenches Areas

SURFICIAL GEOLOGY

#46-0002-A-000018

December 31, 1987

EXPLANATION
Contact
Dashed where approximately located, queried where inferred.
5900
Top of Bedrock Elevation (feet above M.S.L.)
Contour Interval = 10'
4-87 Alluvial Monitor Well
5-87BR Bedrock Monitor Well
1-74 Pre-1986 Monitor Well
7-87 BRA Abandoned Hole
BH 11-87 Borehole
Extent of Rocky Flats Alluvium
Qrf
Contour Interval = 2'
Scale: 1" = 200'
200' 0' 200' 400'
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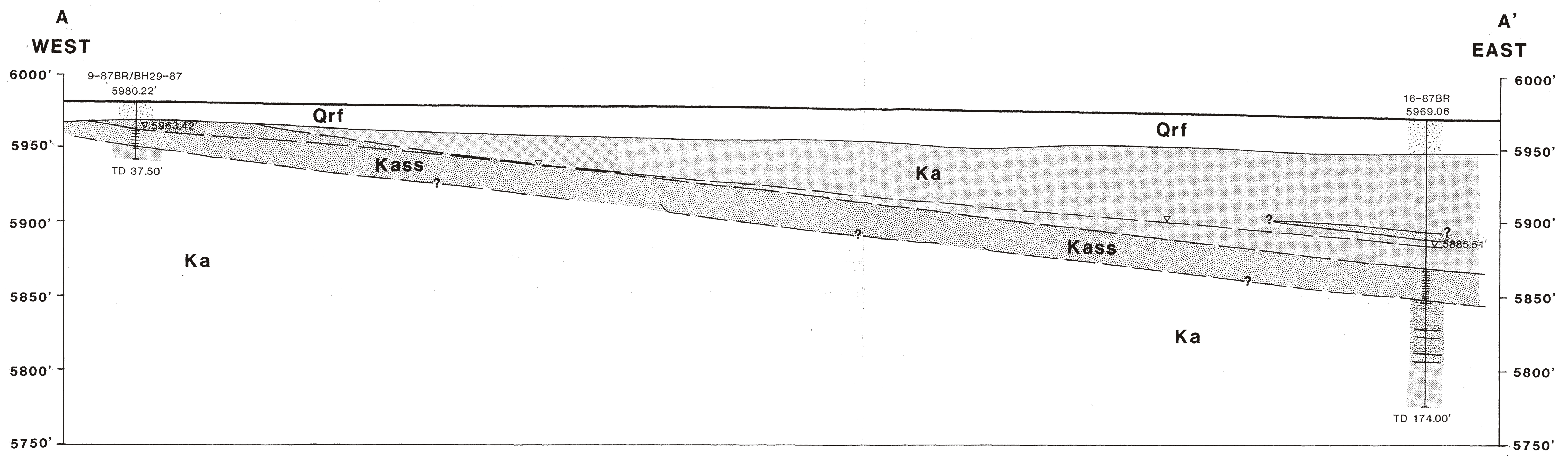
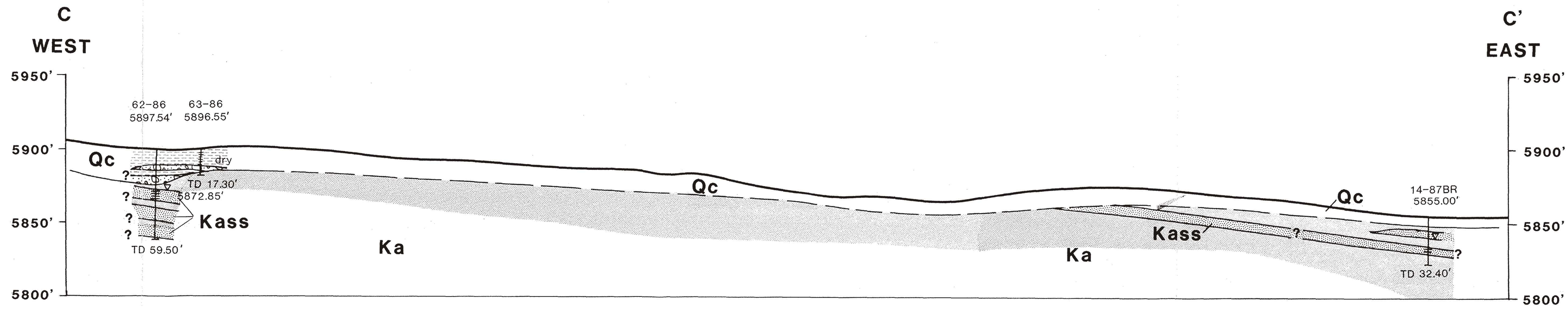
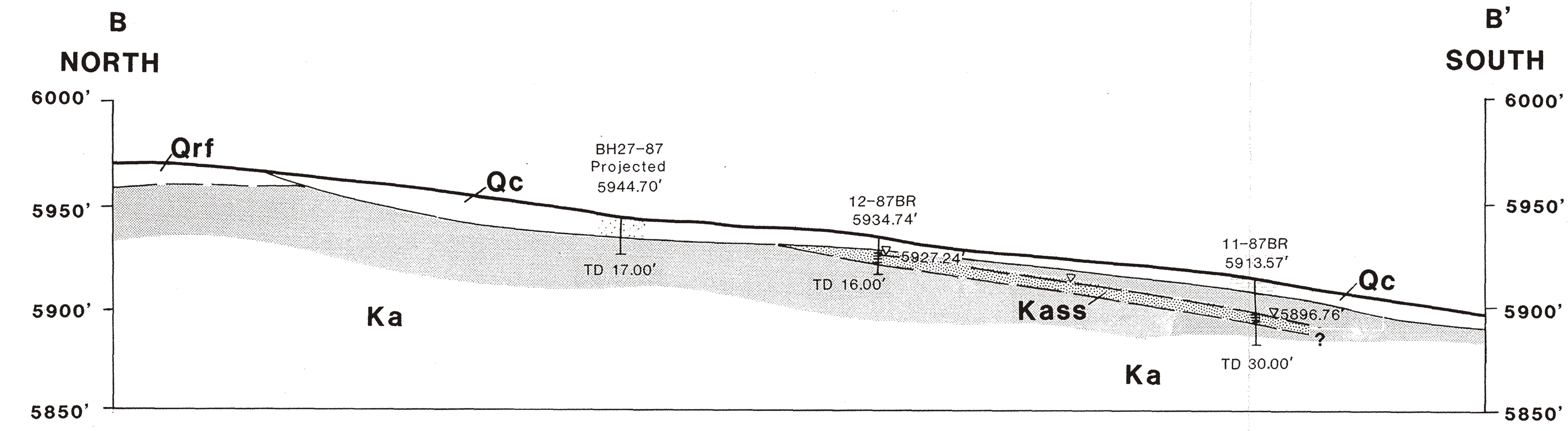
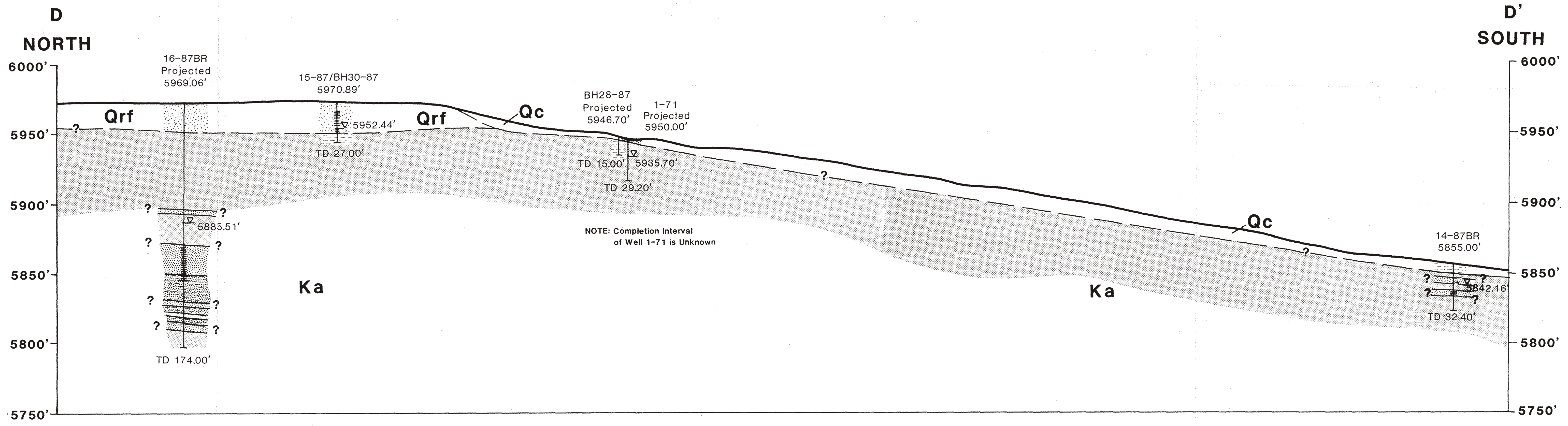
Plate 5-2
903 Pad, Mound, East Trenches Areas
TOP OF BEDROCK ELEVATION
BENEATH ROCKY FLATS ALLUVIUM
December 31, 1987









SCALE: Vertical 1"=50' Feet 0 50; Horizontal 1"=50' 0 Feet 50

EXPLANATION

- 2-87/BH3-87 — Well/Borehole Identification
- Prjtd. — Projected
- 5930.56' — Ground Surface Elevation (Surveyed)
- Water Level (Measured 12/1/87)
- Geologic Contact (Dashed Where Inferred)
- Screened Interval
- TD 16.00' — Total Depth Drilled

QUATERNARY

- Qd — Disturbed Ground
- Qc — Colluvium
- Qrf — Rocky Flats Alluvium
- Qal — Alluvium

CRETACEOUS

- Ka — Arapahoe Formation (Claystone)
- Kass — Arapahoe Formation (Sandstone)

- Clay
- Clayey Sand or Sandy Clay
- Cobbles and/or Gravel
- Sand and Sandstone
- Sand and Gravel
- Silt or Siltstone
- Claystone

Note: Geology inferred between data points see plate 4-1 for cross section locations.

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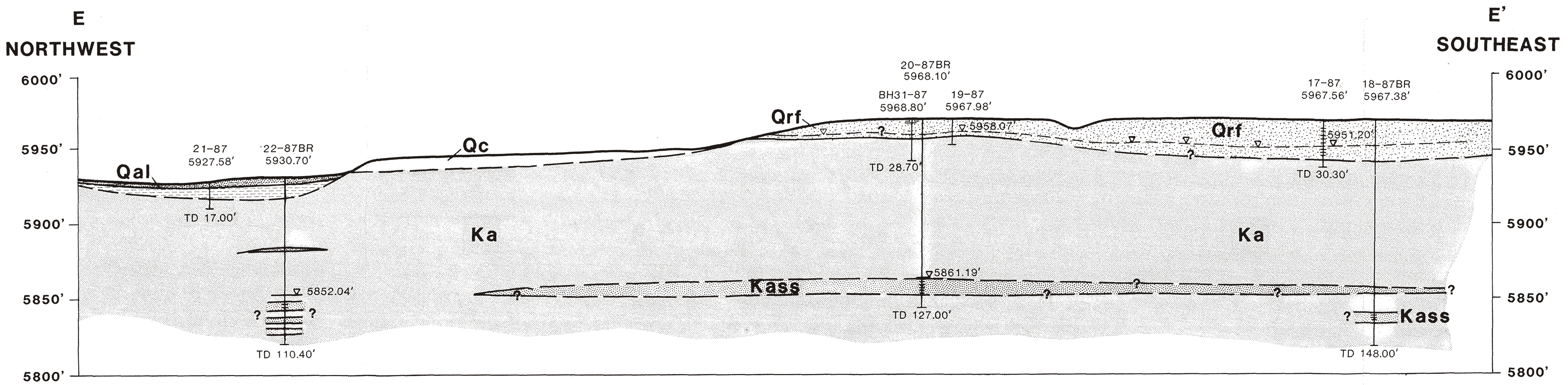
Plate 5-3

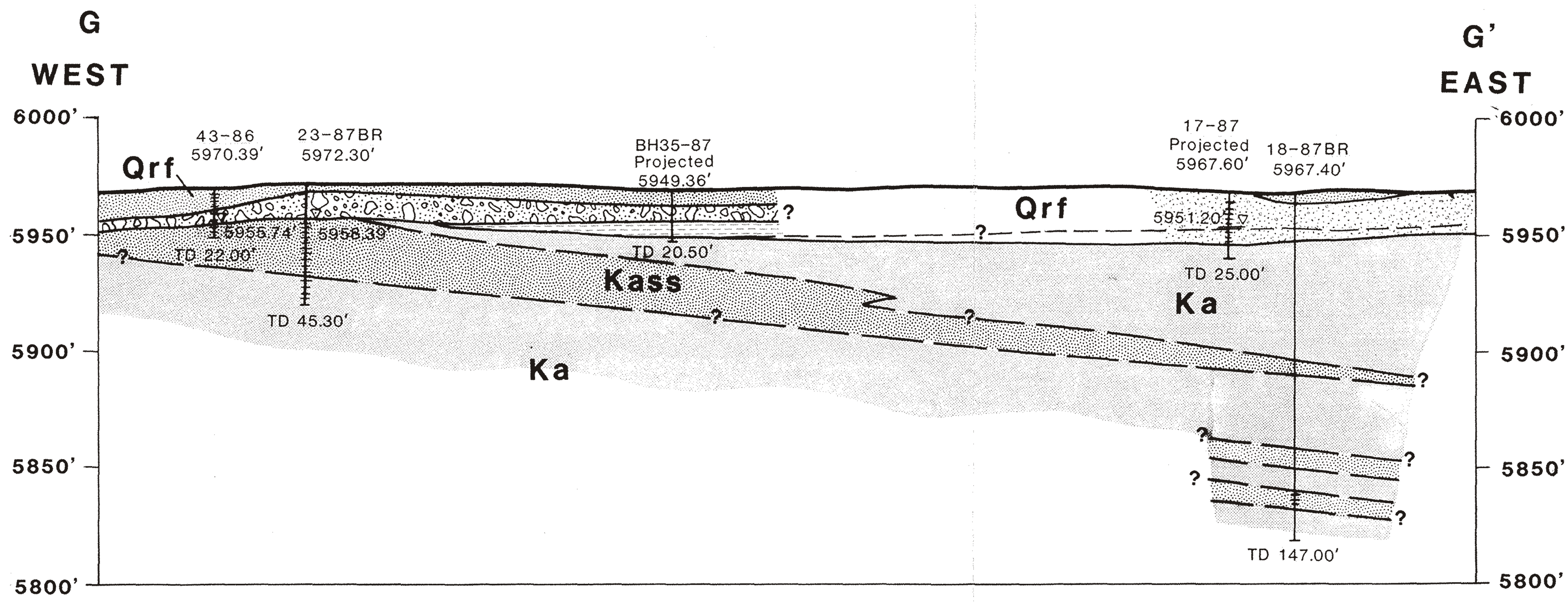
903 Pad, Mound, East Trenches Areas

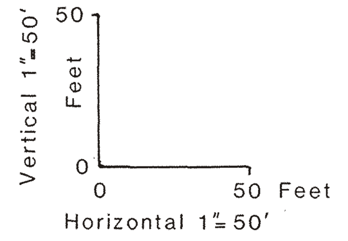
CROSS SECTIONS A-A', B-B', C-C', AND D-D'

OU02-A-000018

December 31, 1987







SCALE

EXPLANATION

2-87/BH3-87	Well/Borehole Identification
Prjtd.	Projected
5930.56'	Ground Surface Elevation (Surveyed)
▽	Water Level (Measured 12/1/87)
—	Geologic Contact (Dashed Where Inferred)
≡	Screened Interval
TD 16.00'	Total Depth Drilled

QUATERNARY

- Qd — Disturbed Ground
- Qc — Colluvium
- Qrf — Rocky Flats Alluvium
- Qal — Alluvium

CRETACEOUS

- Ka — Arapahoe Formation (Claystone)
- Kass — Arapahoe Formation (Sandstone)

- Clay
- Clayey Sand or Sandy Clay
- Cobbles and/or Gravel
- Sand and Sandstone
- Sand and Gravel
- Silt or Siltstone
- Claystone

NOTE: Geology inferred between data points see plate 4-1 for cross section locations.

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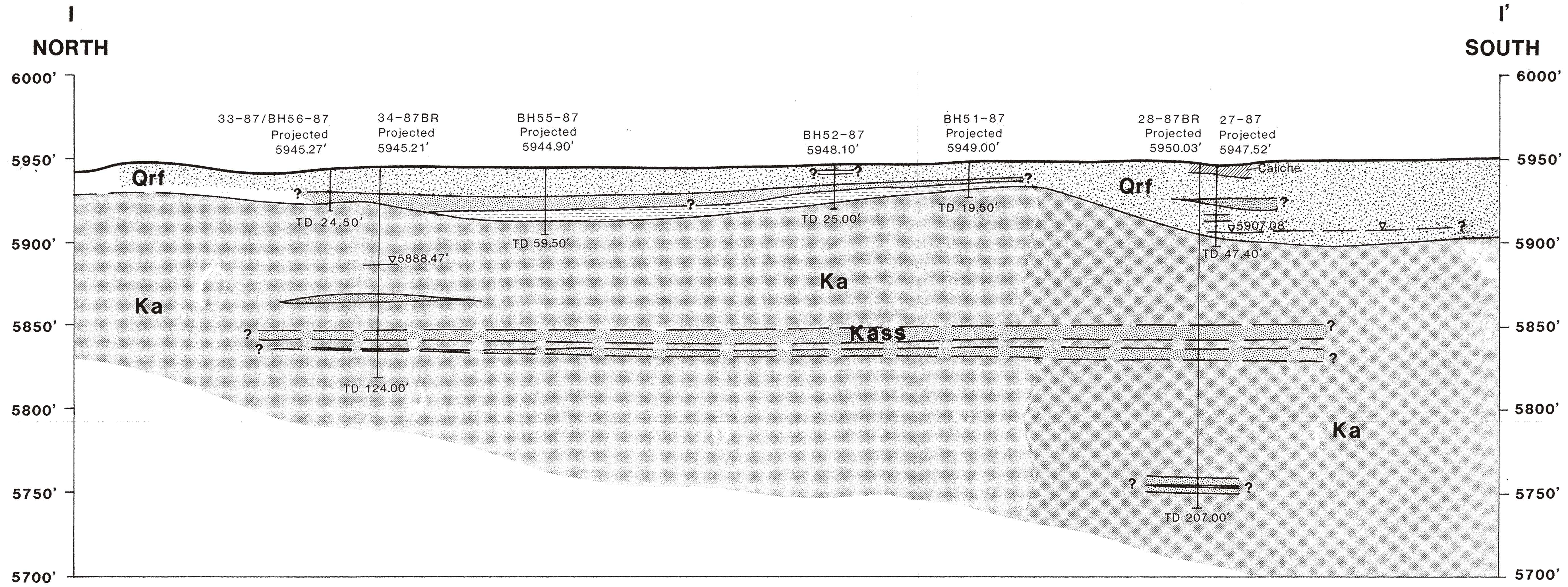
Plate 5-4

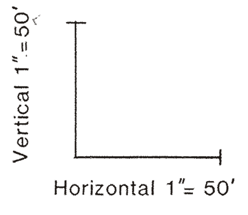
903 Pad, Mound, East Trenches Areas

CROSS SECTIONS E-E', F-F', AND G-G'

0402-A-000018
#49 0402-A-000018

December 31, 1987





SCALE

EXPLANATION

2-87/BH3-87	Well/Borehole Identification
Prjtd.	Projected
5930.56'	Ground Surface Elevation (Surveyed)
	Water Level (Measured 12/1/87)
	Geologic Contact (Dashed Where Inferred)
	Screened Interval
TD 16.00'	Total Depth Drilled

NOTE: Geology inferred between data points, see Plate 4-1 for cross section locations.

QUATERNARY

- Qd Disturbed Ground
- Qc Colluvium
- Qrf Rocky Flats Alluvium
- Qal Alluvium

CRETACEOUS

- Ka Arapahoe Formation (Claystone)
- Kass Arapahoe Formation (Sandstone)

- Clay
- Clayey Sand or Sandy Clay
- Cobbles and/or Gravel
- Sand and Sandstone
- Sand and Gravel
- Silt or Siltstone
- Claystone

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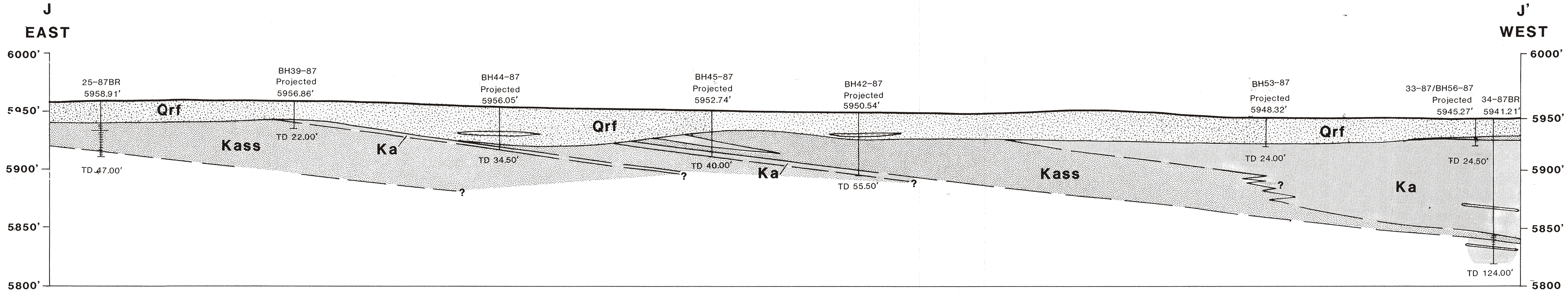
Plate 5-5

903 Pad, Mound, East Trenches Areas

CROSS SECTIONS H-H', AND I-I'

December 31, 1987



EXPLANATION

Symbol	Meaning
2-87/BH3-87	Well/Borehole Identification
Prjtd.	Projected
5930.56'	Ground Surface Elevvation (Surveyed)
▽	Water Level (Measured 12/1/87)
— —	Geologic Contact (Dashed Where Inferred)
╪	Screened Interval
TD 16.00'	Total Depth Drilled

NOTE: Geology inferred between data points, see Plate 4-1 for cross section locations.

Vertical 1"=50' Feet
0 Feet 50'
Horizontal 1"=50'
SCALE

QUATERNARY

- Qd Disturbed Ground
- Qc Colluvium
- Qrf Rocky Flats Alluvium
- Qal Alluvium

CRETACEOUS

- Ka Arapahoe Formation (Claystone)
- Kass Arapahoe Formation (Sandstone)

- Clay
- Clayey Sand or Sandy Clay
- Cobbles and/or Gravel
- Sand and Sandstone
- Sand and Gravel
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- Claystone

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Plate 5-6

903 Pad, Mound, East Trenches Areas

CROSS SECTIONS J-J', AND K-K'

0402-A-000018
#51

December 31, 1987

EXPLANATION

5900 — Contour of Potentiometric Surface in Saturated Alluvium (Feet Above M.S.L.)

Contour Interval: 10'

Approximate Area of Unsaturated Surficial Material

Flow Direction

○ 4-87 Alluvial Monitor Well

● 5-87BR Bedrock Monitor Well

△ 1-74 Pre-1986 Monitor Well

+ 7-87 BRA Abandoned Hole

⬡ BH 11-87 Borehole

N

Contour Interval = 2'

Scale: 1" = 200'

200' 0' 200' 400'

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Plate 5-7

903 Pad, Mound, East Trenches Areas

ELEVATION OF POTENTIOMETRIC SURFACE IN SURFICIAL MATERIALS

0407-A-000018

December 31, 1987