CONSTRUCTION FOUNDATION REPORT

AD-A165 955

NORTHWEST BOUNDARY, RMA CONTAINMENT/ TREATMENT SYSTEM

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18. SUPPLEMENTARY NOTES

This project was authorized by Directive No. 2 Design FY 82 - Rocky Mountain Arsenal dated 8 January 1982, and Directive No. 1, FY 81, PN 36.2 Liquid Waste Disposal, Phase II - WPC dated 14 January 1983.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Northwest Boundary Project is located along the northwest boundary of Rocky Mountain Arsenal, Commerce City, Colorado.

The system was constructed to contain and treat ground water which has been polluted with organic contaminants produced at the arsenal.

The system consists of: 1) A Soil Bentonite cutoff barrier keyed into bedrock, 2) 15 dewatering wells, 3) 21 recharge wells, 4) 17 piezometers, and 5) a carbon adsorption treatment plant.

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Foundation explorations included soil borings, bedrock sampling, ground water hydrology testing, and bedrock and soil permeability tests. Investigations during construction included visually logging well cuttings, inspection of excavated slurry trench materials, blast hole drilling, and slurry and backfill testing.

The contract began in July 1983 and was essentially completed by July 1984. Ms. L. M. Houston was the geotechnical inspector.

Keywords:
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ROCKY MOUNTAIN ARSENAL NORTHWEST BOUNDARY
CONTAINMENT/TREATMENT SYSTEM CONSTRUCTION

FOUNDATION REPORT

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CHAPTER 1. - INTRODUCTION

1.1 **LOCATION AND DESCRIPTION.** Rocky Mountain Arsenal (RMA) occupies 17,000 acres in Adams County, Colorado, 10 miles northeast of downtown Denver, and directly north of Denver's Stapleton International Airport. The Northwest Boundary Containment/Treatment System Project is located along the northwest boundary of RMA, parallel to Colorado State Highway 2 in Section 22, Township 2 South, Range 67 West. The project consists of a combination slurry trench cutoff wall/hydraulic barrier which includes:

(1) A soil-bentonite ground water barrier, which is a minimum of 30-inches wide, and is keyed 3 feet into impervious bedrock. Barrier length is 1,425 feet and is located 800 feet inside and parallel to the northwest boundary, as shown on Plate 4. Average depth of the barrier is 43 feet.

(2) Fifteen dewatering wells, five of which are 50 feet upgradient of the soil-bentonite barrier. The remaining 10 discharge wells form the hydrualic barrier.

(3) Twenty-one recharge wells, 600 feet down gradient of the cutoff wall and discharge wells.

(4) Seventeen piezometers for monitoring ground water elevation and contamination.

(5) A treatment plant for removal of organic contaminants by carbon adsorption.

1.2 **CONSTRUCTION AUTHORITY.** The Northwest Boundary Containment/Treatment System Project was authorized by Directive No. 2, Design FY 82-Rocky Mountain

Arsenal, dated 8 January 1982, and Directive No. 1, 14 January 1983, FY 81, PN 36.2 Liquid Waste Disposal, Phase II-WPC.

1.3 **PURPOSE OF REPORT.** An as-built foundation report is required for all major or unique construction projects as per Regulation No. 1110-1-1801 dated 1 April 1983. These reports insure the preservation for future use of complete records of foundation conditions during construction and of methods used to adapt structures to these conditions. They are also used in planning additional foundation treatment after project completion, if necessary, in evaluating stress, in planning remedial action should structural failure occur due to foundation deficiencies, for guidance in planning foundation explorations and in anticipating foundation problems for comparable future construction projects, and as an information base in determining the validity of claims made by construction contractors in connection with difficulties arising from alleged foundation conditions.

1.4 **PROJECT HISTORY.** RMA was established in 1942 to produce chemical warfare agents and incendiary munitions. Since 1946, portions of the RMA facilities have been leased to private industry for chemical manufacturing. Production of chemical warfare agents continued at RMA until 1957. In 1971, a demilitarization program was initiated to reduce stocks of obsolete chemical agents and munitions. Chemical production by private industry and the demilitarization program were still in operation during construction of the Northwest Boundary Containment/Treatment System Project.

During the production years (1942 to 1957), the industrial wastes generated at RMA by private lessee and Government operations were disposed of in unlined ponds. Basin "A," located in Section 36, was the most extensively used unlined pond. At the peak of production in 1955, the surface water in Basin "A" reached approximately 300 acres in area. The use of the natural basin with no other provisions for waste containment allowed large quantities of contamination to percolate into the ground water system. Unlined Basins "C," "D," "E," and "F" were also used during this time to contain overflow wastes from Basin "A."

The first indication of ground water contamination outside of RMA came with a formal letter of request for investigation from the Great Western Sugar Company to Brigadier General C. S. Shadle, RMA, dated 4 June 1954. A subsequent letter from the Great Western Sugar Company to the Chief of Engineering and Service Division, RMA, dated 18 June 1954, related more information concerning ground water contamination. This letter described a correlation between crop damage and irrigation water from wells in farmland adjacent to RMA as early as 1951. Studies of the problem were initiated in November 1954 by the Corps of Engineers, Omaha District, in cooperation with the U.S. Geological Survey (USGS) at the request of the Commander, Rocky Mountain Arsenal. The Corps of Engineers study, "Report on Ground Water Contamination," September 1955, consisted of well-sample analyses for contamination and an electrical resistivity investigation to determine contaminant migration patterns. The USGS open file report by Petri and Smith was dated August 1956. These studies did delineate general patterns of contaminant migration, and they recommended that a program be implemented to monitor the contaminated ground water.

Another study, conducted by the Ralph M. Parsons Company under contract with the Corps of Engineers, Omaha District, resulted in "The Final Report, Disposal of Chemical Wastes, Rocky Mountain Arsenal" in September 1955. This report described studies of toxicity to plants and chemical constituents in irrigation wells near RMA, and provided recommendations for cost-effective actions, including reduction of the volume of contaminated water discharge from plants, asphalt membrane seals in existing storage reservoirs, and the study of bentonite-sealed reservoirs, reduction of wastes into salable by-products as much as possible, neutralization of surplus acids into salts, and solar evaporation of a portion of the waste liquids in the reservoirs to reduce liquid contents. It also recommended against the use of an injection well for disposal of liquid wastes.

Many of the recommendations were followed for reduction of waste volumes, and existing Basin "F" was lined with an impermeable sprayed asphalt membrane covered with 1 foot of clay soil. Apparently, no study of bentonite-sealed reservoirs was conducted and no other waste reservoirs were lined to prevent continued leaching of contaminants into the ground water aquifer. All process wastes since 1956 have been placed in Basin "F."

The U.S. Public Health Service, acting on claims of crop damage from the use of irrigation water on lands adjacent to RMA in 1958, performed a survey of damages. This study resulted in a report released in November 1959 acknowledging the Government's responsibility for contamination of RMA-area ground water. This report provided impetus for containment and cleanup of contaminated ground water leaving RMA. The Omaha District was directed to perform a preliminary study of the ground water problem at RMA by Office, Chief of Engineers (OCE) Directive No. 1, dated 18 March 1960. Results of this preliminary study were submitted to OCE in report form dated 11 May 1960.

By letter from OCE, dated 11 July 1960, the Omaha District was directed to proceed with completion of the final integrated study of the ground water contamination at RMA, based on information available at that time. This study resulted in the comprehensive report, "Program for Reclamation of Surface Aquifer," dated January 1961. This report accurately described the nature and extent of contamination, the nature of the phytotoxicants, and supplementary methods of waste disposal. It also provided several schemes for correction of the contamination. These schemes included the proper locations for barriers which were used when designing the Northwest Boundary Containment System. Also recommended was a program for monitoring contamination and ground water flows, and a program for further studying the nature of the contaminants and their effect on plants and animals.

By the summer of 1959, Basin "F" was dangerously close to capacity for two reasons: (1) the production of liquid wastes exceeded expectations, and (2) Basin "F," the only lined basin, had only two-thirds the capacity recommended in the Corps of Engineers' sponsored study, due to limited funds available to the Chemical Corps. The Chemical Corps, acting on the advice of their Industrial Advisory Council, decided upon a deep well for the underground injection of future wastes. Under contract to the Omaha District, U.S. Army Corps of Engineers, E. A. Polumbus, Jr., and Associates, Inc., produced the report, "Final Design Analysis, Pressure Injection Disposal Well, Rocky Mountain Arsenal," in July 1960.

The injection well was drilled in 1961 under the supervision of the Omaha District to a depth of over 12,000 feet, penetrating Precambrian gneiss. This well was unique in that it was by far the deepest injection well to date, and that the reservoir consisted of fractures in crystalline rock as opposed to sedimentary rock commonly used for injecting wastes. Regular pressure injection of wastes from Basin "F" began on 8 March 1962. On 23 November 1965, David M. Evans, a Denver geologist, publicly announced the results of a study conducted by him which alleged to prove that injection of liquid wastes in the deep well at RMA was causing earthquakes in the Denver area. Mr. Evans based his allegation on the statistical correlation between volumes of waste injected into the well and the frequency of earthquake events. This correlation covered the period from March 1962 to October 1965, during which a total of 150 million gallons of waste were injected and a total of 710 earthquakes were recorded.

Interest in a relationship between injection of fluids and earthquakes soon became widespread. Upon the advice of the Corps of Engineers, RMA reduced the rate of waste injection on 20 January 1966, and discontinued injection altogether on 20 February 1966. The investigation of the situation then expanded. The U.S. Geological Survey, University of Colorado, Colorado School of Mines, and the Corps of Engineers, Omaha District, cooperated in the investigation. The correlation between injection rates and earthquake frequency was confirmed, and in February 1969, injection of waste was permanently discontinued. Process wastes were again stored in Basin "F."

In 1974, contaminants that originated from RMA operations were detected in surface waters located to the north of RMA and in wells located near the city of Brighton. The State of Colorado Department of Health, following

Resource Conservation and Recovery Act guidelines, issued three Cease and Desist Orders against Shell Chemical Company (SCC) and RMA in April 1975. These orders stated that SCC and RMA:

(1) Immediately stop the off-post discharge of contaminants, both surface and subsurface.

(2) Take action to preclude future off-post discharge of contaminants.

(3) Provide written notice of compliance with Item (1).

(4) Submit a proposed plan to meet the requirements of Item (2).

(5) Develop and institute a surveillance plan to verify compliance with Items (1) and (2).

As a result of these orders, a program was developed and implemented to satisfy the compliance criteria. The Northwest Boundary Containment/Treatment System is one of several projects designed to implement this program.

1.5 <u>DESIGN CONCEPT</u>. Originally, the design concept for the containment system was a total hydraulic barrier. However, the thin saturated thickness and low permeability of the aquifer along the northeast half of the system made a hydraulic barrier along this reach economically and operationally undesirable. The slurry trench cutoff wall was selected to contain the ground water flow in the thin aquifer because it offers several advantages over the hydraulic barrier. Advantages of the slurry trench cutoff wall are:

(1) Less maintenance time and costs, due to the reduced number of wells and pumps. Less shutdown time for well maintenance.

(2) Assures positive cutoff in an area with complex hydrology.

(3) Less complex operation.

(4) Seasonal variations in ground water level will have less effect on system operation.

(5) Less operating cost.

1.6 <u>LOCATION OF CONTAINMENT/TREATMENT SYSTEM</u>. Originally, there were several proposed locations for the containment system. As preconstruction investigations progressed, it became apparent that more favorable subsurface conditions existed closer to the boundary. Moving northwest, away from the bedrock bench situated approximately 1,600 feet inside and roughly parallel to the boundary, the geology and hydrology is more conducive to operation of the containment system. There is greater saturated thickness and less bedrock influence on ground water flow (Plates 22, 24, and 25). Therefore, the final containment system location is as close to the boundary as practical. This location provides several advantages over any other site considered. Some of the advantages are as follows:

(1) Ground water flow in this area is nearly perpendicular to the boundary and the containment system. This allows the DBCP plume to be intercepted with a shorter system. Review of the ground water and bedrock plans indicates that a system located further inside the boundary would be nearly parallel to the ground water flow and the plume. This would require the system to be an additional 1,000 feet in length to assure the entire plume is intercepted.

(2) The saturated thickness increases closer to the boundary. As a result, the length of the slurry cutoff wall is less, because there is less thin aquifer to cutoff.

(3) There is a fairly extensive network of existing monitoring wells in this area. These wells can be used to monitor the system eliminating the need to construct new monitor wells. There is a row of monitor wells along the boundary that can be used to monitor water quality and levels down-gradient of the recharge line. There is also a row of monitor wells that fall approximately midway between the discharge line/slurry wall and the recharge line. These will provide water quality and levels within the system. Several monitor wells are located upgradient of the discharge line/slurry wall to provide ground water data prior to entering the containment system.

(4) The location contains more contaminated ground water initially. By moving the barrier close to the boundary, there is less contaminated ground water between the system and the boundary to flow off the arsenal after startup.

(5) The bedrock high in the vicinity of boring DH82-8A provides a place to tie the northeast end of the cutoff wall into.

(6) Low ground water gradient; reversal can be achieved with minimum drawdown and mounding.

1.7 **CONTRACTORS AND CONTRACT SUPERVISION.** The contract for Rocky Mountain Arsenal Northwest Boundary Containment/Treatment System began in July 1983.

Initial grading and clearing work began in August 1983, with the soil-bentonite barrier beginning on 4 October 1983 and finishing on 20 November 1983. Well drilling proceeded from September 1983 through May 1984. The entire project was essentially completed by July 1984. Subcontractors involved in the project are included in Table 1.

TABLE 1-1 - CONTRACTORS

CONTRACTOR	WORK PERFORMED
Western States Construction Co.. Inc. (Prime Contractor) P.O. Box 598 Loveland, CO 80539	Treatment building,- sumps, well vaults, site grading, service roads, yard piping
Geo-Con, Inc. E. Touchy Avenue Des Plaines, IL 60018	Slurry trench excavation 1011 and backfill Suite 245
Bechtold Construction Co., Inc. West 41st Avenue	Discharge and recharge 7709 wells Wheatridge, CO 80033
Fox Consulting Engineers & Geologists Denver, CO	Piezometers 4765 Independence
Bath Excavating & Construction 1333 80522	Blasting for trench P.O. Box excavation Fort Collins, CO
Western Testing Laboratories, Inc. Sheridan Boulevard Lakewood, CO 80214	Concrete, compaction, 775 gradation, and backfill testing
Chen & Associates El Paso	Barrier permeability 3405 N. testing Denver, CO
Westvaco 1107	Treatment system P.O. Box fabrication Castle Rock, CO
Decker Erectors 474 80457	Metal building P.O. Box fabrication Kittredge, CO

TABLE 1-1 - CONTRACTORS (CONTINUED)

CONTRACTOR	WORK PERFORMED
Meyer-Weddle Co. 12580 W. Cedar Drive Denver, CO 80228	Calgon tank interior piping
Consolidated Engineering, Inc. 11185 E. 51st Avenue Denver, CO	Electrical and instrumentation
Union Power Construction Co. 2045 W. Union Avenue Denver, CO	Overhead electrical
Craftsman Decorating, Inc. 2634 12th Avenue Greeley, CO 80631	Painting, coatings, pipe identifications
Re-Bar Placing, Inc. 9520-B East 104th Avenue Henderson, CO 80640	Reinforcing installation
Steelock Fence Co. 5208 Adams Street Denver, CO 80216	Security fence and gates
Gendreau Construction P.O. Box 696 Glenwood Springs, CO	Concrete formwork

1.8 **RESIDENT AND DESIGN STAFF.** Design of the system was developed by the U.S. Army Engineer District, Corps of Engineers, Omaha, Nebraska, under the direction of District Engineer, COL W. R. Andrews, Jr. Key design personnel in Engineering Division include G. Williams, Military Branch; L. Tate, R. Curnyn, and M. Bayon, Design Branch; and D. Pendrell, J. Topi, and T. McDaniel, Geotechnical Branch. L. Houston, Geotechnical Branch, provided field inspection and geotechnical expertise during the well and ground water barrier construction. Construction Division personnel include M. Mailander, Supervision and Inspection Branch. The Rocky Mountain Area Office, under COL J. I. Coats, Area Engineer, was responsible for project construction. Key Rocky Mountain Area personnel include K. Thonen, Resident Engineer, and R. McRae and J. Minicz, Project Engineers. The treatment plant was designed by Stearns and Roger; and using equipment was designed by Rubel-Hager, Inc. Technical review was provided by the Omaha District.

CHAPTER 2. - FOUNDATION EXPLORATION AND STUDIES

2.1 **PRECONSTRUCTION INVESITGATIONS.** A number of pump tests and interference tests were performed prior to 1961 to determine aquifer and ground water characteristics. From the test data obtained, the hydraulic conductivity factor was 1,500 feet per day; the factor for the average storativity was 20 percent. Average porosity was computed as 35 percent. The distance from Reservoir "A" (Plate 1) to the South Platte River showed a 20-foot per mile hydraulic gradient, with the average velocity of movement of 16 feet per day.

A comprehensive study of ground water contamination was completed by the Omaha District Corps of Engineers in January 1961. This report, titled, "Program for Reclamation of Surface Aquifer, Rocky Mountain Arsenal," was the first report to identify major contaminant sources and contaminated ground water plumes, as well as provide containment/collection system schemes and locations for the proposed systems. All following investigations generally confirmed the hydrologic information and preferred containment system locations as submitted in the 1961 report. The information derived from this report is shown on Plates 22 through 25. The disposal methods for contaminated water are not included in this report.

A field exploration program for the Northwest Boundary project was planned and performed by the Omaha District to provide more detailed geologic, hydrologic, and contaminant data. Field work for the project begain on 18 March 1982 and was completed in January 1983. A total of 89 holes were drilled. Refer to Plate 3 for boring locations. Sixty-seven of the borings were located in five lines parallel to the northwest boundary in Sections 22 and 27. The lines were located approximately 200, 800, 1,600, 2,400, and 3,400 feet southeast of the boundary. The first four lines inside the boundary were situated along three potential locations for the containment system. The fifth line (3,400 feet southeast of the boundary) was drilled to clarify complex hydrology and to determine contaminant flow paths. The remaining 22 holes included 5 wells and 17 observation wells (piezometers) used for performing and monitoring aquifer pump tests.

Drilling for the project was performed by the Army Corps of Engineers' drill crews, Omaha, Nebraska, with the exception of Wells W-1, W-2, and W-3, which were drilled under contract by Caissons, Inc., Denver, Colorado. The majority of the holes were drilled with a CME-75 equipped with a hollow stem auger. Three-inch or two-inch diameter split spoon samples were taken at intervals ranging from 2-1/2 to 5 feet. The remainder of the exploratory borings were drilled with a cable tool (churn) drill rig. Cable tool-drilled holes utilized a Bucyrus-Erie churn, and were sampled continuously. Wells W-1, W-2, and W-3 were drilled with a rotary rig equipped with a 36-inch-diameter flight auger; Well W-4 was drilled with a Failing 1500, and Well W-5 was drilled with the cable tool. Profiles along the dewater well, slurry trench, and recharge well lines, along with logs of adjacent borings, are shown on Plates 5 through 9. Holes were visually logged by Omaha District geologists and samples were forwarded to the Missouri River Division Laboratory for further analysis.

If ground water was encountered in the borings, 2-inch diameter PVC piezometers were installed for water level measurements and sampling for water quality analyses.

Two 48-hour alluvial aquifer pump tests were run to determine the hydraulic characteristics of the aquifer in the vicinity of the proposed containment system. One (W-4) utilized 20 observation wells, and was conducted by Woodward-Clyde Consultants and Omaha District personnel with some technical assistance from the US Geological Survey, Denver. Six observation wells were monitored during the W-5 pump test, which was performed by Omaha District personnel only. Pump test locations are shown on Plate 3. Aquifer characteristics for the alluvial aquifer were determined by using the time-drawdown data from the observation wells. Analyses using Boulton's method, assuming delayed yield for an unconfined aquifer, gave an average transmissivity value of 210,228 gpd/ft and an average specific yield of .085 for Well W-4. Hydraulic conductivities calculated using the values for transmissivity and saturated thickness (25 feet) averaged 1144 ft/day. For Well W-5 an average transmissivity of 33,213 gpd/ft, specific yield of .25, and hydraulic conductivity of 587 ft/day was calculated.

2.2 **INVESTIGATIONS DURING CONSTRUCTION.** Investigations during construction included visually logging the well cuttings, inspection of excavated slurry trench materials, additional drilling performed by Geo-Con for blasting purposes, and slurry and backfill testing.

WELL LOGGING. Using a strainer, grab samples of the well cuttings were taken during drilling. A jar sample of aquifer material was also taken from each well. Samples were logged according to ASTM D 2488, "Description of Soil. (Visual-Manual Procedure)." Logs are compiled in Plates 12 through 16.

TRENCH INVESTIGATIONS. Bedrock samples were taken at the minimum excavation depths (as shown on Plate 16) at 20-foot horizontal intervals using the sampler shown in Photo No. 14. The sampler was pinned to a tooth on the backhoe bucket and pushed vertically into the bedrock until refusal. When samples indicated heavy weathering, silt, sand, or fractured zones, excavation was continued until less permeable material was encountered.

A total of 213 blast holes were rotary drilled along the slurry trench line from Stations 16+6+ to 18+50 for removal of sandstone lenses. The holes were not logged; however, the upper and lower contacts of the argillaceous sandstone were determined by the driller as shown in Table 2-1.

TABLE 2-1 - BLASTING

Hole No.	Station	Top of Rock (ft)	Bottom of Rock (ft)*	Thickness of Rock (ft)*	Bottom of Hole (ft)	No. of Sticks "Tovex"	Pounds of "Tovex"
19	16+64	40.5	41	0.5	45.5	1	2.27
20	16+67.8	43	4.5	1.5	44.9	1	2.27
94	16+69.4	43	44.5	1.5	44.4	1	2.27
21	16+71.2	43	45	2	44	1	2.27
93	16+73	43	45	2	47.6	1	2.27
22	16+74.8	42	45	3	46	2	4.50
92	16+76.6	42	45	3	46	2	4.50
23	16+78.4	41	45.5	4.5	46	3	6.80
24	16+82	40.5	46	5.5	47	4	9.08
90	16+83.8	40.5	46	5.5	45	3.5	7.90
25	16+85.6	40.5	46	5.5	48.5	4	9.08
89	16+87.4	40.5	46	5.5	45.2	3.5	7.90
26	16+89.2	40	46.5	6.5	46.1	4.5	10.20
88	16+91	40	46.5	6.5	45.6	4	9.08
27	16+92.8	39	46.5	7.5	48.5	5	11.35
87	16+94.6	39	46.5	7.5	46.2	5	11.35
28	16+96.4	38.5	46.5	8	46.9	6	13.60
86	16+98.2	38.5	46.5	8	48	6	13.60
29	17+00	38	47	9	46.8	6.5	14.75
85	17+01.8	38	47	9	46.9	6	13.60
30	17+03.6	39	46.5	7.5	45.8	5	11.35
84	17+05.4	39	46.5	7.5	45.5	5	11.35
31	17+07.2	40	46.5	6.5	46.8	4.5	10.20
83	17+09	40	46.5	6.5	45.6	4	9.08
32	17+10.8	41	46.5	5.5	46.2	4	9.08
82	17+12.6	41	46.5	5.5	46.5	4	9.08
33	17+14.4	42	46.5	4.5	47	3	6.80
81	17+16.2	42	46.5	4.5	46.2	3	6.80
34	17+18	43.5	47	3.5	46.5	2	4.54
80	17+19.8	43.5	47	3.5	46	2	4.54
35	17+21.6	44	47	3	47	2	4.05
79	17+23.4	44	47	3	47.8	2	4.05
36	17+25.2	44	47	3	46.8	2	4.05
78	17+27	44	47	3	46.5	2	4.05
37	17+28.8	44	46.5	2.5	45.8	2	4.05
77	17+30.6	44	46.5	2.5	45.5	2	4.05
38	17+32.4	44	46	2	45.8	1	2.27
76	17+34.2	44	46	2	46.8	1	2.27
39	17+36	43.5	45.5	2	45.8	1	2.27
75	17+37.8	43.5	45.5	2	50	1	2.27
40	17+39.6	43	45	2	?	1	2.27
44	17+41.4	43	45	2	?	1	2.27
73	17+45	43.5	44	0.5	43.5	1	2.27
42	17+46.8	42.5	43	0.5	42.5	1	2.27
72	17+48.6	43	44.5	1.5	44	1	2.27
71	17+50.4	42.5	43	0.5	42.5	1	2.27

TABLE 2-1 - BLASTING (CONTINUED)

Hole No.	Station	Top of Rock (ft)	Bottom of Rock (ft)*	Thickness of Rock (ft)*	Bottom of Hole (ft)	No. of Sticks "Tovex"	Pounds of "Tovex"
43	17+52.2	42.5	43	0.5	42.5	1	2.27
57	17+99.8	44	48	4	57.1	3	6.80
200	18+02.6	42	47	5	52.4	4	9.08
201	18+03.4	43	48	5	53.5	4	9.08
202	18+06.2	45	48	3	55.2	2	4.54
203	18+07	43	48	5	53.7	4	9.08
204	18+10	42	49	7	54.3	5	11.35
205	18+10.6	44	48	4	50	3	6.80
208	18+17	42	49	7	57.2	5	11.35
209	18+17.8	41	49	8	56	6	13.62
210	18+20.6	42	50	8	50.6	6	13.62
211	18+21.4	41	49	8	57.6	6	13.62
213	18+25	44	49	5	52	4	9.08

***NOTE:** Bottom of rock and feet of rock as determined by contractor. For actual rock profile, see Plate No. 16.

CHAPTER 3. - GEOLOGY

The following is a general discussion of the regional and site geology and hydrology. A much more detailed discussion is presented in the Concept Design Analysis for the NW Boundary Containment, FN37, Rocky Mountain Arsenal.

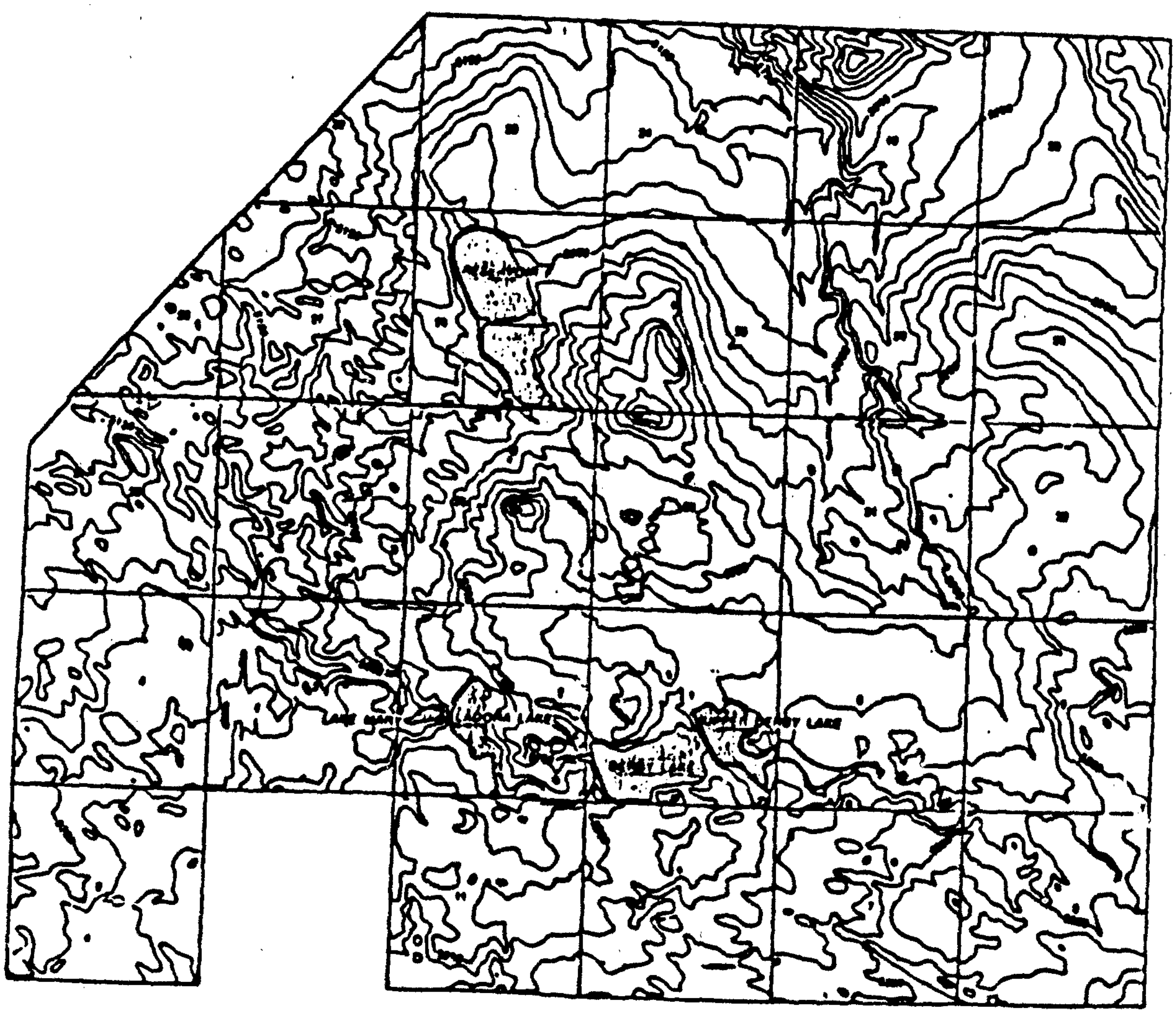
3.1 GENERAL GEOLOGY.

3.1.1 PHYSIOGRAPHY. Rocky Mountain Arsenal is located within the Colorado Piedmont section of the Great Plains physiographic province and is characterized by late mature to old elevated plains and low rolling topography. The site itself is on the eastern edge of a broad valley of the South Platte River, east of the foothills of the Front Range of the Rocky Mountains. Topographic relief across the entire Arsenal is approximately 200 feet, with the land surface generally sloping northwest toward the South Platte River (see Figure 3-1).

3.1.2 DESCRIPTION OF OVERBURDEN. The overburden consists primarily of alluvial clays, sands, silts, gravels, cobbles, and small boulders in various combinations. Above the bedrock, the soils are quaternary alluvial deposits ranging from 0 to 70 feet in thickness, with irregular, braided channel deposits and lenses characteristic of alluvium. Occasional calcareous cemented zones occur in the alluvium and may vary from several inches to several feet in thickness. The alluvium is overlain in places by more recent deposits of windblown silts and sands.

3.1.3 BEDROCK STRATIGRAPHY. The Denver and Arapahoe Formations are the bedrock units immediately underlying the Rocky Mountain Arsenal. They consist of deltaic shales, claystones, sandstones, and conglomerates.

Studies by WES (1980) indicate that the Denver Formation is 250 to 400 feet thick in the vicinity of the northwest boundary and, therefore, this formation is the only bedrock unit of concern for this project. All further references to bedrock in this report refer to the Denver Formation.



TOPOGRAPHIC MAP
OF
ROCKY MOUNTAIN ARSENAL

SCALE

FIGURE 3-1

The Denver Formation is of probable Paleocene age consisting of sequences of deltaic deposits. The depositional environment resulted in a predominance of fine grained materials rich in organic matter. Lignite seams have been reported nearby and fragments of lignite were encountered in boreholes during this study. Interbedded with the fine grained sediments are sand deposits and silty sands that apparently represent stream channel deposits that were probably deposited in meandering channels and adjacent portions of flood plains.

The sandstones of the Denver Formation constitute important aquifer zones in the Denver Basin and yield water to domestic, municipal, and industrial wells. Individual sandstone beds are lens shaped in cross section, but may extend for long distances along sinuous channels. Interweaving of these channels provides good regional lateral interconnection by occasional overlapping of channel deposits. Thickening with vertical overlapping or stacking provides good vertical interconnection over wide areas although this vertical interconnection may be poor at a given location. As a result, individual sandstone beds by themselves are not important aquifers, but rather groups of beds act as aquifer zones that respond or act much as a single aquifer. This condition is typical of the major ground water basins of much of the Western United States and the Atlantic and Gulf coastal plains where they are composed of deep alluvial fill.

3.1.4 **BEDROCK STRUCTURE**. RMA is located near the northwestern flank of the Denver Basin, an oval structural basin measuring approximately 120 by 70 miles. This basin is filled with about 15,000 feet of sedimentary rocks. The bedrock at RMA is a thick sequence of Paleocene and Cretaceous deltaic and alluvial deposits with gentle regional dips to the southeast, toward the axis of the Denver basin (see Figure 3-2).

In late Cretaceous and early Tertiary times, major deposition occured in the Denver Basin. In the Tertiary Period, the Laramide Orogeny began, resulting in uplift of the entire area and the development of the Rocky Mountains to the west of the site. In time, the uplift caused erosion which removed most of the Tertiary sediments and exposed the late Cretaceous sediments. The remnants of this erosional period are pediments formed along the eastern plains near the foothills. With the retreat of the glaciers in the Quaternary Period, massive erosion of the Cretaceous formations continued, shaping the present bedrock topography in the RMA area.

No significant faulting has been noted at RMA, although some seismic activity in basement rock was associated with the deep well disposal program in the mid-1960's.

3.2 SITE GEOLOGY.

3.2.1 BEDROCK. In the northwest boundary area, the Denver Formation consists of predominantly gray to gray-brown shale or claystone, with irregular, discontinuous sandstone lenses.

The Denver Formation is jointed and fractured in the vicinity of the barrier, as observed in sample cores and described in borehole logs. The clay shales or claystones are relatively massive and do not exhibit shale partings. They are not fissile. Joints and fractures are probably related to stress relief due to unloading by erosion, and perhaps more importantly, due to dessication resulting in contraction cracks. The upper part of the unit, especially in the weathered zone, is often classified as intensely fractured or crushed. Iron staining was noted on fracture surfaces which indicates the joints and fractures were open enough to transmit water when the rocks were unsaturated and an oxidizing environment existed.

Along the barrier alinement, bedrock is weathered to depths ranging from 2 to 5 feet below the erosional surface of the formation. Weathering is gradational with color changes from shades of brown in the weathered zone to gray colors in the unweathered materials. This weathering indicates the erosional surface of the Denver Formation has been exposed to air and dessication permitting oxidation and decomposition of mineral constituents. This suggests that the weathered zone was unsaturated during the geologic past, during the Tertiary Period or possibly early Pleistocene.

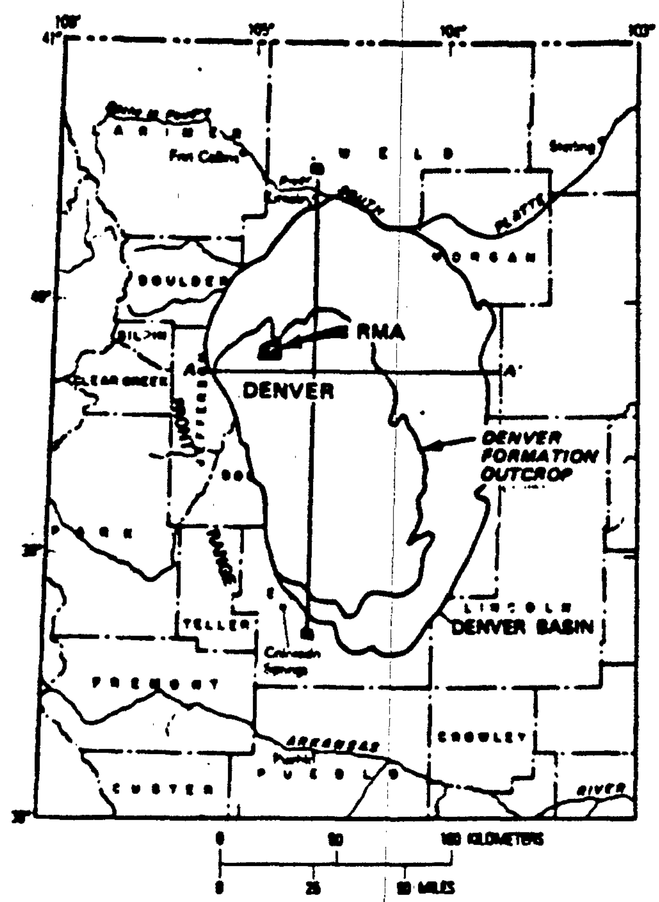


FIGURE 3-2 Rocky Mountain Arsenal in relation to the Denver Basin and outcrop pattern of Denver formation (Robson and Romero 1981)

The degree of weathering, freshness, and fracturing of the bedrock during construction was determined by examination of trench bottom samples and boring samples. Trenching operations frequently extended 3 to 5 feet deeper than the minimum excavation line due to fracturing and weathering of the Denver Formation near the bedrock surface. The Denver Formation sandstones at the northwest boundary frequently contained yellow-brown stained weathered zones near the base of blue-gray unweathered zones. These zones were slightly softer than the blue-gray sandstone and appeared to be slightly more permeable. These areas contained numerous pockets of clay and loose fine grained sands. During excavation, the alluvium-sandstone contacts were distinct over the site, but alluvium-claystone contacts were frequently ambiguous due to the similar characteristics of weathered claystone and the overlying alluvium.

3.2.2 **ALLUVIUM.** The alluvium was deposited during the Quatenary Period. It was deposited primarily by tributaries of the ancient Platte River drainage System.

Bedrock is directly overlain by unconsolidated and occasionally cemented coarse alluvium. This is the alluvial aquifer material and consists of highly permeable sands and gravels with varying amounts of silt, cobbles, and occasional boulders. The thickness of the alluvial aquifer ranges from over 25 feet to less than 5 feet.

The alluvial aquifer material is overlain by fine-grained overbank alluvial sediments. This material can act as a confining layer to ground water. The fine-grained sediments are predominantly sandy or silty lean clays, or less commonly, highly plastic clays. Zones of clayey sands were occasionally encountered. The thickness of these sediments averages 20 feet.

3.2.2.1 **EOLIAN DEPOSITS.** A thin mantle of eolian soils overlies the northwest boundary area. These Wisconsin Age deposits were derived from glacial outwash material. They are generally a fine grained, fairly uniform silty sand.

Plates 12 through 16 indicate the types of materials encountered throughout the project area.

3.3 GROUND WATER HYDROLOGY. At the northwest boundary area of RMA, it is reasonable to separate the regional flow system into two subsystems based on geology; alluvium and bedrock flow. The Quaternary Alluvium in this area is predominantly underlain by clay shales, siltstones, and sandstones of the Denver Formation.

Regional studies of the ground water flow system by Geraghty and Miller (Evaluations of the Hydrogeologic and Contamination Migration Patterns, Rocky Mountain Arsenal, Denver, Colorado, January 1981) indicate a general north to northwesterly flow angling toward the South Platte River. The shallow or upper Denver Formation and the alluvial deposits interact in transmitting flows and are both part of the same flow system. Flow in the Denver Formation is both confined and unconfined, and in the alluvium, it is generally unconfined, but may be locally semiconfined. Potentiometric levels in both units generally correspond rather closely. Locally potentiometric levels between may vary greatly due to locally imposed stresses such as heavy pumping from one of the units or by local recharge. Even though flow through both geologic units is part of one system, there are significant differences that were used to advantage in developing pollution containment systems. In general, the alluvial aquifer is much more permeable than sandstones or other materials in the Denver Formation.

The shallow alluvial aquifer is composed of the sand, gravel, clay, and silt as described in Paragraph 3.2.2, and is the most used aquifer in the RMA area. The flow of water through this aquifer generally conforms to the bedrock surface, which slopes from southeast to northwest. Zones of impermeable clays and silts in the aquifer may slightly alter the flow or may form isolated perched water tables. The flow pattern is also locally modified by seepage from ponds, lagoons, and canals. The seepage type of artificial recharge is the primary cause of the extensive contamination at RMA, the main sources being the disposal basins for process wastes.

Only minor fluctuations in ground water level have been recorded over several years, indicating the relative stability of the ground water system.

The ground water in the alluvial aquifer is rather mineralized and of poor quality, with an average total dissolved solids concentration of 1,300 mg/liter. This water is marginally suitable to unsuitable for domestic supplies, but is used where better quality water is not available.

3.4 **ENGINEERING CHARACTERISTICS OF OVERBURDEN.** The permeability of the alluvial aquifer was determined to be 2.07×10^{-1} to 3.88×10^{-1} cm/sec, based upon pump tests performed by the Corps of Engineers. Select material was chosen over native material for backfilling the trench to decrease permeability of the barrier. Cemented zones in the alluvium caused some difficulty in well drilling, but little in trench excavation. Cobbles and small boulders (to 16 inches) were encountered in discharge and recharge wells throughout the aquifer, which seriously impeeded drilling.

3.5 **ENGINEERING CHARACTERISTICS OF BEDROCK.** The permeability of the upper Denver Formation claystones was found to be 4.7×10^{-6} cm/sec in the vertical direction and 0.19×10^{-6} cm/sec in the horizontal direction, (WES, 1982 "Hydrogeology of Rocky Mountain Arsenal, Colorado") indicating an increase of permeability in the vertical movement of water. This increase was attributed to joints, fractures, and weathering in this direction, and was a major basis for keying the barrier into a significantly less weathered zone several feet into the claystone. Based on a slug test run on Well 5A (See Plate 3 for location), the coefficient of permeability of the sandstone lenses was calculated to be 4 to 5×10^{-5} cm/sec. As this would allow contaminated ground water to flow under the barrier through the sandstone units, the decision was made to remove the sandstone while excavating the trench.

CHAPTER 4. - EXCAVATION PROCEDURES

4.1 **GENERAL EXCAVATIONS.** Standard excavation methods were used on structure excavations using backhoes and tracked dozers. Scrapers and graders were used to build roads and working surfaces. Equipment used for the project is listed in Table 4-1.

TABLE 4-1 - EQUIPMENT

Model No.	Type
Cat 623B	Scraper
Cat DW10	Scraper
Cat 12	Grader
Cat D8K	Dozer
Komatsu D65E	Dozer
Allis-Chalmers HD16	Dozer
Cat C920	Front End Loader
John Deere JD510	Front End Loader
Dyanhoe 190	Front End Loader
Ford A-62	Front End Loader
Case 1450	Front End Loader
TCI H4M80	Torque Converter
Cat C815B	Sheepsfoot Compactor
Hyster	Sheepsfoot Compactor
Cat C215	Backhoe
Link-Belt LS-7400A	Backhoe
Kelley K12	Reverse Rotary Drill
Port-A-Drill 522	Air-Foam Rotary Drill
CME-45	Auger Drill
Atlas-Copco	O-Dex Rotary Drill

4.2 **SCHEDULING.** Installation of the treatment system building and recharge wells was concurrent with trench excavation. As RMA would not allow any pumping until the entire system was complete, all phases of construction were independent of one another, excepting the requirement that Discharge Well DW-10 and Piezometers P-4 and P-11 be installed after trench construction. Barrier construction was a priority, as no backfill was to be mixed or placed when the air temperature was below 20 degrees Fahrenheit.

4.3 **EXCAVATION GRADES.** Excavation was to the lines and grades as shown on the drawings in Plates 16 and 18 through 21, excluding the changes discussed in the following paragraphs.

The minimum excavation line for the slurry trench was used as a guideline. Actual termination depth was determined by the Corps inspector after examining bedrock samples as described in paragraph 2.2.2. Actual termination depths generally ranged from 2 to 4 feet below the minimum excavation, with Station 25+50 requiring 12 feet of excavation below the minimum excavation line.

Of the 36 wells drilled on site, 24 wells had field adjustments from the design depth, which is common for well designs. See Plate 10 for well details.

Recharge Well RW-15 contained only 4 feet of poor quality aquifer and produced 1.5 gpm during test pumping. It was abandoned and RW-15A was drilled 50 feet to the northeast. It was also a nonproducing well and was subsequently abandoned. Well RW-15B was intalled 50 feet southwest of the original RW-15. It is a successful well, producing 160 gpm.

Discharge Well DW-11 produces 6 gpm. The calculated design capacity was 25 gpm. The well was not relocated as the aquifer quality deteriorates towards DW-12 as per exploratory borings, and any movement to the south would adversely effect the capacity of Well DW-10. The wells adjacent to DW-11 are capable of pumping over design capacity to compensate for its low production.

4.4 WELL DRILLING. Alluvial discharge and alluvial recharge wells were drilled for the project by the reverse circulation rotary method using a Kelly K-12 drill rig (see Photo No. 3) with 6-inch drill pipe and Moab bit. A 16-inch diameter bit was used for the discharge wells, and a 26-inch bit for the recharge wells. A 2,500 pound drill collar with tri-cone roller rock bit was utilized for drilling through heavily cemented zones and cobbles in the aquifer. Well designs are shown on Plate 10. In general, materials encountered during drilling of the wells corresponded with the preconstruction borings. A major exception was the occurrence of cobbles and small boulders (to 16 inches) throughout the aquifer in nearly every well drilled.

The use of augers and 2- and 3-inch split spoon samplers in the preconstruction borings did not allow for the recovery of these larger diameter materials.

Both the alluvial discharge and recharge wells were drilled by the reverse circulation rotary method using only clean, clear water as a drilling fluid. This particular drilling method and fluid was used to prevent clogging of the aquifer. The reverse circulation rotary method worked well except in zones of cobbles, where the drill pipe, valves, and pump tended to trap the objects. A rock bailer was used to remove loose cobbles and boulders from the drill hole. Drilling rates were significantly slowed during such encounters.

4.4.1 **WELL TESTING AND DEVELOPMENT**. The discharge and recharge wells were developed as follows: air-water jetting for a minimum of three cycles using the jetting tool shown in Photo 26, 2 hours of pumping, disinfection with sodium hypochlorite to a concentration of 1,000 ppm, followed by a 4-hour pump test after a minimum of 24 hours. In addition, percolation tests were conducted on the recharge wells. Test data is compiled in Tables 4-2 and 4-3.

Piezometers were drilled with a CME-45 equipped with 7-inch hollow stem continuous flight augers.

TABLE 4-2 - WELL TESTING AND DEVELOPMENT

Well No.	Screen Depth	Initial W.L.	Final W.L.	GPM
RW-1	33.0-54.0	28'2"	30'6"	200
RW-2	32.0-53.0	27'5"	31'0"	200
RW-3	30.0-51.0	27'5"	30'6"	200
RW-4	29.0-49.0	30'0"	38'2"	200
RW-5	30.0-50.0	28'0"	30'1"	200
RW-6	30.6-50.6	28'0"	31'1"	200
RW-7	33.0-52.0	25'1"	31'6"	200
RW-8	32.0-50.0	26'0"	29'0"	200
RW-9	29.0-44.0	27'0"	35'4"	200
RW-10	32.0-45.0	27'2"	33'2"	200
RW-11	32.0-43.0	27'0"	35'1"	110
RW-12	35.0-43.0	28'0"	34'8"	180
RW-13	34.0-44.0	27'0"	35'0"	75
RW-14	32.5-44.5	28'7"	33'0"	145
RW-15B	42.5-48.0	33'5"	40'0"	160
RW-16	37.0-45.0	35'1"	40'0"	55
RW-17	35.0-45.0	36'0"	39'0"	100
RW-18	38.0-46.0	36'6"	40'5"	75
RW-19	35.0-44.0	38'0"	42'2"	75
RW-20	40.0-49.0	37'0"	38'7"	100
RW-21	43.0-49.0	39'6"	42'0"	60
DW-1	38.0-56.0	30'0"	37'4"	150
DW-2	32.0-55.0	31'0"	36'3"	150
DW-3	39.0-57.0	31'25"	48'1"	200
DW-4	42.0-59.0	33'0"	45'1"	200
DW-5	40.0-56.0	29'5"	38'1"	200
DW-6	37.4-54.0	31'0"	34'9"	200
DW-7	37.0-54.0	30'0"	34'3"	200
DW-8	36.0-54.0	30'0"	33'7"	200
DW-9	37.0-52.0	33'3"	36'8"	150
DW-10	42.0-50.0	34'0"	41'4"	100
DW-11	44.0-49.0	37'0"	46'0"	6
DW-12	41.0-46.0	42'0"	44'1"	40
DW-13	32.0-40.0	34'0"	36'1"	35
DW-14	41.0-48.0	38'0"	40'5"	25
DW-15	42.0-49.0	38'4"	41'7"	30

TABLE 4-3 - RECHARGE WELL PERCOLATION TEST

Well No.	Static Water Level	Gallons Added	Recovery Time
RW-1	28'2"	4,000	45 sec.
RW-2	28'5"	3,000	30 sec.
RW-3	30'5"	2,250	2 min.
RW-4	38'2"	2,300	1 min.
RW-5	28'0"	2,300	45 sec.
RW-6	28'0"	2,300	45 sec.
RW-7	25'1"	2,300	45 sec.
RW-8	26'0"	2,300	2 min.
RW-9	27'0"	2,300	2 min.
RW-10	27'2"	2,300	3 min.
RW-11	27'0"	2,300	4 min.
RW-12	28'0"	2,300	2 min.
RW-13	27'0"	2,300	5 min.
RW-14	28'7"	2,300	4 min.
RW-15B	33'5"	2,300	4 min.
RW-16	35'1"	2,300	4 min.
RW-17	37'0"	2,300	3 min.
RW-18	36'6"	2,300	5 min.
RW-19	38'0"	2,300	3 min.
RW-20	37'0"	2,300	1 min.
RW-21	39'6"	2,300	5 min.

4.4.2 **PIEZOMETER TESTING AND DEVELOPMENT.** Piezometers were disinfected with sodium hypochlorite to achieve a 400 ppm concentration and were left undisturbed for a minimum of 24 hours. Two well volumes of water were then removed by bailing. Recovery rates are recorded in Table 4-4.

TABLE 4-4 - PIEZOMETER TESTING AND DEVELOPMENT

Piezometer No.	Screen Depth	Static W.L.	Bailing & Recovery Recovery Time
P-1	35.5-55.5	33'7"	6 min.
P-2	39.0-58.0	36'0"	3 min. 30 sec.
P-3	35.5-54.5	34'0"	5 min. 25 sec.
P-4	41.0-49.0	36'6"	7 min.
P-5	41.0-49.0	37'0"	11 min. 5 sec.
P-6	37.0-45.0	38'7"	7 min. 10 sec.
P-7	37.0-45.0	38'4"	5 min.
P-8	41.0-50.0	41'6"	12 min. 45 sec.
P-9	41.0-50.0	41'6"	15 min.
P-10	30.0-35.0	31'2"	8 min. 20 sec.
P-11	30.0-35.0	31'0"	4 min. 50 sec.
P-12	33.0-54.0	33'0"	9 min. 30 sec.
P-13	35.0-51.0	31'1"	2 min.
P-14	34.0-46.0	34'0"	7 min. 10 sec.
P-15	32.0-42.0	35'0"	9 min. 15 sec.
P-16	42.0-51.0	44'0"	8 min. 35 sec.
22-13	34.0-44.0	37'8"	9 min.

4.5 **BARRIER CONSTRUCTION.** The working surface for the barrier was made by standard cut and fill methods, using scrapers, graders, and dozers. Minimal fill was required.

Dry sodium bentonite was supplied in 50 pound bags and mixed with potable water (supplied by a temporary 4-inch water line) in a 5 cubic yard collidal mixer with a diesel-powered pump. Slurry storage ponds were not used as the mixer was capable of producing 1,000-gallon batches in 10 to 15 minutes. Slurry was pumped from the mixer to the trench by the use of a centrifugal pump and a 6-inch temporary piping system.

4.5.1 **TRENCH EXCAVATION.** The slurry trench was excavated with an FMC Link Belt LS-7400A backhoe with an extended boom to allow excavation to 55 feet (Photos 1 and 2). The bucket used was nonperforated, with the exception of two holes that allowed the release of the vacuum formed by the wet overburden. Initial excavation began 50 feet northeast of the plan starting station and was sloped down to full depth at the starting point. This enabled placement of backfill by sliding it down the slope and eliminated the need for a clamshell or tremie for initial backfill placement. Slurry was pumped into the trench and generally maintained within 2 feet of the working surface by adding slurry as the excavation progressed.

4.5.1.1 **SLURRY TESTING.** The slurry used in the excavation and backfill of the barrier was a mixture of ultrafine natural sodium cation-based montomorillonite clay and potable water. Slurry properties were tested following the American Petroleum Institute (API) Code RP13B. Initially, the slurry was tested four times daily. Testing showed that the slurry properties changed very little in the course of a day; subsequently testing was reduced to twice daily. The slurry in the trench was sampled at intervals of every 10 feet of depth and at 50-foot horizontal intervals. Tests required were: density (not less than 64 pounds per cubic foot), filtration (not greater than 20 cc at 100 psi in 30 minutes), viscosity (not less than 40 seconds at 65 degrees F.), and sand content. Prior to mixing the slurry with backfill material, density was to be not less than 70 pounds per cubic foot nor greater than 85 pounds per cubic foot. Slurry from the trench had an average viscosity of 44 seconds, density of 77 pounds per cubic foot, filtrate of 20 cc, and sand content of 10 percent. Slurry was used directly from the mixer for blending with backfill.

4.5.2 **TRENCH BACKFILL.** A dike was formed along the trench to prevent unblended material from flowing in. The select backfill material was mixed with fresh slurry by tracking and blading with dozers, and was then tested as described in Chapter 2. The blended backfill was then pushed from the working surface into the trench, allowing it to slide down the initially inclined surface, and later down the surface of the previously placed backfill. The toe of the backfill lagged behind the trench excavation by a maximum of 100 feet. Backfill was sounded twice daily to determine sliding and settlement. The backfill was capped by a minimum of 1-1/2 feet of relatively impervious material within 3 days after the backfill reached the top of the slurry trench. Bulldozers placed the material and it was compacted in 12-inch thick layers with a sheepsfoot compactor to a dry density of 95 percent of maximum density at optimum moisture (within 2 percent).

4.5.2.1 **BACKFILL TESTING.** Backfill consisted of a mixture of slurry and select soil. Gradation tests were taken for every 300 cubic yards of fill placed in the trench. Procedures for the gradation analyses were according to ASTM C 136-81, and were to conform with the following requirements:

Screen Size or Number (U.S. Standard)	Percent Passing By Dry Weight
3-inch	100
1-1/2-inch	95-100
3/4-inch	80-100
No. 4	50-100
No. 30	25-70
No. 200	12-35

Test results are shown in Table 4-5.

Slump tests were performed twice daily on the backfill mixture just prior to placement in the trench. Testing was according to ASTM C 143-78, with an allowable slump range from 2 to 5 inches.

TABLE 4-5. BACKFILL GRADATION ANALYSIS

Sieve	Spec.	10/3	10/6	10/11	10/12	10/17	10/25	10/27	10/29	11/09
3"	100%	100	100	100	100	100	100	100	100	100
1-1/2"	95-100%	100	100	100	100	100	100	100	100	100
3/4"80-100%	80-100%	100	100	100	100	100	100	100	100	100
No. 4	50-100%	98	98.4	98.5	98	98.2	97.5	97.6	97.6	96.2
No. 30	25-70%	76.2	70.6	80.4	78.6	72.9	76.7	71	70.1	56.3
No. 200	12-35%	13.4	21.7	30.7	28.6	18	22.7	16	16.4	32.3

Backfill permeability determinations were made on undisturbed samples obtained from the completed trench in accordance with ASTM D 1587. A 7-inch diameter hollow stem auger was used to advance the hole to sampling depth. Three-inch diameter Shelby tube samples were obtained from 10.0 to 12.5 feet below the surface. One sample was recovered and tested for each 300 linear feet of backfilled slurry trench. Samples were tested for permeability in accordance with EM 1110-2-1906, Appendix VII, Back-Pressure Method. Test results are compiled in Table 4-6.

TABLE 4-6 - BACKFILL PERMEABILITY

Sample No.	Station No.	Coefficient of Permeability (CM/Sec)
1	22+50	2.9x10-8
2	13+50	3.1x10-8
3	19+50	6.6x10-8
4	16+50	1.8x10-8

4.6 BLASTING. Bath Excavating and Construction was hired by Geo-Con to remove two lenses of argillaceous sandstone from Stations 18+50 to 17+99 and 17+50 to 16+64. HD detaprime caps and primacord were used to detonate 1-3/4 inch by 16-inch DuPont "Tovex" water gel with a 25 millisecond delay between holes. The two blasts used patterns of 2-inch thinwall PVC cased holes in two rows on 3.6-foot centers with 3 feet between the rows. Blasting information is listed in Table 2-1.

4.7 SAFETY PRECAUTIONS. Standard safety procedures were followed as per the Corps of Engineers' Safety and Health Requirements Manual, EM 385-1-1. When blasting was performed, RMA Security was notified of each imminent blast. No explosives were stored on site.

CHAPTER 5. - CHARACTER OF FOUNDATION

5.1 **GENERAL**. Conditions encountered during construction have been described in Chapter 3. The specific locations of each condition as determined from trenching and well drilling operations are discussed below.

5.2 **CEMENTED ZONES**. Occasional calcuim carbonate cemented zones of sand and gravel were encountered in several of the discharge and recharge wells at the northeast end of the line (Plates 13 through 16). The random zones were moderately hard to hard, and ranged from 6 inches to 6 feet in thickness. There was minimal impact on trenching, but some difficulty in drilling when such zones were encountered.

5.3 **COBBLES AND BOULDERS**. Cobbles and small boulders were encountered throughout the aquifer. The effect of this material on slurry trench excavation was negligible. They did, however, cause serious delay in drilling operations. The cobbles and boulders lodged in the bit intake, return valve in the Kelley, and in the pump (Photo No. 22). The contractor filed a claim and was compensated as the Government considered the number and location of the cobbles a type one differing site condition (see Appendix A).

5.4 **DENVER FORMATION SANDSTONES**. Two lenses of very hard blue-gray sand-stone were encountered along the slurry trench between Station 18+25 and Station 16+64, as shown on Plate 16. The total sandstone thickness ranged from 1 to 13 feet, at depths of 38 to 51 feet. Blasting was required to fracture the rock prior to removal. Excavation continued below the bottom of the sandstone to assure a tie-in with the clay shale bedrock.

5.5 **CLAY SHALE**. The uppermost layers of clay shale bedrock are highly fractured and moderately to very weathered to depths of up to 5 feet into the rock. Below this, the rock is essentially unweathered.

CHAPTER 6. - POSSIBLE FUTURE PROBLEMS

6.1 **POTENTIAL PROBLEM CONDITIONS.** Aside from mechanical failure, which is beyond the scope of this report, potential conditions which could produce problems with the effectiveness of the containment/treatment system are discussed below.

Zones of high permeability occurring as windows in the slurry trench backfill could allow seepage of contaminated ground water through the barrier. Windowing could occur by sloughing of portions of the trench sides during excavation, sand layers settled out of the slurry, or pockets of unblended backfill. Any of these could allow a higher permeability zone through the trench, and would be difficult to locate upon completion of construction.

Isolated seepage through permeable sand lenses, fractures, or lignite seams in the Denver Formation below the depth of the barrier could allow leakage beneath the barrier.

Any cemented sands or fractured rock remaining at the base of the trench could also allow leakage beneath the barrier.

Unexpected high ground water levels could overtax the dewater/recharge system. This is unlikely under the range of expected situations for which the system was designed. The possibility for such an occurrence does exist under a combination of conditions such as a high ground water level and heavy precipitation combined with a prolonged shutdown of the system, where ground water could build up along the barrier until the system was again operational.

6.2 **RECOMMENDED OBSERVATIONS.** The system as designed will require periodic maintenance. Constant observation is recommended as follows:

(1) Regular readings of piezometers and wells down gradient of the barrier should indicate the total effectiveness of the system, and would provide indications of problem areas of the barrier.

(2) Monitoring of wells and piezometers on the up gradient side of the system is also essential. Readings here could provide information on pre-treatment contaminant levels and possibly on migrating ground water patterns as well. Additional monitoring wells could be installed as required to detect any change in shape or depth of the contamination plumes.

(3) Regular inspection of the surface of the slurry wall is recommended. Slumps or depressions along the surface of the barrier may be an indication of a "window" condition caused by improper backfill. Saturated surface conditions might indicate ineffective dewater/recharge system function.

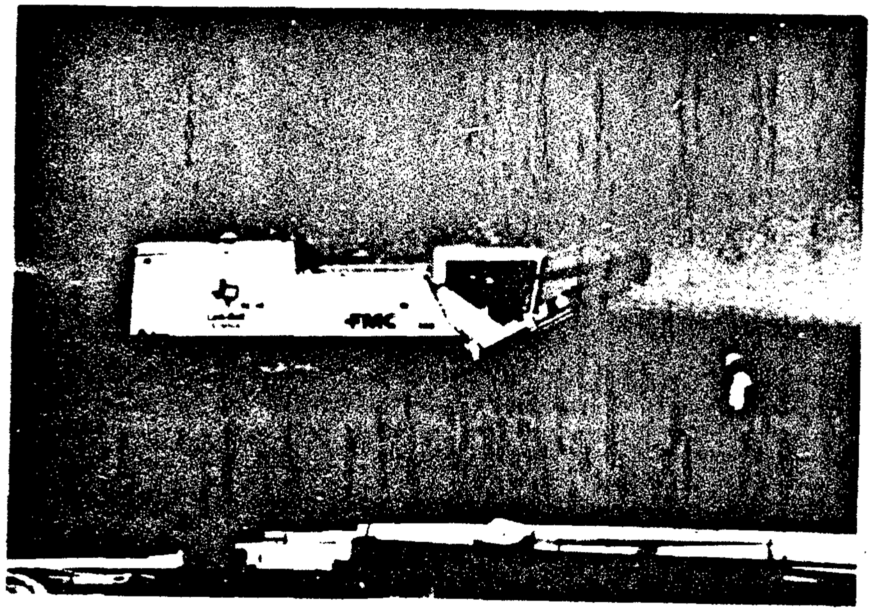
APPENDIX A

Contract Modifications

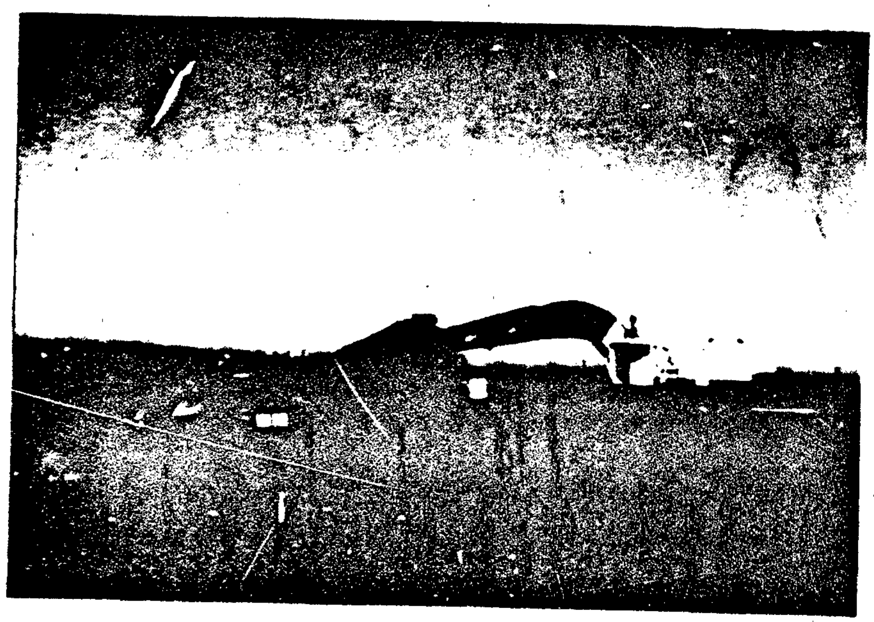
CONTRACT MODIFICATIONS

Mod.	Description	Cost
P00001	Delete booster pump. Provide flow controls on emergency showers. Provide pressure reducing valve.	$5,519
P00002	Add bends at valve pit.	$2,703
P00003	Claim--Cobbles in wells.	$97,175
P00004	Relocate two power poles.	$1,382
P00005	Not executed.	-----
P00006	Not executed.	-----
P00007	Extend contract 5 days.	No cost
	Total Mod Costs	$ 106,799
	Contract Bid	2,641,580
	Total Cost	$2,748,359

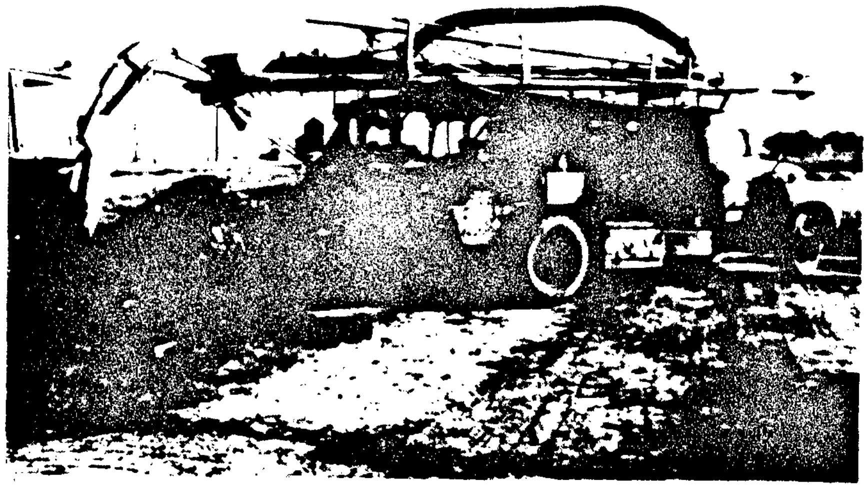
PHOTOGRAPHS



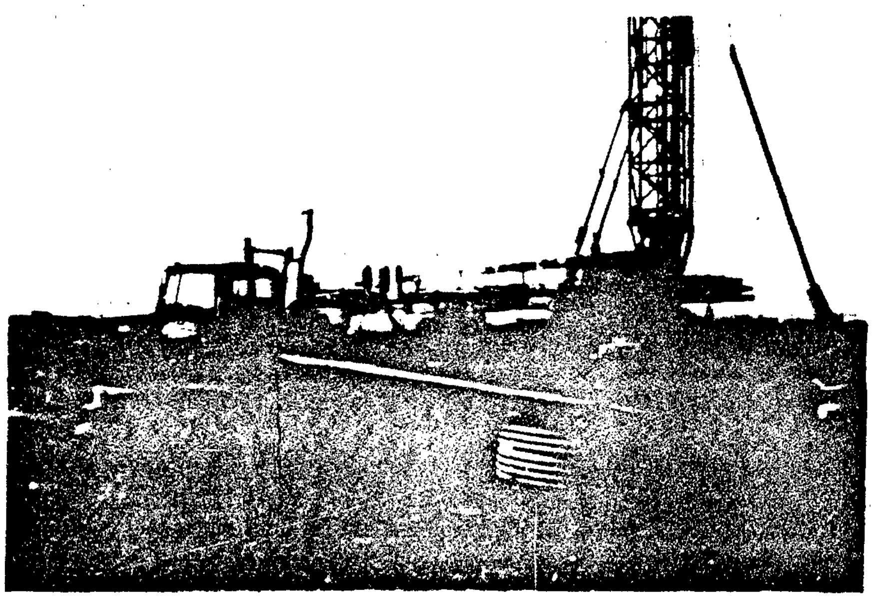
Photograph 1. FMC Link-Belt LS-7400 A, used for slurry trench excavation.



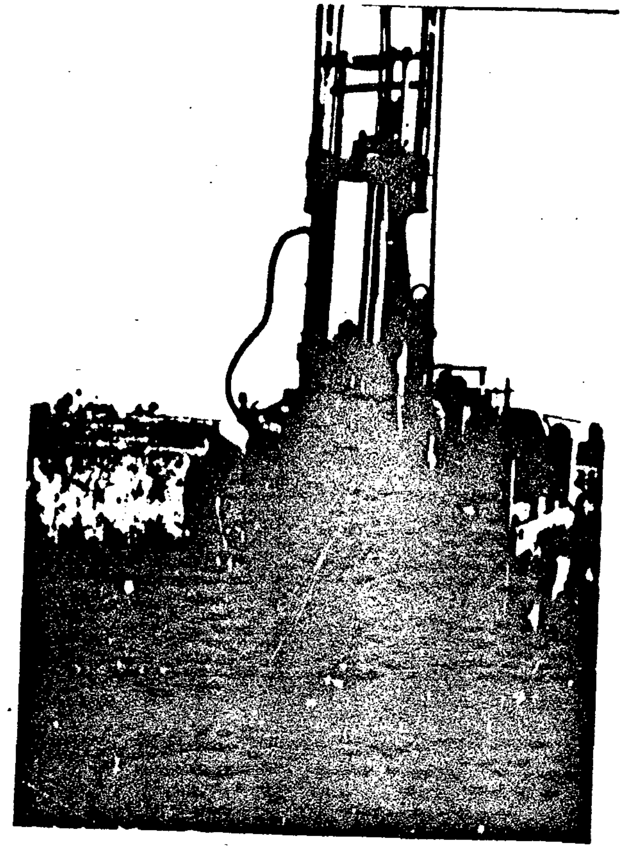
Photograph 2. LS-7400 A with 55 foot dipper stick and boom.



Photograph 3. Kelley K12 Reverse Circulation Rotary Drill used for well drilling.

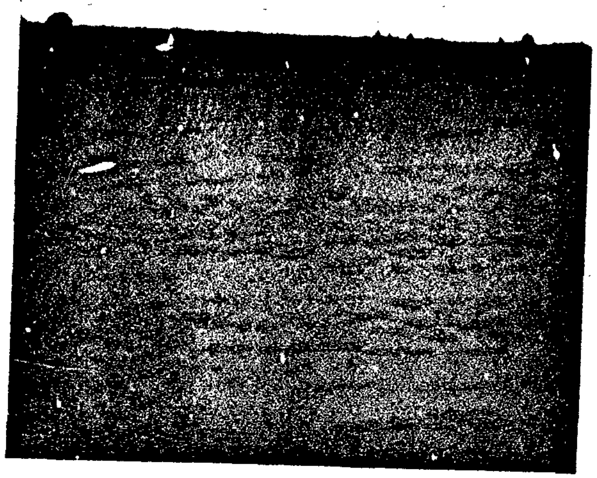


Photograph 4. Port-A-Drill Air-Foam Rotary Drill used for well development.



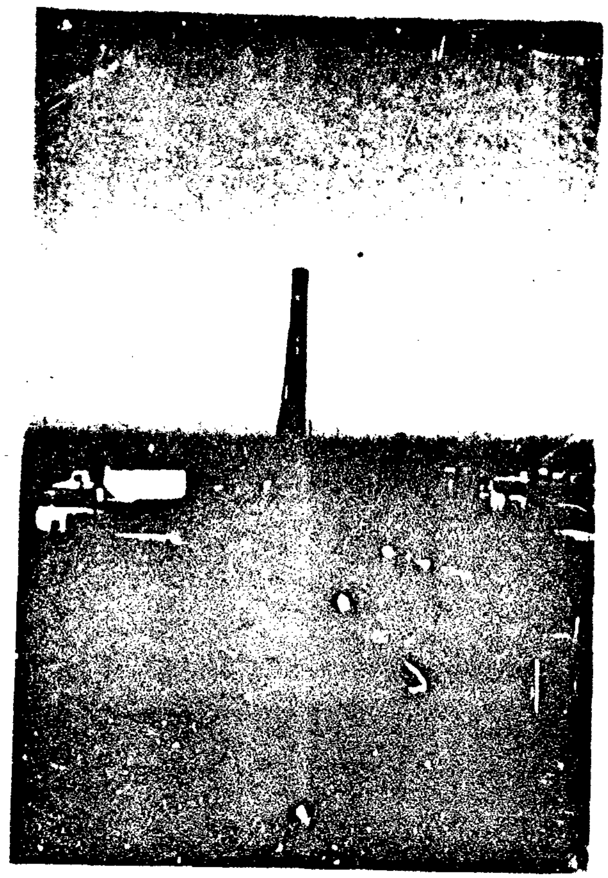
Photograph 5.

CME-45 Auger Drill used for piezo-
meter installation.



Photograph 6.

Preparing slurry trench working
surface, looking southwest from
Station 22+50.

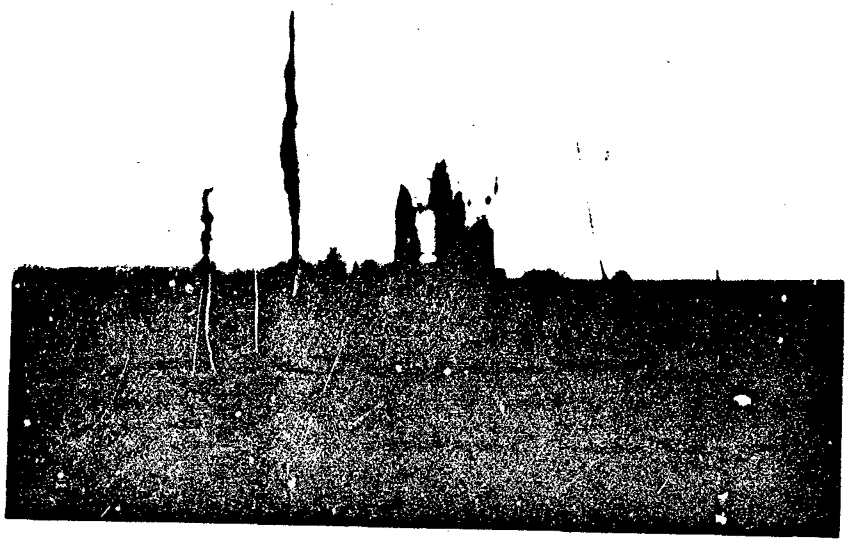


Photograph 8.

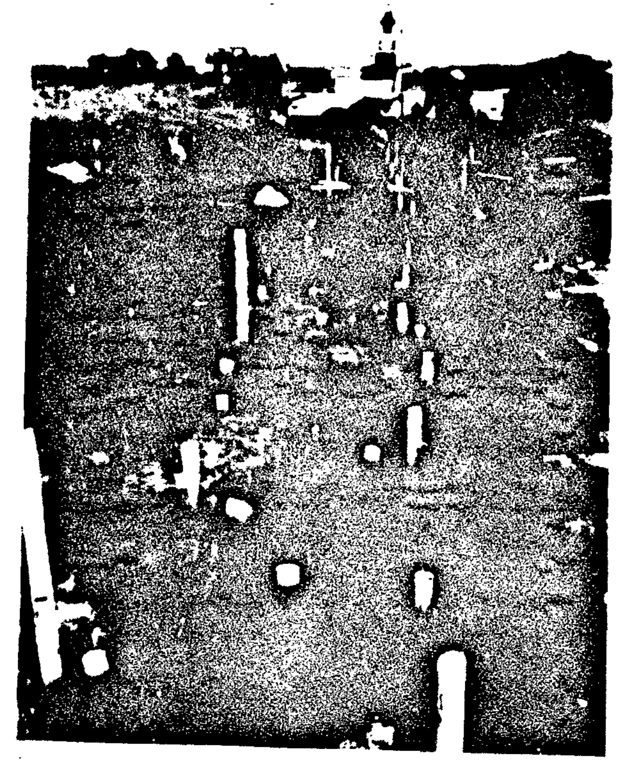
Blast hole drilling at Stations 18+50 to 17+99 and 17+50 to 16+64, looking southwest.

Photograph 7.

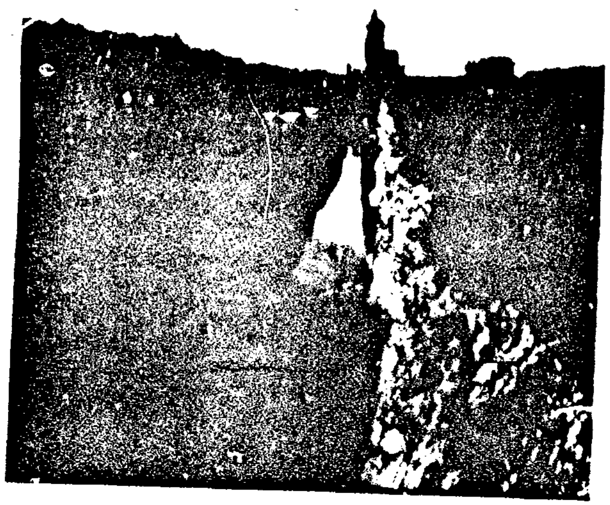
Slurry trench working surface, looking northeast from Station 22+50.



Photograph 10. Blasting sandstone lenses along slurry trench.

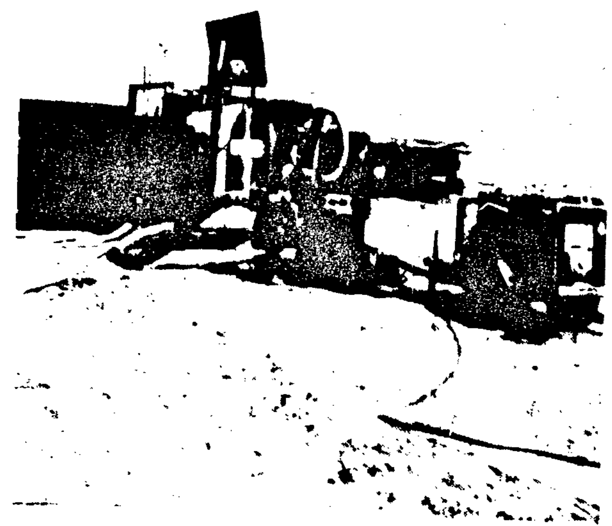


Photograph 9. Loading blast holes.



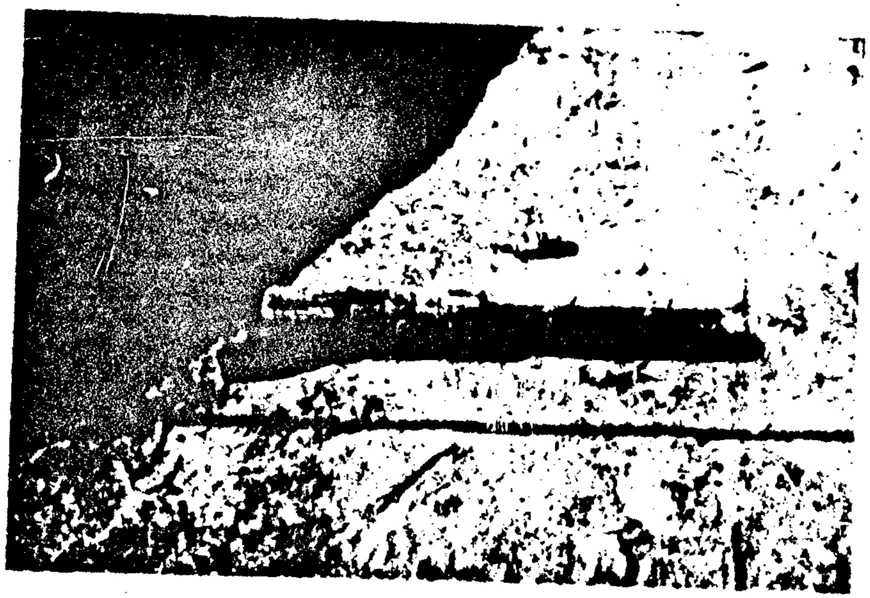
Photograph 12.

Slurry trench excavation, looking southwest from Station 14+00.



Photograph 11.

Colloidal Slurry mixer and pump for mixing bentonite.

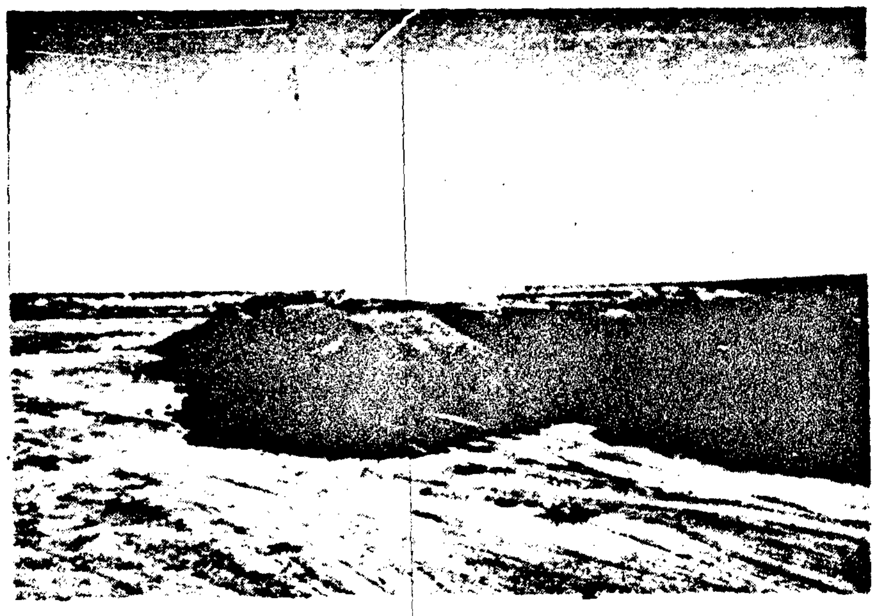


Photograph 14.

Bedrock Sampler

Photograph 13.

Slurry trench excavation, looking northeast from Station 12+00.



Photograph 15. Backfill material for slurry trench.

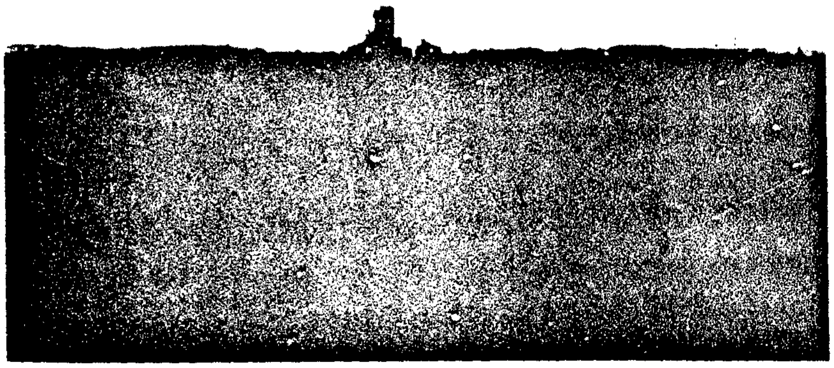
Photograph 16. Mixing backfill and slurry.

Photograph 18.

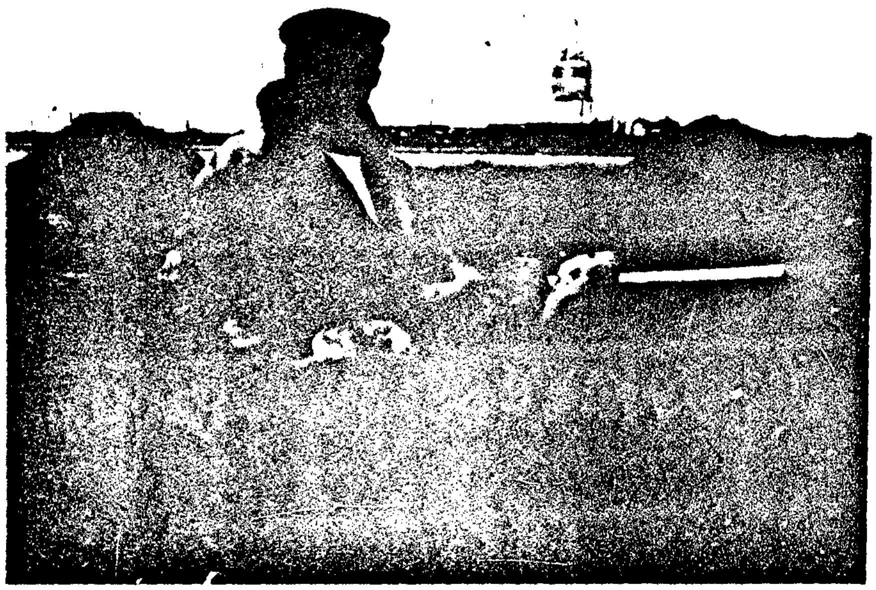
Placement of backfill in trench with dozer, Station 25+50.

Photograph 17.

Slump testing backfill for trench.



Photograph 19. Capping trench, looking south-west from Station 25+00.

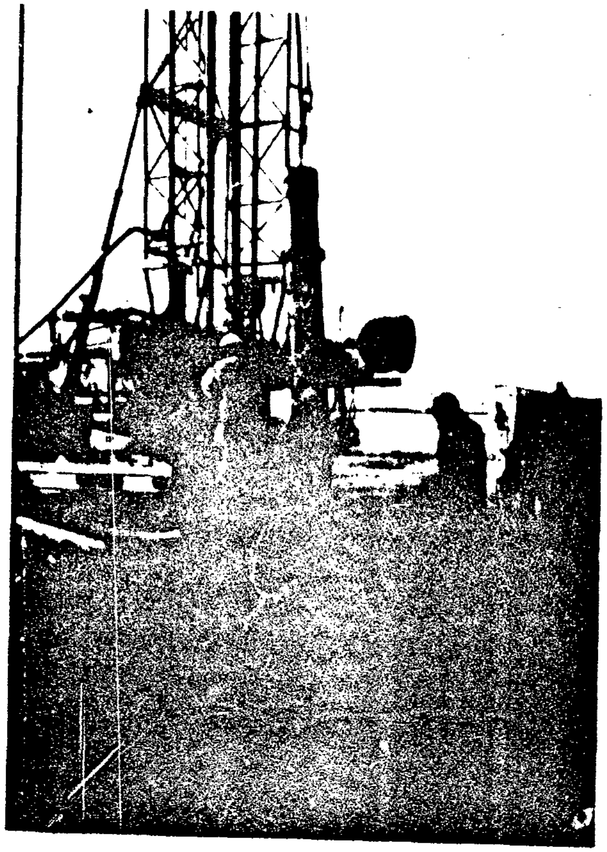


Photograph 20. Cobbles from DW-2.

Photograph 22.

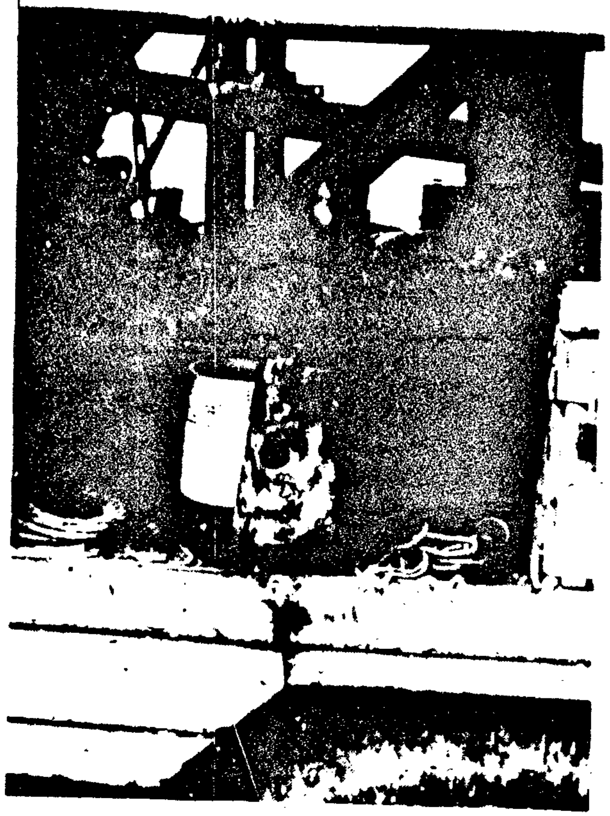
Cobbles from top of aquifer of DW-3 will not go through drill rod.

Photograph 21. Cobbles removed from DW-2.



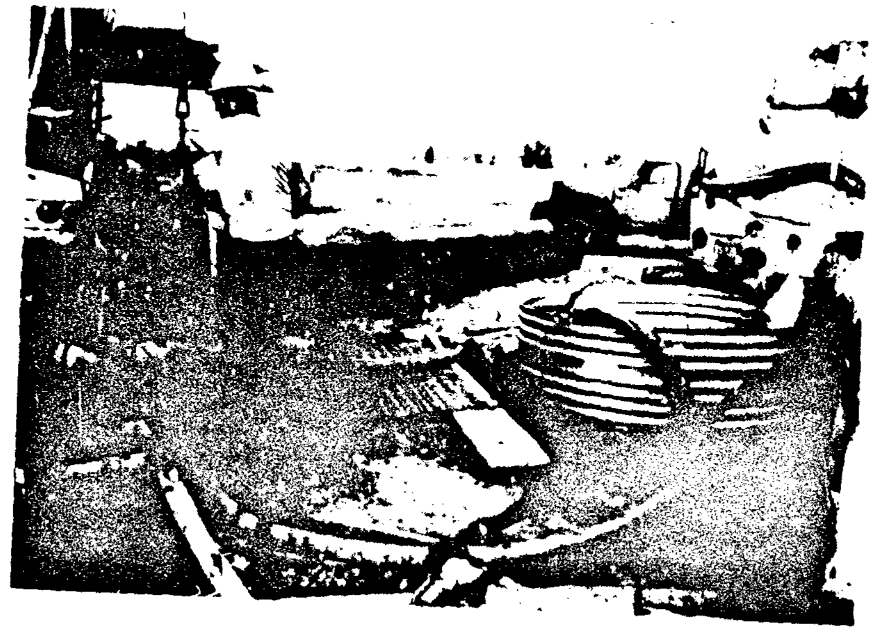
Photograph 24. Placing well screen.

Photograph 23. Recharge well screen with tail-pipe.

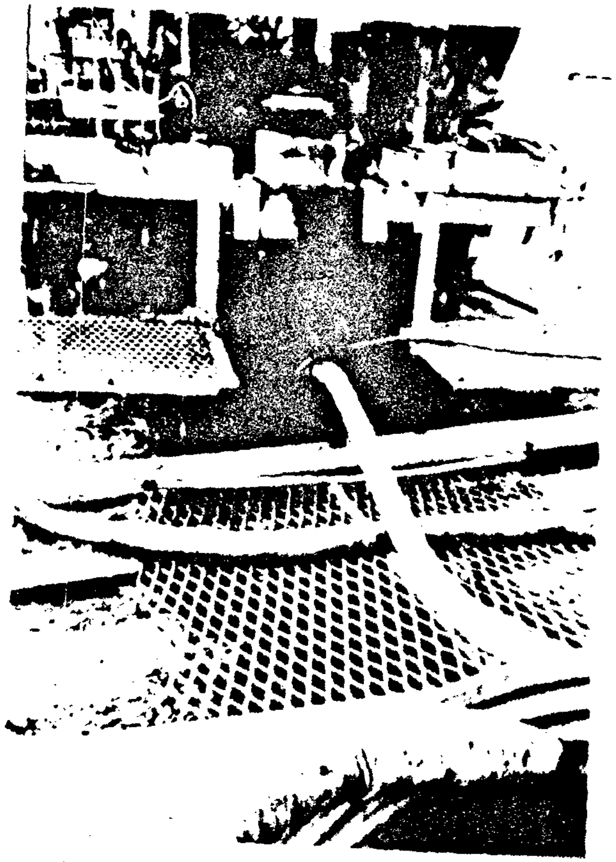


Photograph 26. Jetting tool for well development.

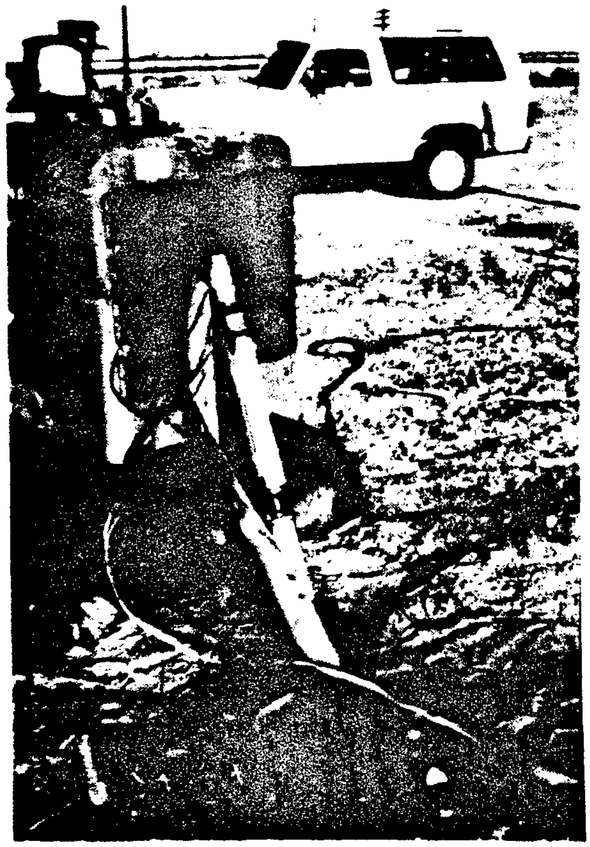
Photograph 25. Installing riser.



Photograph 27. Well development setup.



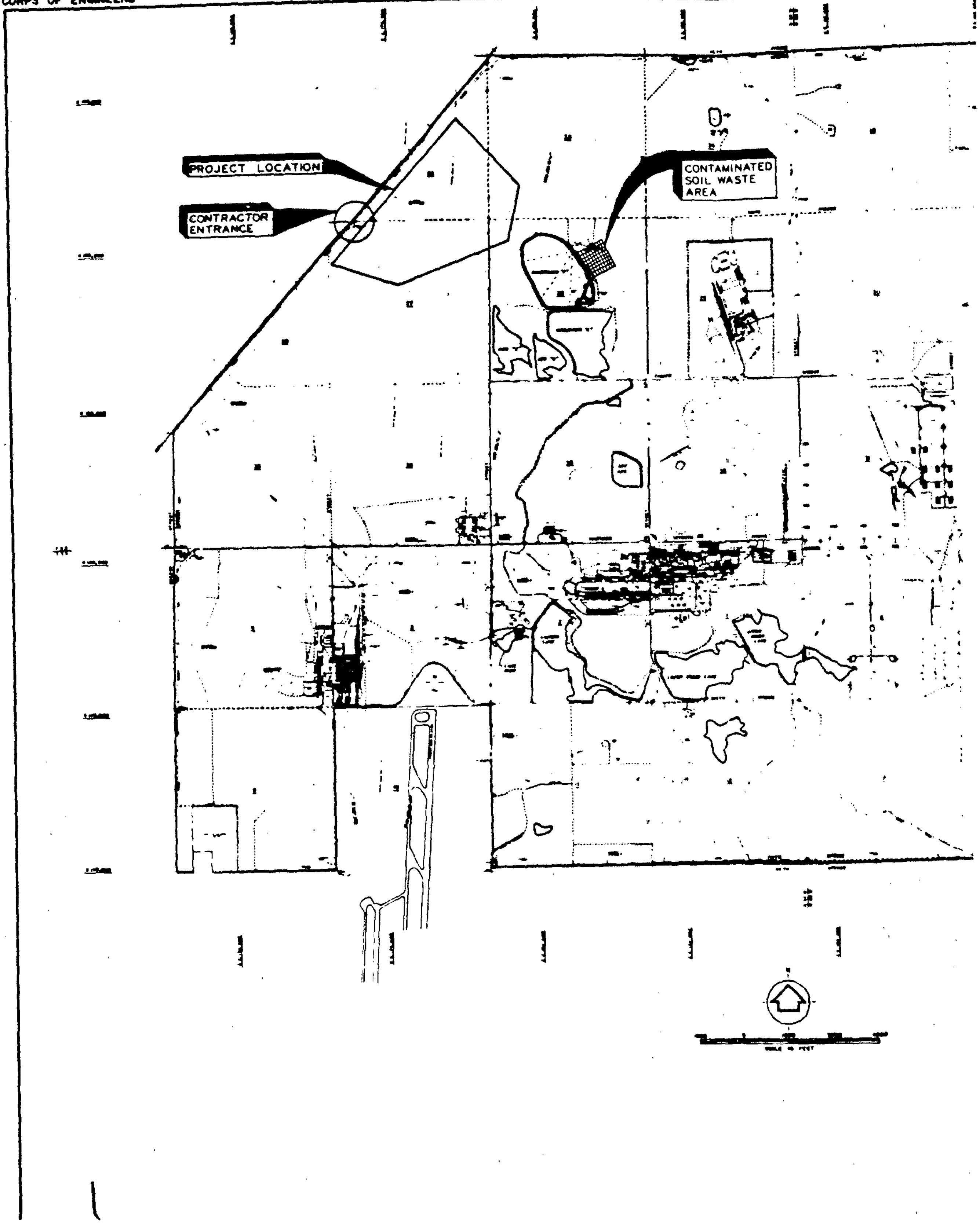
Photograph 28. Well development setup.



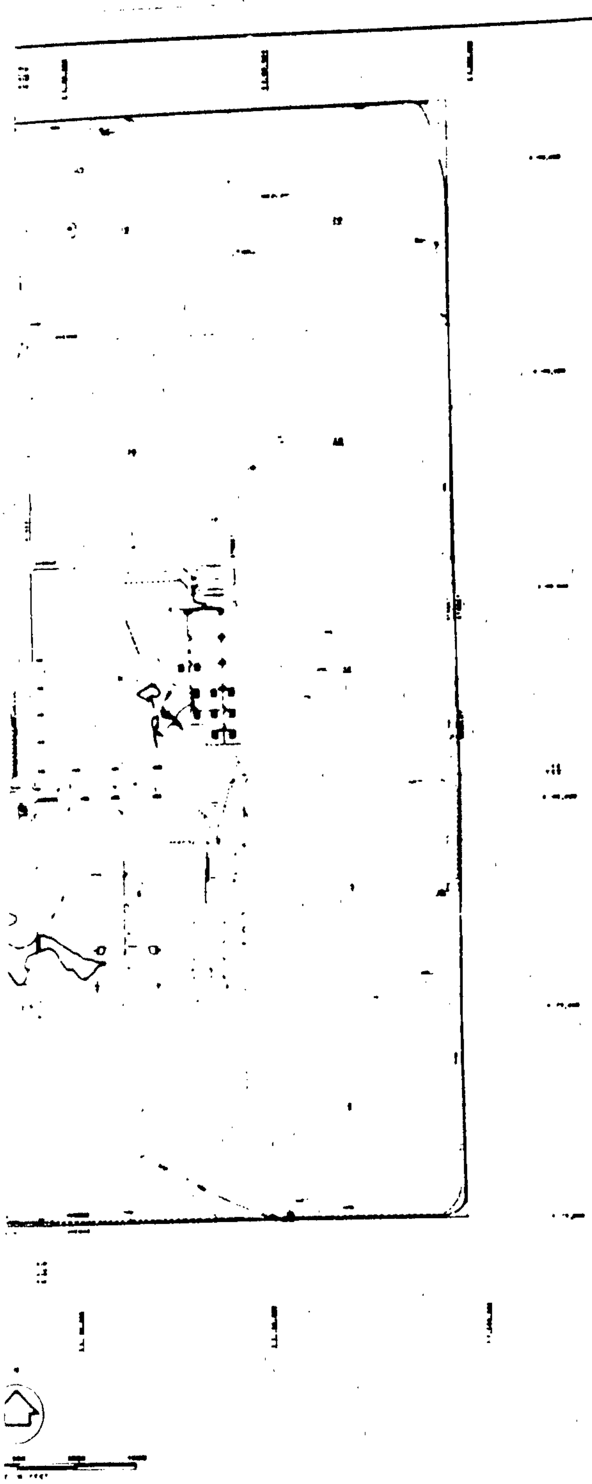
Photograph 29. 2½ h.p. submersible pump for pump test.

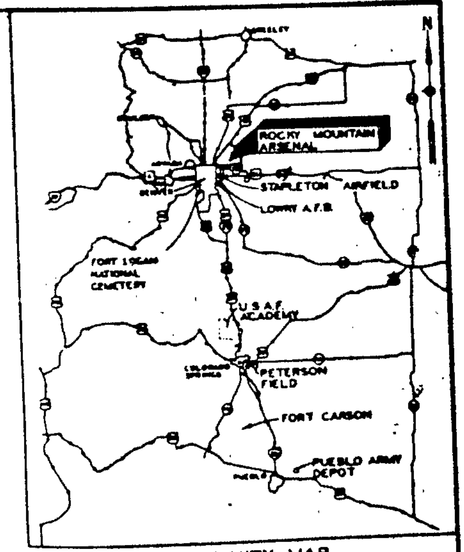
PLATES

CORPS OF ENGINEERS



U. S. ARMY





VICINITY MAP
NO SCALE.

NOTE

Exact location of Contaminated Soil Waste Area shall be coordinated with the Contracting Officer.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

NORTHWEST BOUNDARY CONTAINMENT
LOCATION PLAN

F 841-40-01

2

... REPORT (1984) PLATE 1

SOIL CLASSIFICATIONS

SYMBOL	LETTER	DESCRIPTION
	GW	Well graded gravels or gravel-sand mixtures. Little or no fines
	GP	Poorly graded gravels or gravel-sand mixtures. Little or no fines
	GM	Silty gravels. Gravel-sand-silt mixtures
	GC	Clayey Gravels Gravel-sand-clay mixtures
	GM-GW	Dual Classification
	GM-GP	Dual Classification
	SP	Poorly graded sands or gravelly saInds. Little or no fines
	SW	Well graded sands or gravelly sands. Little or no fines
	SM	Silty Sands. Sand-silt mixtures
	SC	Clayey sands. Sand-clay mixtures
	SM-SC	Dual Classification
	SM-SP	Dual Classification
	ML	Inorganic silts and very fine sands. Rock flour silty or clayey fine sands or clayey silts with slight plasticity
	CL	Inorganic clays of low to medium plasticity gravelly clays, sandy clays, silty clays lean clays
	ML-CL	Dual Classification
	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of medium to high plasticity
	SM-SW	Dual Classification

ROCK CLASSIFICATIONS

	Sandstone, silty or clayey sandstone
	Clay Shale

CLAY CONSISTANCY

CHARACTERISTIC	DESCRIPTION	EQUIVAl S.P.T. BLOWS
Very soft	without form	
Soft	Readily deformed by fingers with light pressure or easily squeezed through fingers.	2-
Medium stiff	Easily deformed by fingers with moderate pressure, but cannot be squeezed through fingers.	4
Stiff	Deformed with difficulty by fingers. A pencil jabbed into the sample will penetrate and tend to stick.	8-
Very Stiff		15
Hard	Can be gouged by fingernail. A pencil jabbed into the sample will penetrate slightly, but does not tend to stick	3

DENSITY (SILT AND SAND)

CHARACTERISTIC	S.P.T. BLOWS/ FT.
Loose	< 10
Medium Dense	10-30
Dense	30-50
Very Dense	> 50

ROCK-STRUCTURE

CHARACTERISTIC	DESCRIPTION
Fragmented	Samples completely broken up (Most likely mechanically induced)
Friable	Crumbles naturally or is easily broken pulverized or reduced to powder
Highly Fractured	Fractures spaced generally less than 4 inches apart.
Fractured	Fractures spaced generally between 4 inches and 1 foot apart.

ROCK - HARDNESS

CHARACTERISTIC	DESCRIPTION
V. Soft	Can be deformed by hand
Soft	Can be scratched with fingernail.
Moderately Hard	Can be scratched easily with a knife.
Hard	Difficult to scratch with a knife.
Very Hard	Cannot be scratched with a knife.

BEDROCK WEATHERING

CHARACTERISTIC	DESCRIPTION
Highly Weathered	Rock is reduced to a soil with relict rock structure can be generally molded and crumbled by hand.
Weathered	Entire mass is discolored, alteration pervades nearly all of the rock with some pockets of less weathered rock noticeable, some minerals leached away, retains only a fraction of original strength.
Slightly Weathered	Slight discoloration on surfaces, slight alteration along discontinuities, less than 10% of the rock volume is altered, strength is substantially unaffected.
Unweathered	No evidence of any mechanical or chemical alteration.

CONSISTENCY

DESCRIPTION	EQUIVALENT S.P.T. BLOWS/FT
Without form	2
Readily deformed by fingers with light pressure or easily squeezed through fingers	2-4
Easily deformed by fingers with moderate pressure but cannot be squeezed through fingers	4-8
Deformed with difficulty by fingers. A pencil jabbed into the sample will penetrate and tend to stick	8-15
	15-30
Can be gouged by fingernail. A pencil jabbed into the sample will penetrate slightly but does not tend to stick	30

DENSITY (SILT AND SAND)

	S.P.T. BLOWS/FT
	10
	10-30
	30-50
	> 50

ROCK-STRUCTURE

DESCRIPTION
Samples completely broken up (Most likely mechanically induced)
Crumbles naturally or is easily broken pulverized or reduced to powder
Fractures spaced generally less than 4 inches apart
Fractures spaced generally between 4 inches and 1 foot apart

HARDNESS

DESCRIPTION
Can be deformed by hand
Can be scratched with fingernail
Can be scratched easily with a knife
Difficult to scratch with a knife
Cannot be scratched with a knife

BEDROCK WEATHERING

DESCRIPTION
Rock is reduced to a soil with relict rock structure. Can be generally molded and crumbled by hand
Entire mass is discolored; alteration pervades nearly all of the rock with some pockets of less weathered rock noticeable; some minerals leached away; retains only a fraction of original strength
Slight discoloration on surfaces; slight alteration along discontinuities; less than 10% of the rock volume is altered; strength is substantially unaffected
No evidence of any mechanical or chemical alteration.

SYMBOLS

SYMBOL	DEFINITION
	Estimated ground water level measured at time of drilling.
	Water level measured from Piezometer
	Drill Hole
DW	Discharge Well
RW	Recharge Well
	Discharge well and Drill Hole at same location
	Piezometer
	Water Level
	Indicates well used for aquifer pump test.
S.P.T.	Standard Penetration Test
S.S.	Split Spoon
	Indicates interval sampled on boring logs

GEOTECHNICAL NOTES

1. The data shown on Plates 5 through 9 are compilations of data from the field logs which are the only record of the actual geologic features observed from detailed examination of samples obtained during exploratory drilling. This presentation of data from the field log is provided to assist the contractor in evaluating the site. Actual field logs of all the borings shown on Plate 3 are available for review at the Omaha District Office.
2. The logs shown on Plates 5 through 9 and the field logs are representative of subsurface conditions for the exploratory boring at their respective locations as shown on the drawings. Local variations characteristic of subsurface materials in this region are anticipated.
3. Letter symbols such as GC, SC, SP, SM, CL, etc., are in accordance with the Unified Soil Classification System, COE, Technical Memorandum No. 3-357, May, 1957.
4. Bedrock classifications shown on the logs are based on visual inspection of 2 or 3 inch diameter split spoon drive samples. The degree of weathering, fracturing, etc., of the rock was determined by the physical appearance and condition of the samples. The sandstone encountered in borings P-1/W-5 was cored in auxiliary holes W-5A and W-5B. PQ 3.345 inch diameter core samples of the sandstone are available for inspection at Rocky Mountain Arsenal. Bidders should examine the core samples to satisfy themselves as to the physical properties of the rock.
5. Most of the borings drilled for this project were drilled with a 7-7/8 inch hollow stem auger. Some were drilled utilizing a churn drill and drive barrel. The drilling method for each hole is indicated on the original field logs.
   A. All borings shown on Plates 5 through 9 were drilled with the hollow stem auger.
6. Sampling was accomplished by:
   A. In augered holes, 3 or 2 inch diameter split spoon samples were taken at 2-1/2 or 5 foot intervals, using a 140 pound hammer. See boring logs for sample intervals and diameter.
   B. Churn drilled holes were sampled continuously using a 6 inch diameter drive barrel.
   C. Core drilling was accomplished using a 10 foot long P.C. 4.827-inch O.D. Core Barrel with inner barrel.
7. Only the logs for the borings along the discharge line/slurry wall and recharge line are shown in these plans. The logs for all the borings shown in plan only on Plate 3 are available for inspection at the Omaha District, Corps of Engineers.
8. Ground Water levels are not available for all boreholes. Absence of ground water data on a boring log does not necessarily mean that ground water will not be encountered at that location within the vertical reach of the boring. Ground Water levels indicated on boring logs reflect the level at the time measured. Ground Water levels will vary with time.
9. Relative density of sand strata and consistency of silt or clay were estimated by visual inspection of soil samples at time of drilling and by the number of blows required to drive the samplers.
10. Moisture content descriptions were estimated by visual inspection of samples at the time of drilling.
11. More detailed information on drilling progress, water data, fractures and other data are shown on the field logs. Copies of the field logs are available for inspection in the office of the U. S. Army Engineer District, Omaha, NE.
12. Lines between borings designation as top of bedrock, top of aquifer, or top of ground are estimates only.
13. All unified soil classification symbols shown on the boring logs are laboratory classifications of the soils from the corresponding split spoon samples.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

NORTHWEST BOUNDARY CONTAINMENT

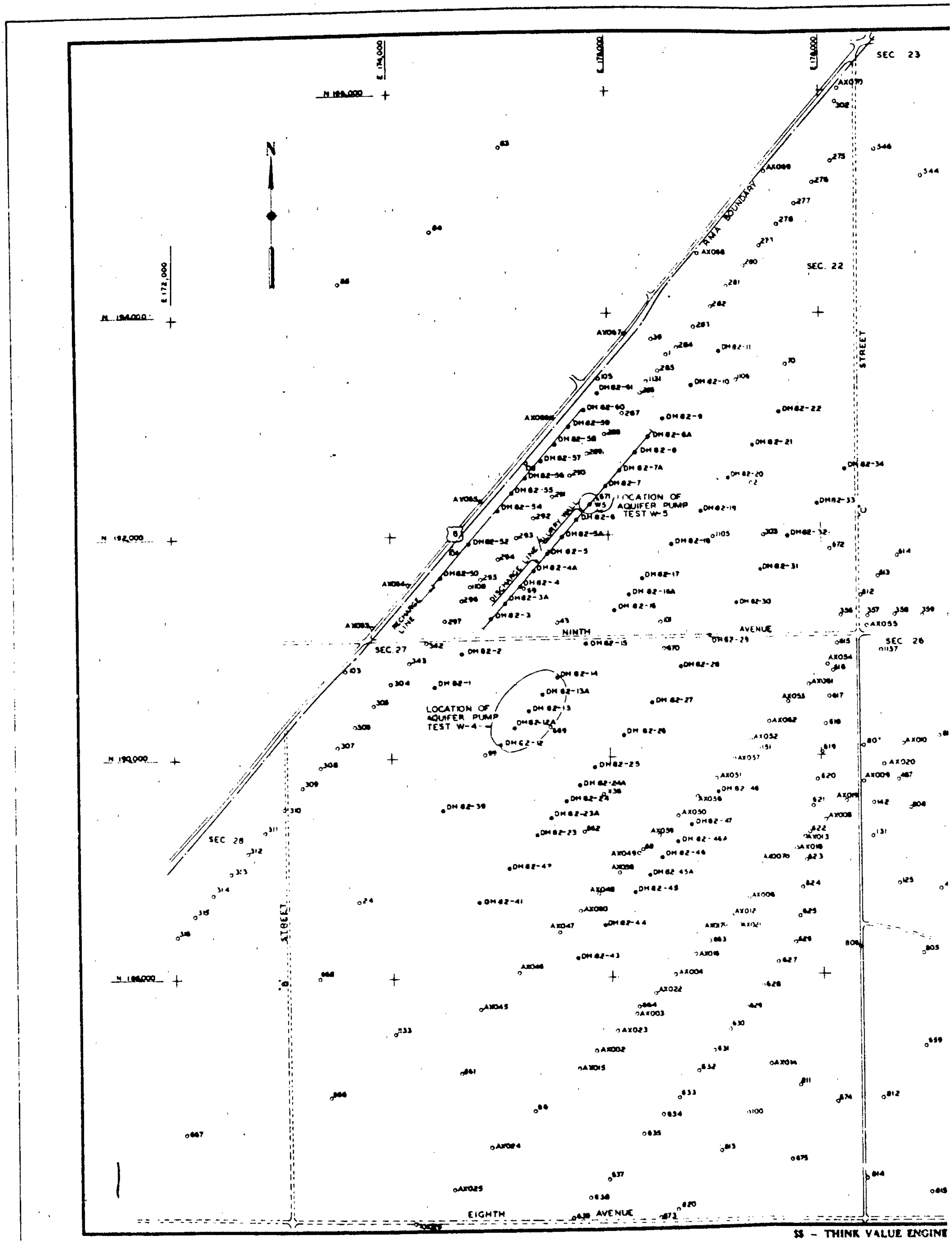
GEOTECHNICAL
LEGEND AND NOTES

FY 81 MCA PN 34.2

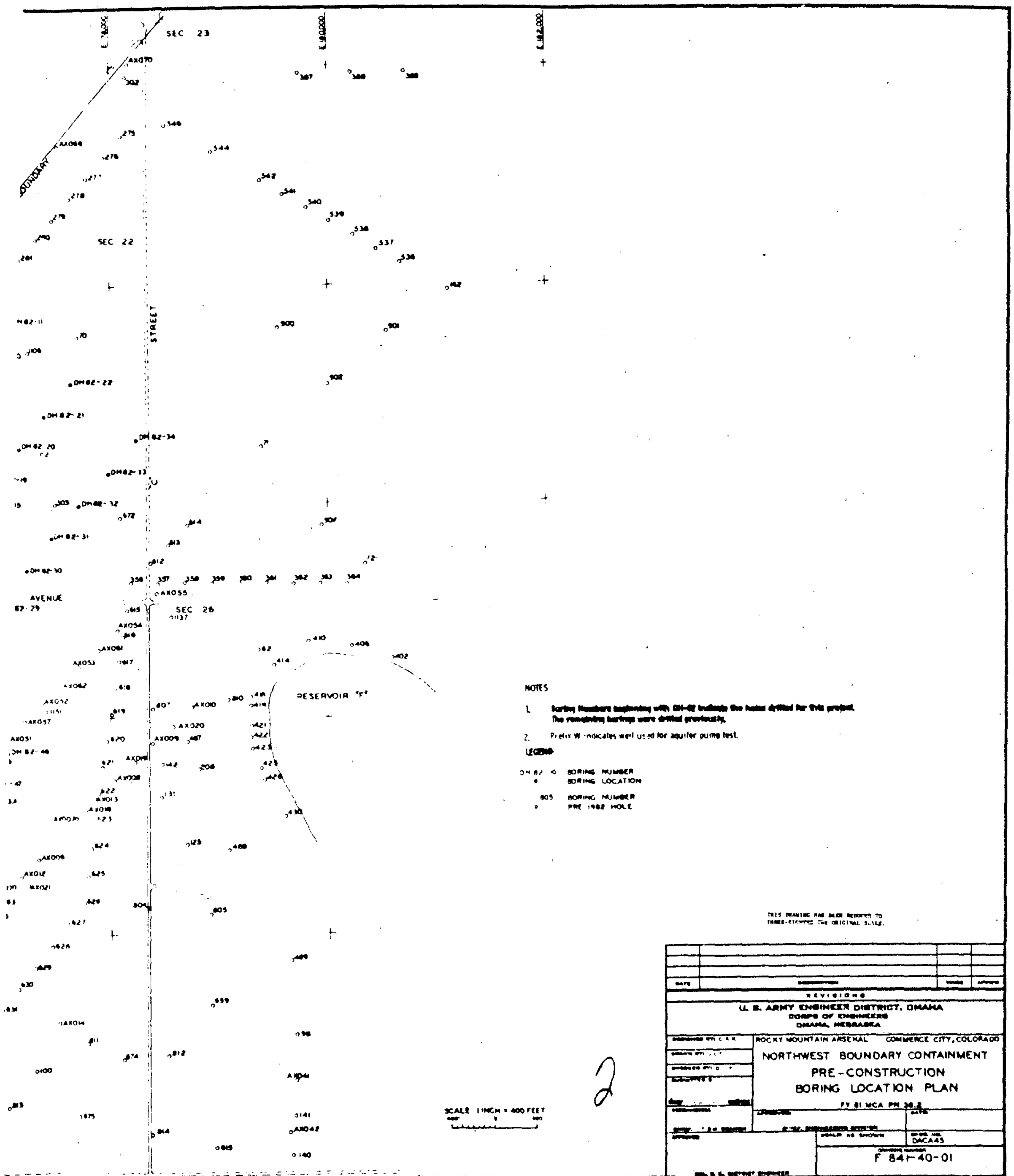
DACA45

T 841-40-01

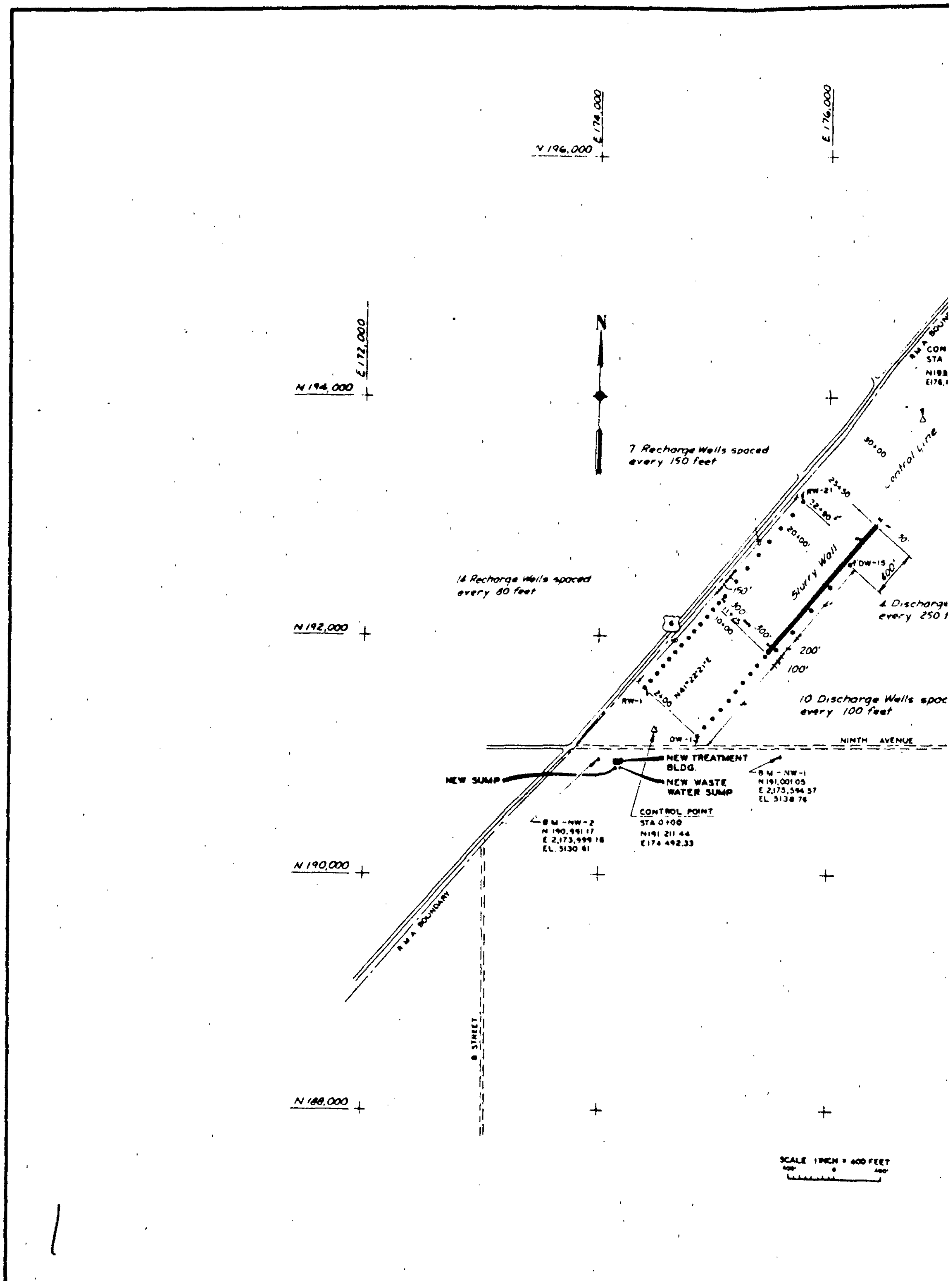
2



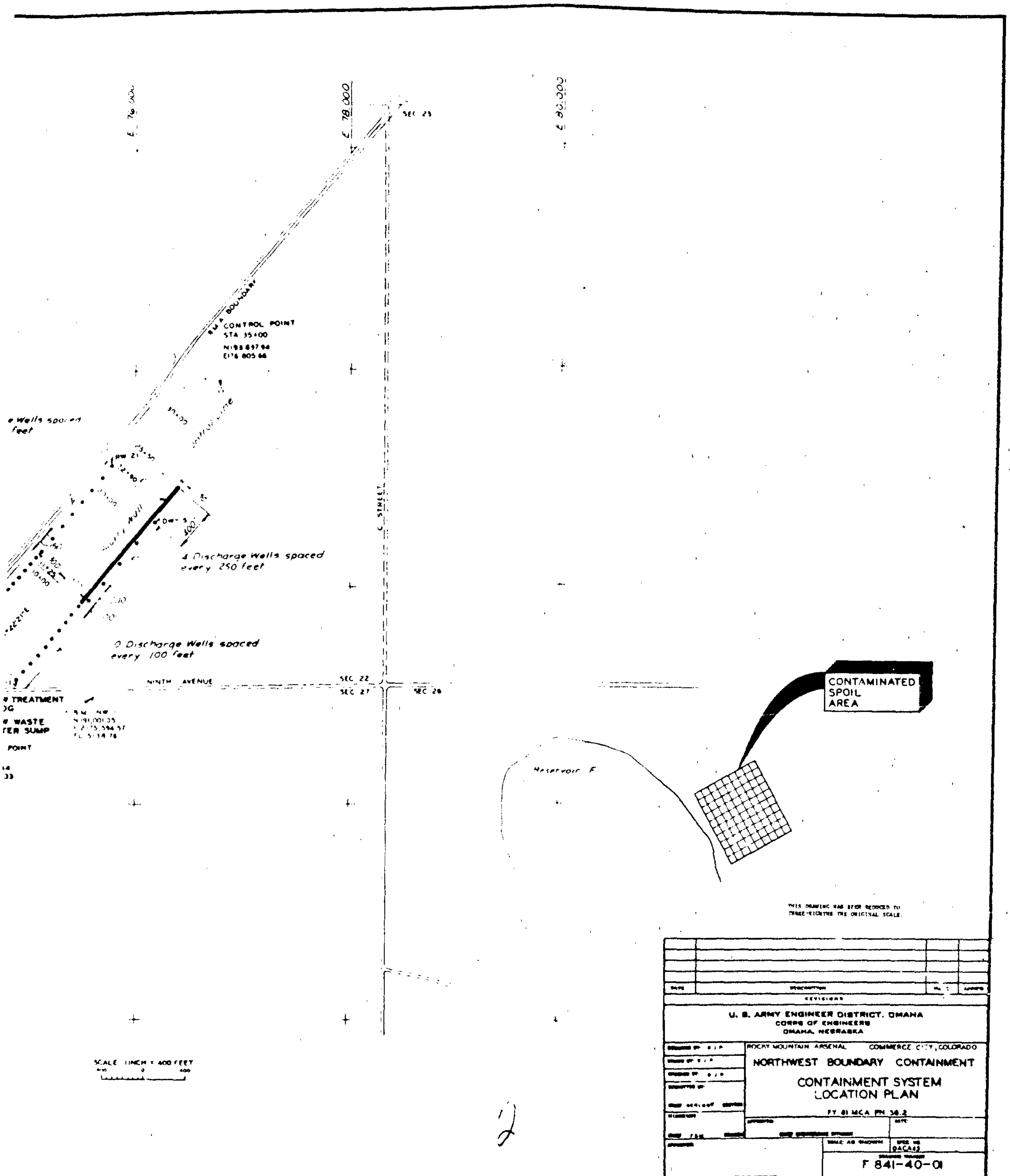
SS - THINK VALUE ENGINE



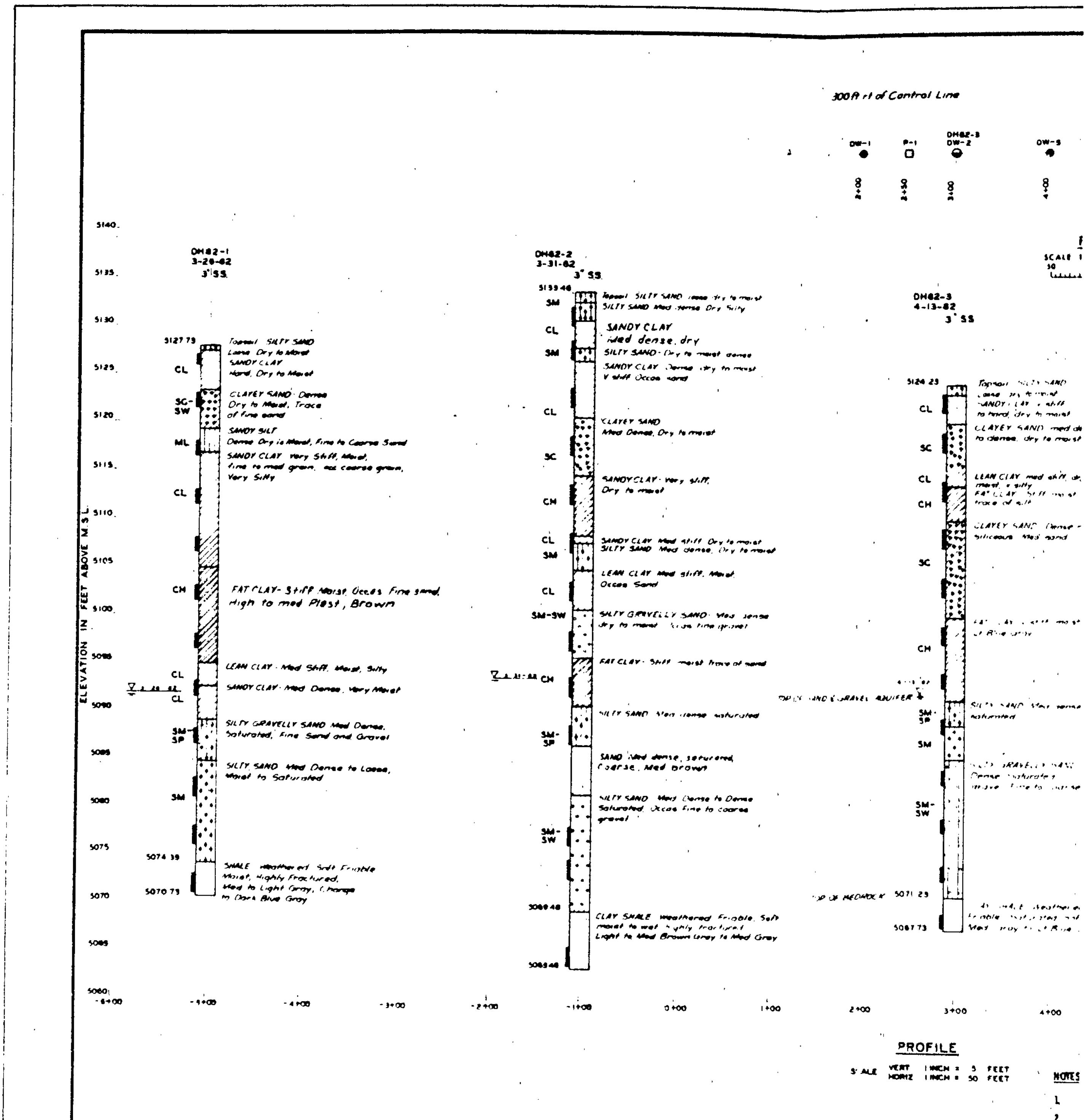
SEC 23
SEC 22
SEC 26
BOUNDARY
STREET
AVENUE
RESERVOIR "F"
E 180,000
E 182,000
NOTES:
1. Boring Numbers beginning with DH-82 indicate the holes drilled for this project. The remaining borings were drilled previously.
2. Prefix W indicates well used for aquifer pump test.
LEGEND
DH 82 10 BORING NUMBER
BORING LOCATION
805 BORING NUMBER
PRE 1982 HOLE
SCALE 1 INCH = 400 FEET
THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.
REVISIONS
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO
NORTHWEST BOUNDARY CONTAINMENT
PRE-CONSTRUCTION
BORING LOCATION PLAN
FY 81 MCA PN 36.2
SCALE AS SHOWN
DACA45
F 84-40-01
2

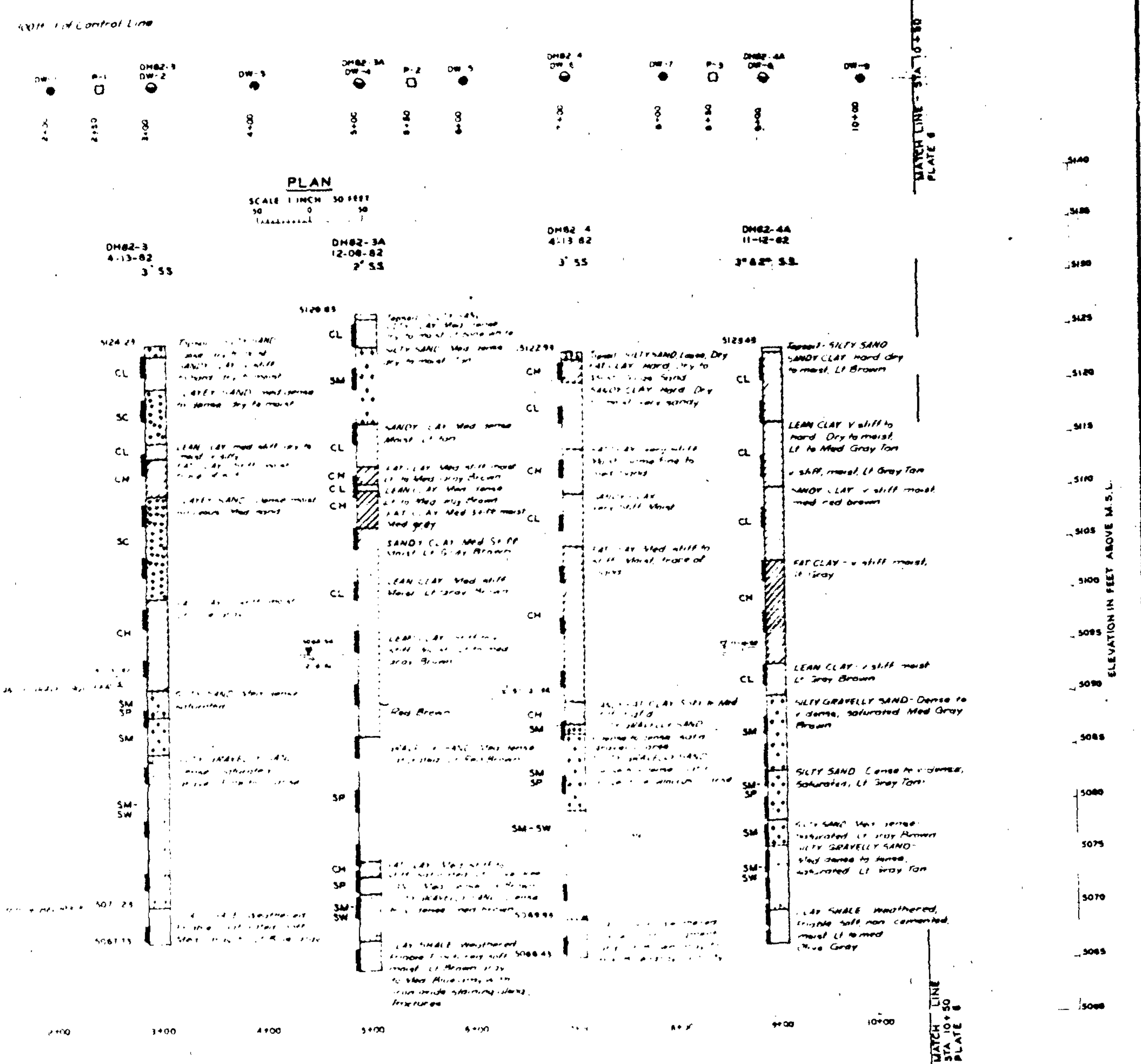


N 196,000
E 174,000
E 176,000
E 172,000
N 194,000
N
7 Recharge Wells spaced every 150 feet
Control Line
Slurry Wall
14 Recharge Wells spaced every 80 feet
N 192,000
10 Discharge Wells spac every 100 feet
NINTH AVENUE
NEW TREATMENT BLDG.
NEW WASTE WATER SUMP
NEW SUMP
CONTROL POINT
STA 0+00
N191 211.44
E174 492.33
N 190,000
R M A BOUNDARY
B STREET
N 188,000
SCALE 1 INCH = 400 FEET



E. 78,000
E. 80,000
SEC 23
R.M.A. BOUNDARY
CONTROL POINT
STA 35+00
4 Discharge Wells spaced every 250 feet
0 Discharge Wells spaced every 100 feet
C STREET
NINTH AVENUE
SEC 22
SEC 27
SEC 26
TREATMENT
WASTE
POINT
CONTAMINATED SPOIL AREA
Reservoir F
SCALE 1 INCH = 400 FEET
THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.
REVISIONS
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
ROCKY MOUNTAIN ARSENAL
COMMERCE CITY, COLORADO
NORTHWEST BOUNDARY CONTAINMENT
CONTAINMENT SYSTEM
LOCATION PLAN
FY 81 MCA PN 34.2
SCALE AS SHOWN
DACA45
F 841-40-01


300 ft rt of Control Line
OW-1
P-1
DH82-3
OW-2
OW-5
DH82-1
3-29-82
3" SS
DH82-2
3-31-82
3" SS
DH82-3
4-13-82
3" SS
ELEVATION IN FEET ABOVE M.S.L.
5140
5135
5130
5125
5120
5115
5110
5105
5100
5095
5090
5085
5080
5075
5070
5065
5060
5127.73
Topsoil SILTY SAND Loose, Dry to Moist
SANDY CLAY Hard, Dry to Moist
CLAYEY SAND Dense Dry to Moist, Trace of fine sand
SANDY SILT Dense Dry to Moist, Fine to Coarse Sand
SANDY CLAY Very Stiff, Moist, fine to med grain, occ coarse grain, Very Silty
FAT CLAY - Stiff Moist Occas Fine sand, High to med Plast, Brown
LEAN CLAY Med Stiff, Moist, Silty
SANDY CLAY Med Dense, Very Moist
SILTY GRAVELLY SAND Med Dense, Saturated, Fine Sand and Gravel
SILTY SAND Med Dense to Loose, Moist to Saturated
5074.39
SHALE Weathered Soft Friable Moist, Highly Fractured, Med to Light Gray, Change to Dark Blue Gray
5070.73
5133.48
Topsoil SILTY SAND
SILTY SAND Med dense Dry Silty
SANDY CLAY Med dense, dry
CLAYEY SAND Med Dense, Dry to moist
SANDY CLAY Med stiff, Dry to moist
LEAN CLAY Med stiff, Moist, Occas Sand
FAT CLAY Stiff moist trace of sand
SAND Med dense, saturated, Coarse, Med brown
5069.48
CLAY SHALE Weathered Friable, Soft moist to wet highly fractured Light to Med Brown Grey to Med Grey
5065.48
5124.23
SAND & GRAVEL AQUIFER
TOP OF BEDROCK 5071.23
5067.73
CL
SC-SW
ML
CH
SM-SP
SM
SC
SM-SW
SM-SP
-6+00
-5+00
-4+00
-3+00
-2+00
-1+00
0+00
1+00
2+00
3+00
4+00
PROFILE
SCALE VERT 1 INCH = 5 FEET
HORIZ 1 INCH = 50 FEET
NOTES
1.
2.
3.



PROFILE

SCALE VERT 1 INCH = 5 FEET
HORIZ 1 INCH = 50 FEET

NOTES:

1. See Plate 10 for Well and Piezometer Observation Schedule.
2. The Descriptive data at the right of the logs are the results of field descriptions made by the geologist in the field at the time of drilling and laboratory data. Laboratory classifications at the left of the Logs are in accordance with the Unified Soil Classification System TM-3-357, May, 1967.
3. See Plate 2 for Geotechnical Legend and Notes.

2

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

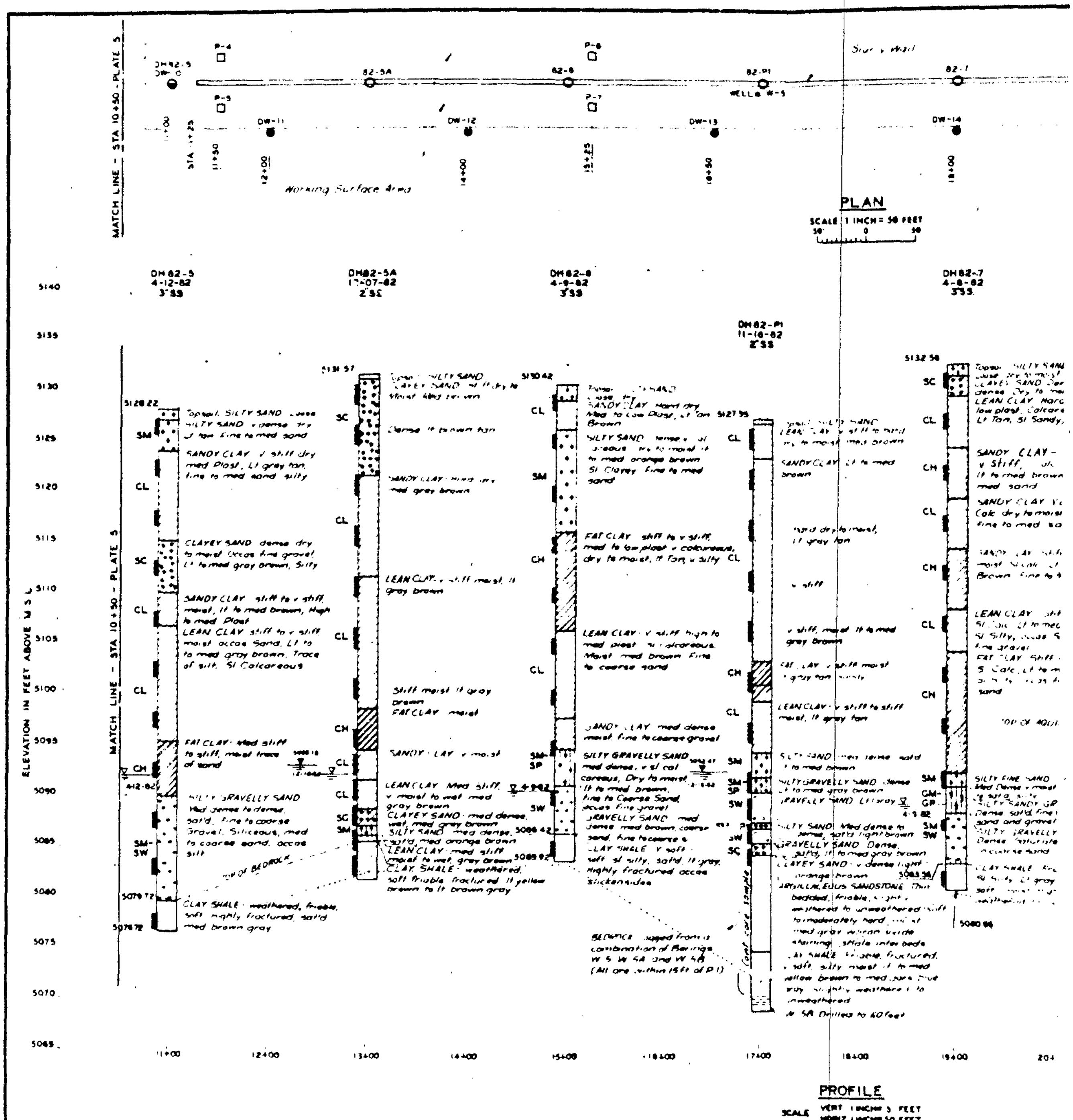
ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

NORTHWEST BOUNDARY CONTAINMENT
PLAN AND PROFILE OF
DISCHARGE LINE/SLURRY WALL
LOG OF BORINGS - DH 82-1 THRU 4A

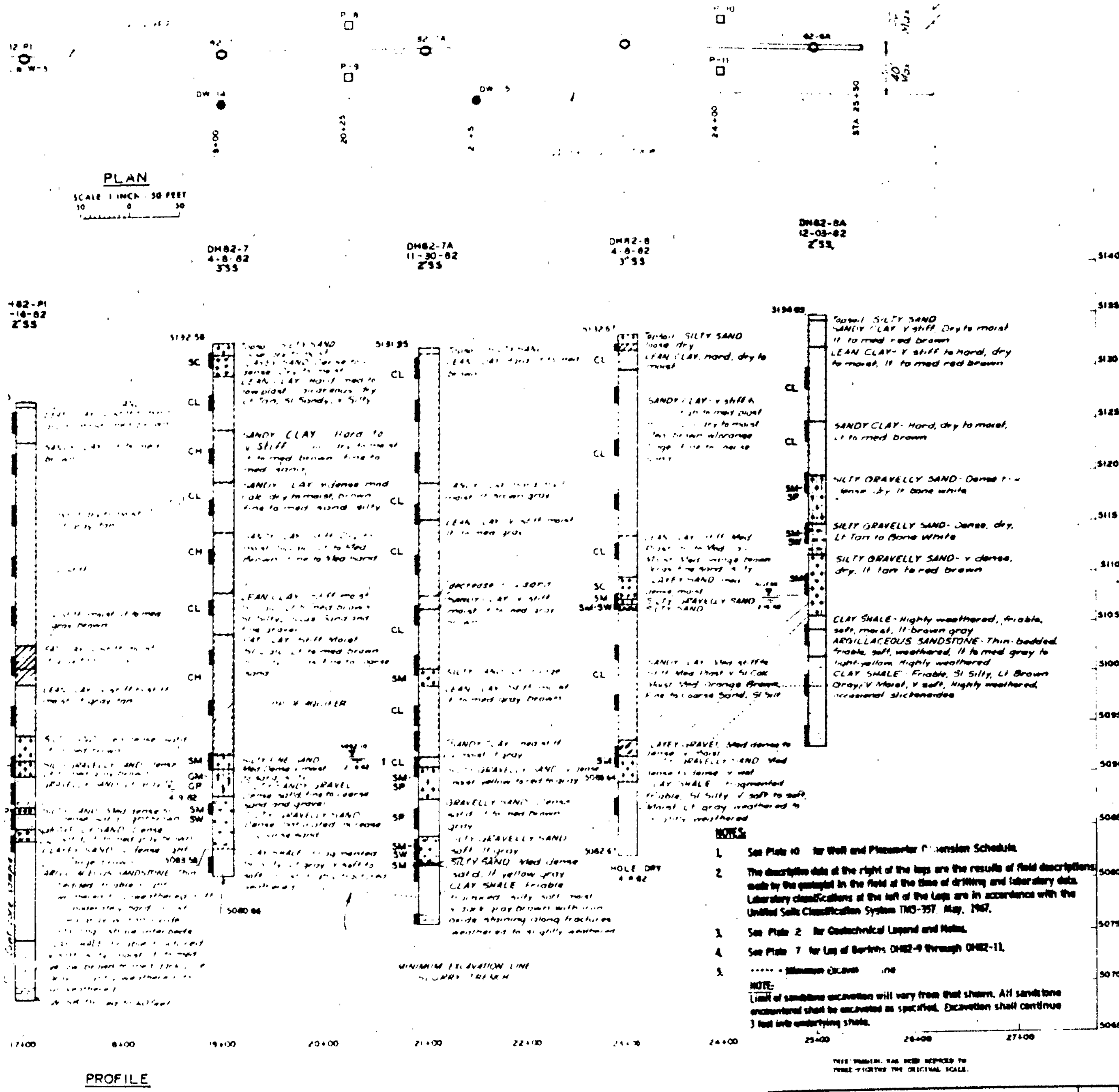
FY 81 MCA PN 36.2

DACA45

F 841-40-01



MATCH LINE - STA 10+50 - PLATE 5
DH82-5
82-5A
82-8
82-P1
WELL & W-5
82-7
P-4
P-5
P-6
P-7
DW-11
DW-12
DW-13
DW-14
Working Surface Area
PLAN
SCALE 1 INCH = 50 FEET
DH 82-5 4-12-82 3" SS
DH82-5A 12-07-82 2" SS
DH 82-8 4-9-82 3" SS
DH 82-P1 11-16-82 2" SS
DH 82-7 4-8-82 3" SS
ELEVATION IN FEET ABOVE M S L
Topsoil, SILTY SAND Loose
SANDY CLAY v stiff dry med Plast, Lt gray tan, fine to med sand silty
CLAYEY SAND dense dry to moist Occas fine gravel Lt to med gray brown, Silty
SANDY CLAY stiff to v stiff, moist, lt to med brown, High to med Plast
LEAN CLAY stiff to v stiff, moist occas Sand, Lt to to med gray brown, Trace of silt, Sl Calcareous
FAT CLAY Med stiff to stiff, moist trace of sand
SILTY GRAVELLY SAND Med dense to dense, sat'd, fine to coarse Gravel, Siliceous, med to coarse sand, occas silt
TOP OF BEDROCK
CLAY SHALE weathered, friable, soft highly fractured, sat'd med brown gray
LEAN CLAY v stiff moist, lt gray brown
FAT CLAY moist
SANDY CLAY v moist
LEAN CLAY Med stiff v moist to wet med gray brown
CLAYEY SAND med dense, wet, med gray brown
SILTY SAND med dense, sat'd, med orange brown
LEAN CLAY med stiff moist to wet, gray brown
CLAY SHALE weathered, soft friable fractured lt yellow brown to lt brown gray
SANDY CLAY Hard dry Med to Low Plast, Lt Tan Brown
SILTY SAND dense, sl calcareous dry to moist lt to med orange brown Sl Clayey Fine to med sand
FAT CLAY stiff to v stiff, med to low plast v calcareous, dry to moist, lt Tan, v silty
LEAN CLAY v stiff high to med plast, sl calcareous, Moist med brown Fine to coarse sand
SANDY CLAY med dense moist, fine to coarse gravel
SILTY GRAVELLY SAND med dense, v sl calcareous, Dry to moist lt to med brown, fine to Coarse Sand, occas fine gravel
GRAVELLY SAND med dense med brown, coarse sand, fine to coarse
CLAY SHALE v soft soft sl silty, sat'd, lt gray, Highly fractured occas slickensides
BEDROCK logged from a combination of Borings W 5, W 5A and W 5B (All are within 15 ft of P1)
ARGILLACEOUS SANDSTONE
W 5A Drilled to 60 feet
PROFILE
SCALE VERT 1 INCH = 5 FEET HORIZ 1 INCH = 50 FEET



NOTES:

1. See Plate 10 for Well and Piezometer Completion Schedule.
2. The descriptive data at the right of the logs are the results of field descriptions made by the geologist in the field at the time of drilling and laboratory data. Laboratory classifications at the left of the Logs are in accordance with the Unified Soils Classification System TM3-357, May, 1967.
3. See Plate 2 for Geotechnical Legend and Notes.
4. See Plate 7 for Log of Borings DH82-9 through DH82-11.
5. ----- = Minimum Excavation Line

NOTE:
Limit of sandstone excavation will vary from that shown. All sandstone encountered shall be excavated as specified. Excavation shall continue 3 feet into underlying shale.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

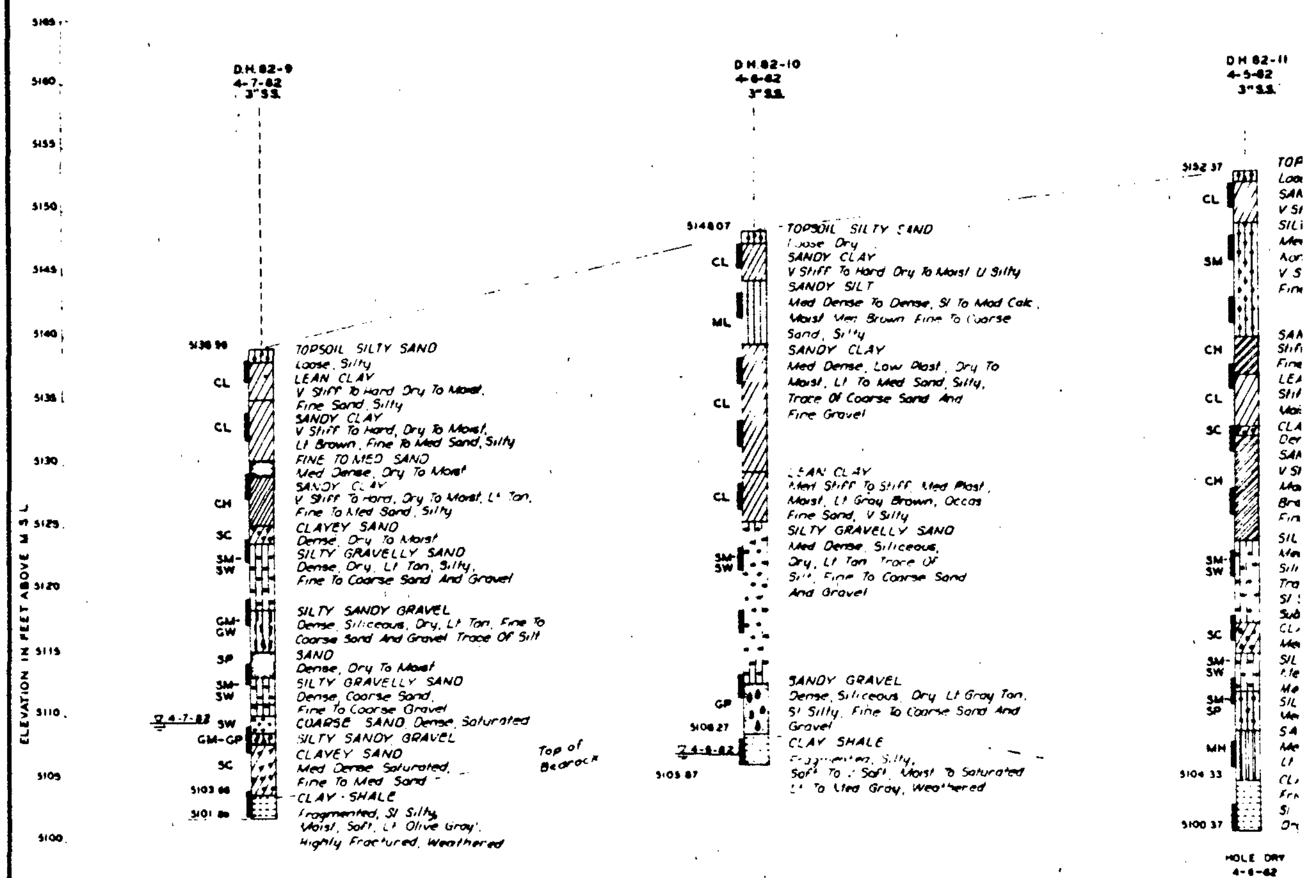
ROCKY MOUNTAIN ARSENAL — COMMERCE CITY, COLORADO

NORTHWEST BOUNDARY CONTAINMENT
PLAN AND PROFILE OF
DISCHARGE LINE/SLURRY WALL
LOG OF BORINGS - DH 82-5 THRU 8A
FY 81 MCA PN 36.2

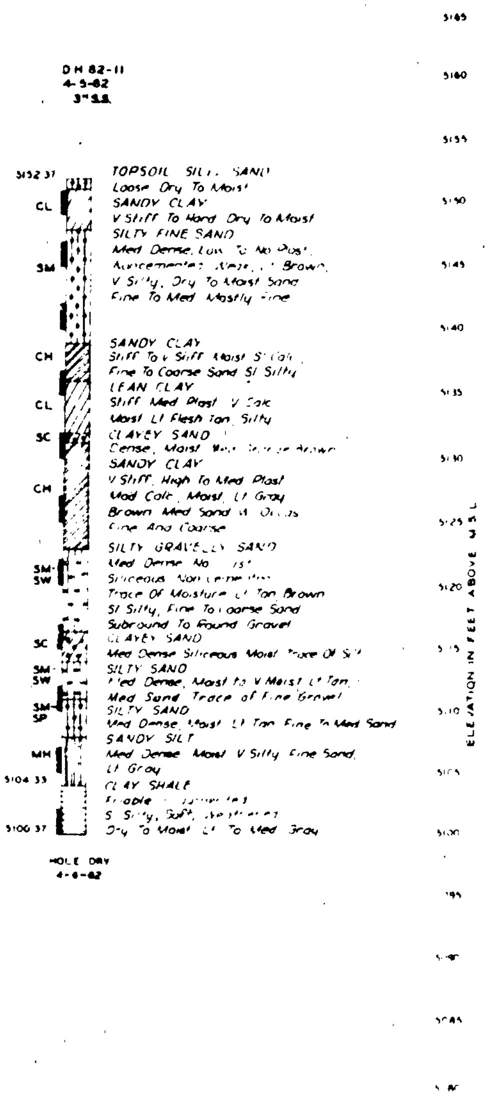
DACA45

F 841-40-01

2



ELEVATION IN FEET ABOVE M.S.L.
5165
5160
5155
5150
5145
5140
5135
5130
5125
5120
5115
5110
5105
5100
5095
5090
5085
5080
D.H. 82-9
4-7-82
3" S.S.
5138.99
TOPSOIL SILTY SAND
Loose, Silty
LEAN CLAY
V Stiff To Hard Dry To Moist, Fine Sand, Silty
SANDY CLAY
V Stiff To Hard, Dry To Moist, Lt Brown, Fine To Med Sand, Silty
FINE TO MED SAND
Med Dense, Dry To Moist
SANDY CLAY
V Stiff To Hard, Dry To Moist, Lt Tan, Fine To Med Sand, Silty
CLAYEY SAND
Dense, Dry To Moist
SILTY GRAVELLY SAND
Dense, Dry, Lt Tan, Silty, Fine To Coarse Sand And Gravel
SILTY SANDY GRAVEL
Dense, Siliceous, Dry, Lt Tan, Fine To Coarse Sand And Gravel Trace Of Silt
SAND
Dense, Dry To Moist
SILTY GRAVELLY SAND
Dense, Coarse Sand, Fine To Coarse Gravel
COARSE SAND Dense, Saturated
SILTY SANDY GRAVEL
CLAYEY SAND
Med Dense Saturated, Fine To Med Sand
CLAY SHALE
Fragmented, Sl Silty, Moist, Soft, Lt Olive Gray, Highly Fractured, Weathered
CL
CL
CH
SC
SM-SW
GM-GW
SP
SM-SW
SW
GM-GP
SC
4-7-82
5103.66
5101.86
Top of Bedrock
D.H. 82-10
4-6-82
3" S.S.
5148.07
TOPSOIL SILTY SAND
Loose, Dry
SANDY CLAY
V Stiff To Hard Dry To Moist U Silty
SANDY SILT
Med Dense To Dense, Sl To Mod Calc, Moist, Med Brown, Fine To Coarse Sand, Silty
SANDY CLAY
Med Dense, Low Plast, Dry To Moist, Lt To Med Sand, Silty, Trace Of Coarse Sand And Fine Gravel
LEAN CLAY
Med Stiff To Stiff, Med Plast, Moist, Lt Gray Brown, Occas Fine Sand, V Silty
SILTY GRAVELLY SAND
Med Dense Siliceous, Dry, Lt Tan, Trace Of Silt, Fine To Coarse Sand And Gravel
SANDY GRAVEL
Dense, Siliceous, Dry, Lt Gray Tan, Sl Silty, Fine To Coarse Sand And Gravel
CLAY SHALE
Fragmented, Silty, Soft To Sl Soft, Moist To Saturated, Lt To Med Gray, Weathered
CL
ML
CL
CL
SM-SW
GP
5106.27
4-6-82
5105.87
D.H. 82-11
4-5-82
3" S.S.
5152.37
CL
SM
CH
CL
SC
CH
SM-SW
SC
SM-SW
SM-SP
MH
5104.33
5100.37
HOLE DRY
4-6-82



NOTES:

1. The descriptive data at the right of the logs are the results of field descriptions made by the geologist in the field at the time of drilling and laboratory data. Laboratory classifications at the left of the logs are in accordance with the Unified Soils Classification System TM-3-357, May 1967.
2. See Plate 2 for geotechnical Legend and Notes.
3. See Plates 5 & 6 for Log of Borings DH82-1 through DH82-8A.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

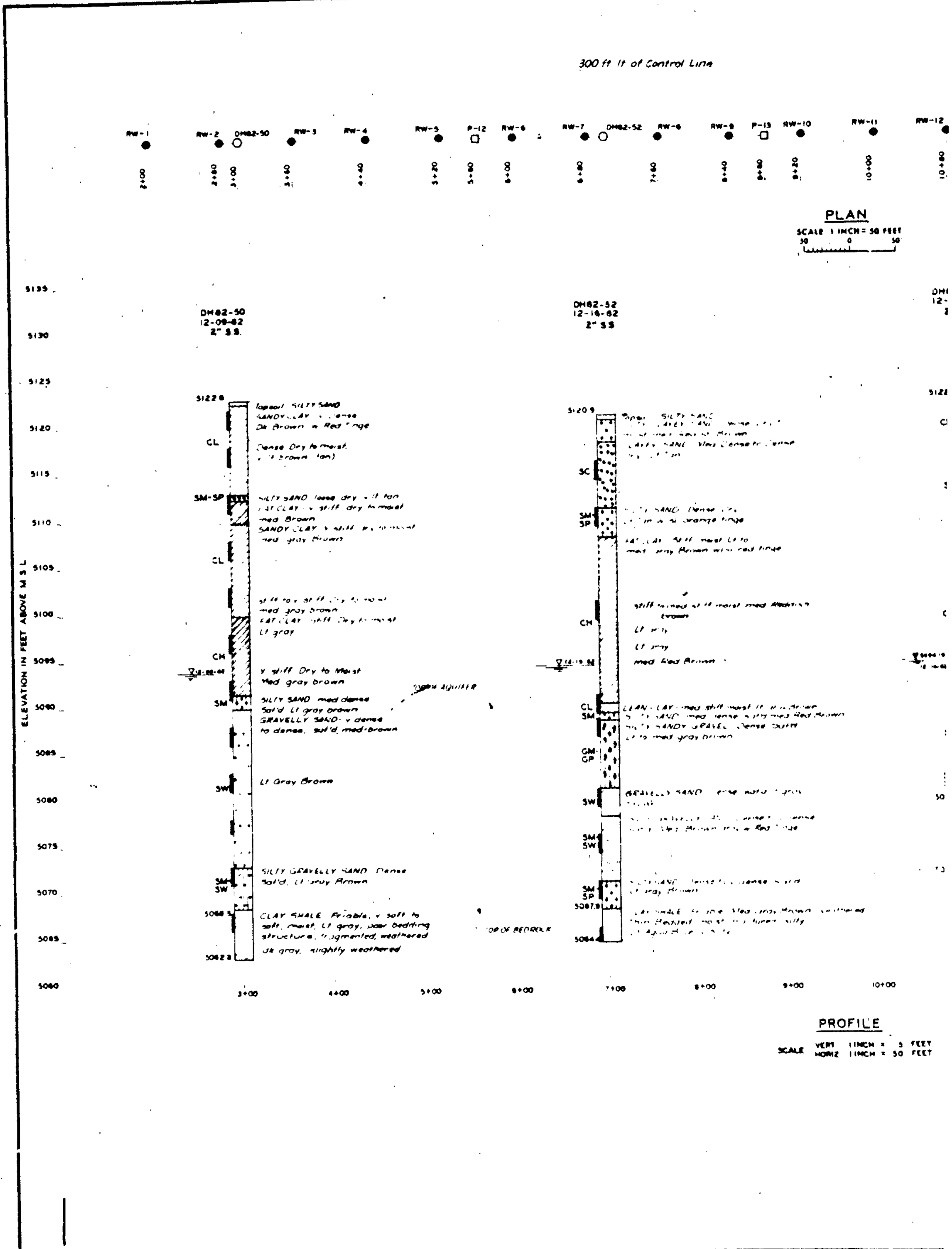
NORTHWEST BOUNDARY CONTAINMENT
PLAN AND PROFILE OF
DISCHARGE LINE/SLURRY WALL
LOG OF BORINGS
DH 82-9 THROUGH DH 82-11

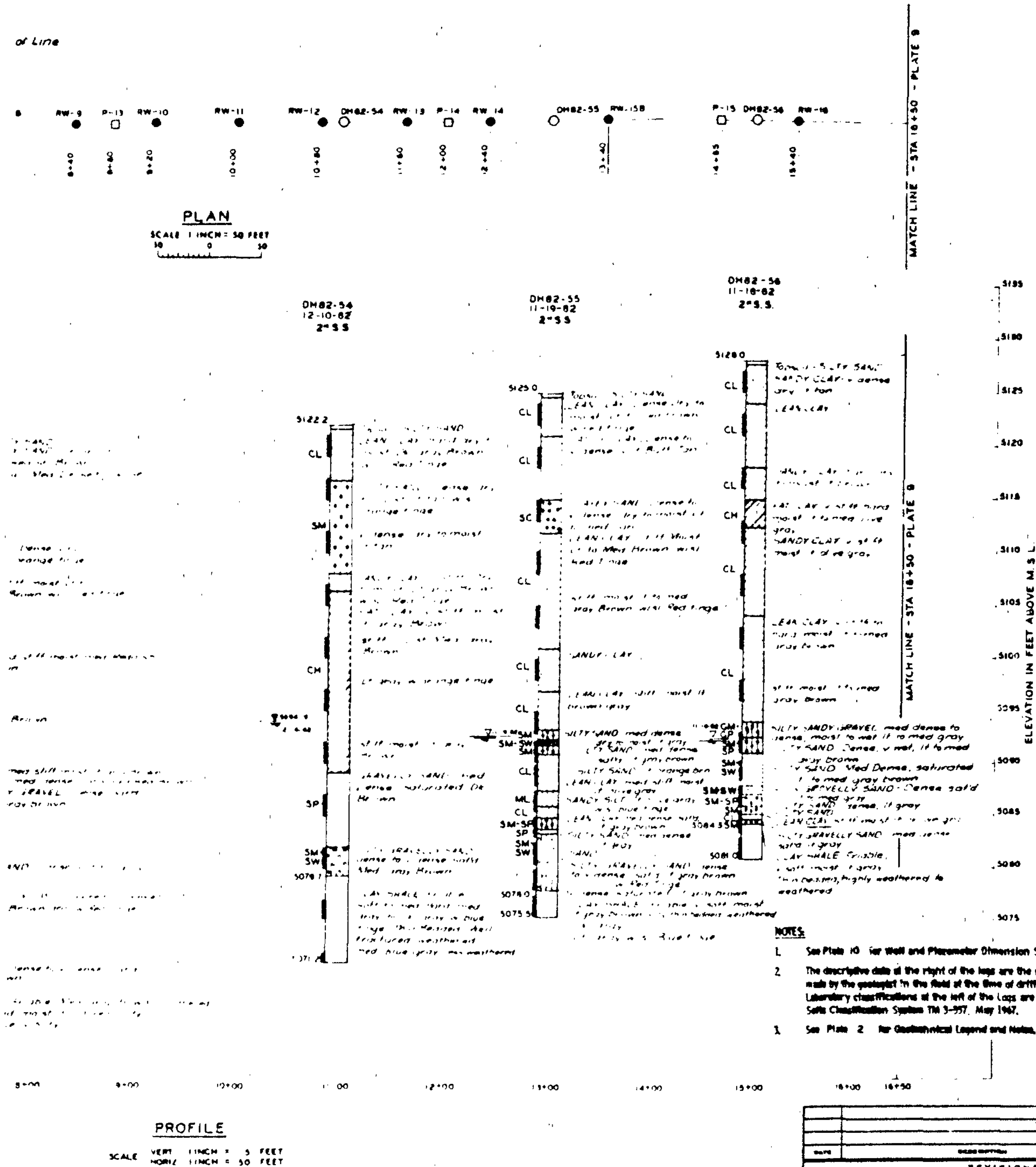
SCALE AS SHOWN

DACA45

F 841-40-01

2


300 ft lt of Control Line
RW-1
RW-2
DH82-50
RW-3
RW-4
RW-5
P-12
RW-6
RW-7
DH82-52
RW-8
RW-9
P-13
RW-10
RW-11
RW-12
PLAN
SCALE 1 INCH = 50 FEET
ELEVATION IN FEET ABOVE M S L
DH82-50
12-09-82
2" SS
DH82-52
12-16-82
2" SS
Topsoil SILTY SAND
SANDY CLAY
Dk Brown w Red Tinge
Dense Dry to moist
SILTY SAND loose dry
FAT CLAY
med Brown
SANDY CLAY
med gray Brown
med gray brown
FAT CLAY
Lt gray
v stiff Dry to Moist
Med gray brown
SILTY SAND med dense
Sat'd Lt gray brown
GRAVELLY SAND v dense
to dense, sat'd med brown
Lt Gray Brown
SILTY GRAVELLY SAND Dense
Sat'd, Lt gray Brown
CLAY SHALE Friable, v soft to
soft, moist, Lt gray, poor bedding
structure, fragmented, weathered
dk gray, slightly weathered
TOP OF BEDROCK
med Red Brown
SILTY SANDY GRAVEL
GRAVELLY SAND
PROFILE
SCALE VERT 1 INCH = 5 FEET
HORIZ 1 INCH = 50 FEET



NOTES:

1. See Plate 10 for Well and Piezometer Dimension Schedule.
2. The descriptive data at the right of the logs are the results of field descriptions made by the geologist in the field at the time of drilling and laboratory data. Laboratory classifications at the left of the logs are in accordance with the Unified Soils Classification System TM 3-357, May 1967.
3. See Plate 2 for Geotechnical Legend and Notes.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

NORTHWEST BOUNDARY CONTAINMENT
PLAN AND PROFILE OF
RECHARGE LINE
LOG OF BORINGS - DH82-50 THRU 56

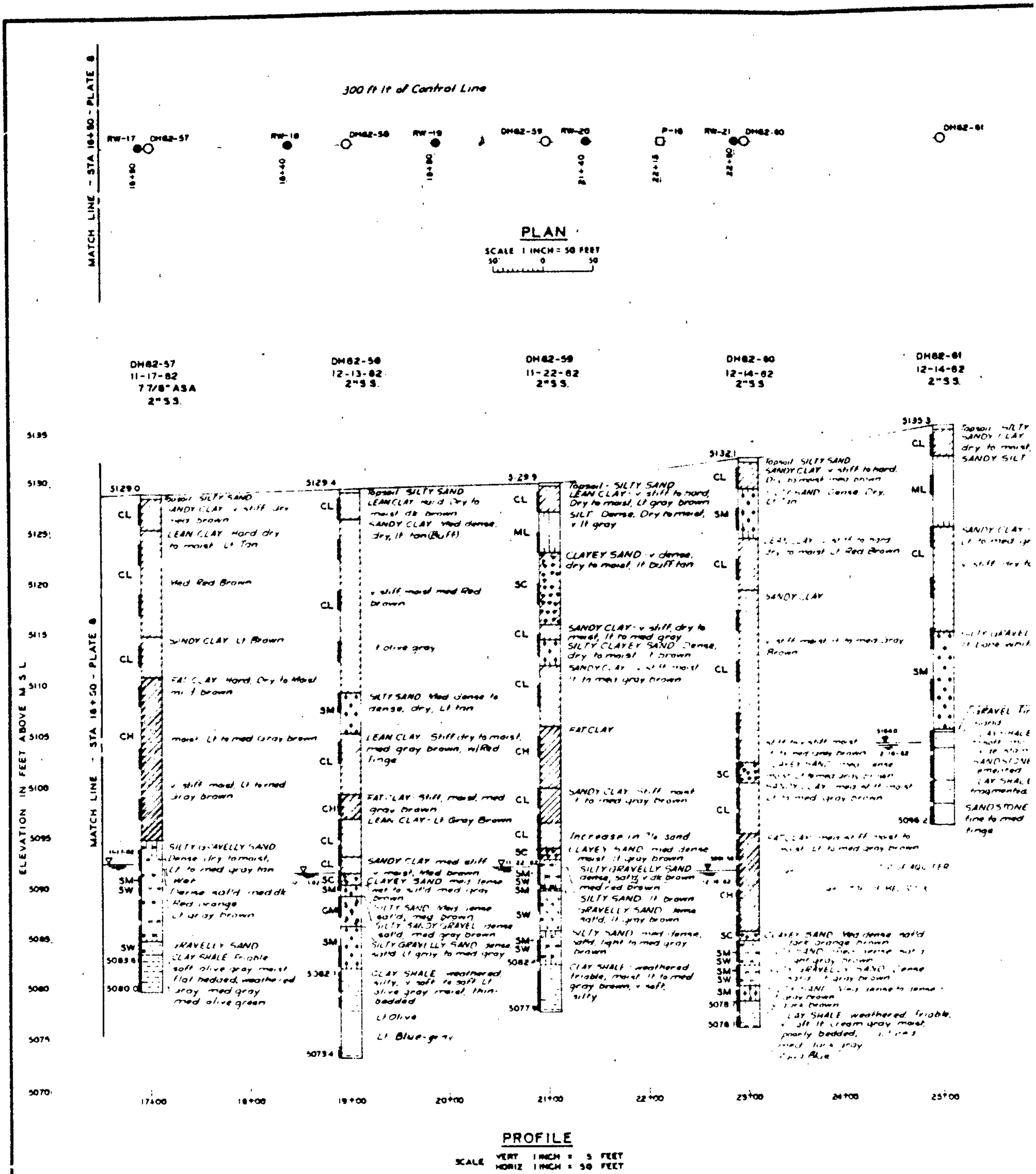
FY 81 MCA PN 36.2

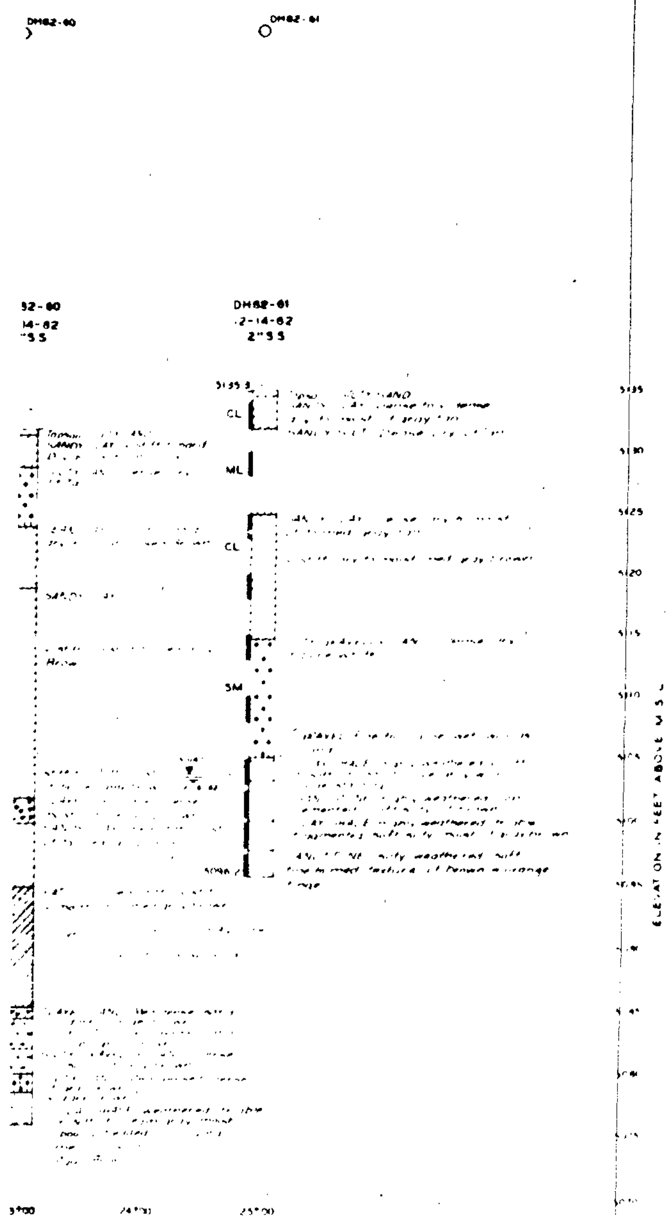
SCALE AS SHOWN

DACA45

F 841-40-01

2


MATCH LINE - STA 16+90 - PLATE 8
300 ft lt of Control Line
RW-17
DH82-57
RW-18
DH82-58
RW-19
DH82-59
RW-20
P-16
RW-21
DH82-60
DH82-61
PLAN
SCALE 1 INCH = 50 FEET
DH82-57
11-17-82
7 7/8" ASA
2" S.S.
DH82-58
12-13-82
2" S.S.
DH82-59
11-22-82
2" S.S.
DH82-60
12-14-82
2" S.S.
DH82-61
12-14-82
2" S.S.
ELEVATION IN FEET ABOVE M.S.L.
MATCH LINE - STA 16+50 - PLATE 8
Topsoil SILTY SAND
SANDY CLAY v stiff dry
LEAN CLAY Hard dry to moist Lt Tan
Med Red Brown
SANDY CLAY Lt Brown
FAT CLAY Hard, Dry to Moist
moist Lt to med Gray brown
v stiff moist Lt to med gray brown
SILTY GRAVELLY SAND
Dense dry to moist, Lt to med gray tan
Wet
Dense sat'd med dk Red orange
Lt gray brown
GRAVELLY SAND
CLAY SHALE friable soft olive gray moist flat bedded, weathered gray med gray med olive green
Topsoil SILTY SAND
LEAN CLAY Hard Dry to moist dk brown
SANDY CLAY Med dense, dry, lt tan (Buff)
v stiff moist med Red brown
Lt olive gray
SILTY SAND Med dense to dense, dry, Lt tan
LEAN CLAY Stiff dry to moist, med gray brown, w/Red tinge
FAT CLAY Stiff, moist, med gray brown
LEAN CLAY Lt Gray Brown
SANDY CLAY med stiff v moist, Med brown
CLAYEY SAND med dense wet to sat'd med gray brown
SILTY SAND Very dense sat'd, med brown
SILTY SANDY GRAVEL dense sat'd med gray brown
SILTY GRAVELLY SAND dense sat'd Lt gray to med gray
CLAY SHALE weathered silty, v soft to soft Lt olive gray moist, thin-bedded
Lt Olive
Lt Blue-gray
Topsoil - SILTY SAND
LEAN CLAY v stiff to hard, Dry to moist, Lt gray brown
SILT Dense, Dry to moist, v lt gray
CLAYEY SAND v dense, dry to moist, lt buff tan
SANDY CLAY v stiff, dry to moist, lt to med gray
SILTY CLAYEY SAND Dense, dry to moist
FAT CLAY
SANDY CLAY Stiff, moist
Increase in % sand
CLAYEY SAND med dense
SILTY GRAVELLY SAND dense, sat'd v dk brown med red brown
SILTY SAND lt brown
GRAVELLY SAND dense sat'd, lt gray brown
SILTY SAND med dense, sat'd, light to med gray brown
CLAY SHALE weathered friable, moist lt to med gray brown, v soft, silty
Topsoil SILTY SAND
SANDY CLAY v stiff to hard, Dry to moist med brown
SAND Dense Dry, Lt Tan
Red Brown
SANDY CLAY
FAT CLAY
CLAYEY SAND Very dense sat'd
CLAY SHALE weathered friable, soft lt cream gray moist, poorly bedded
Blue
SANDY SILT
SANDY CLAY
GRAVEL
SANDSTONE emersted
CLAY SHALE fragmented
SANDSTONE fine to med tinge
5135
5130
5125
5120
5115
5110
5105
5100
5095
5090
5085
5080
5075
5070
5129.0
5129.4
5129.9
5132.1
5135.3
5083.6
5080.0
5082.1
5073.4
5082.4
5077.9
5078.7
5076.1
5096.2
17+00
18+00
19+00
20+00
21+00
22+00
23+00
24+00
25+00
PROFILE
SCALE VERT 1 INCH = 5 FEET
HORIZ 1 INCH = 50 FEET



NOTES:

1. See Plate 10 for Well or Piezometer Dimension Schedule.
2. The descriptive data at the right of the logs are the results of field descriptions made by the geologist in the field at the time of drilling and laboratory data. Laboratory classifications at the left of the logs are in accordance with the Unified Soils Classification System TM 3-357, May 1967.
3. See Plate 2 for Geotechnical Legend and Notes.

DATE	DESCRIPTION	MADE	APPR'D

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

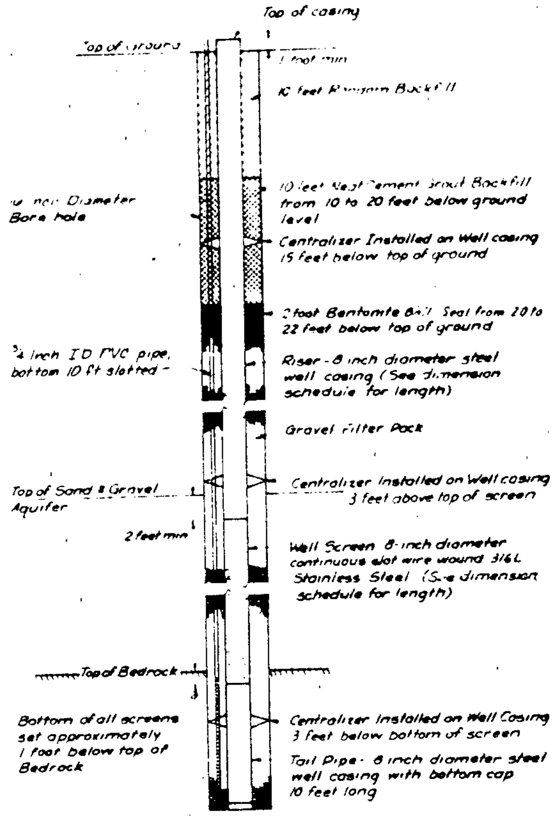
ROCKY MOUNTAIN ARSENAL — COMMERCE CITY, COLORADO

NORTHWEST BOUNDARY CONTAINMENT
PLAN AND PROFILE OF
RECHARGE LINE
LOG OF BORINGS - DH 82-57 THRU 61

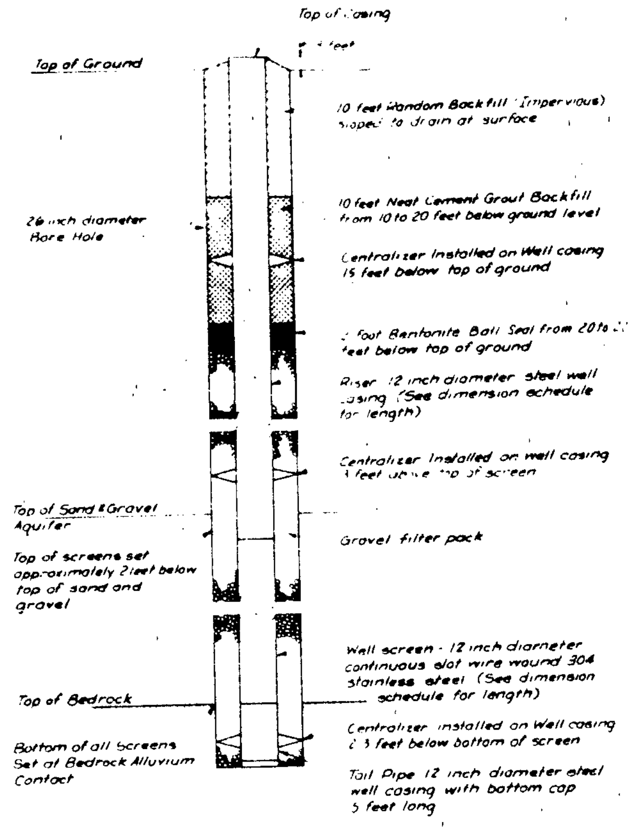
FY 81 MCA PN 34.2

SCALE: AS SHOWN
SPEC. NO. DACA45
DRAWING NUMBER F 841-40-01

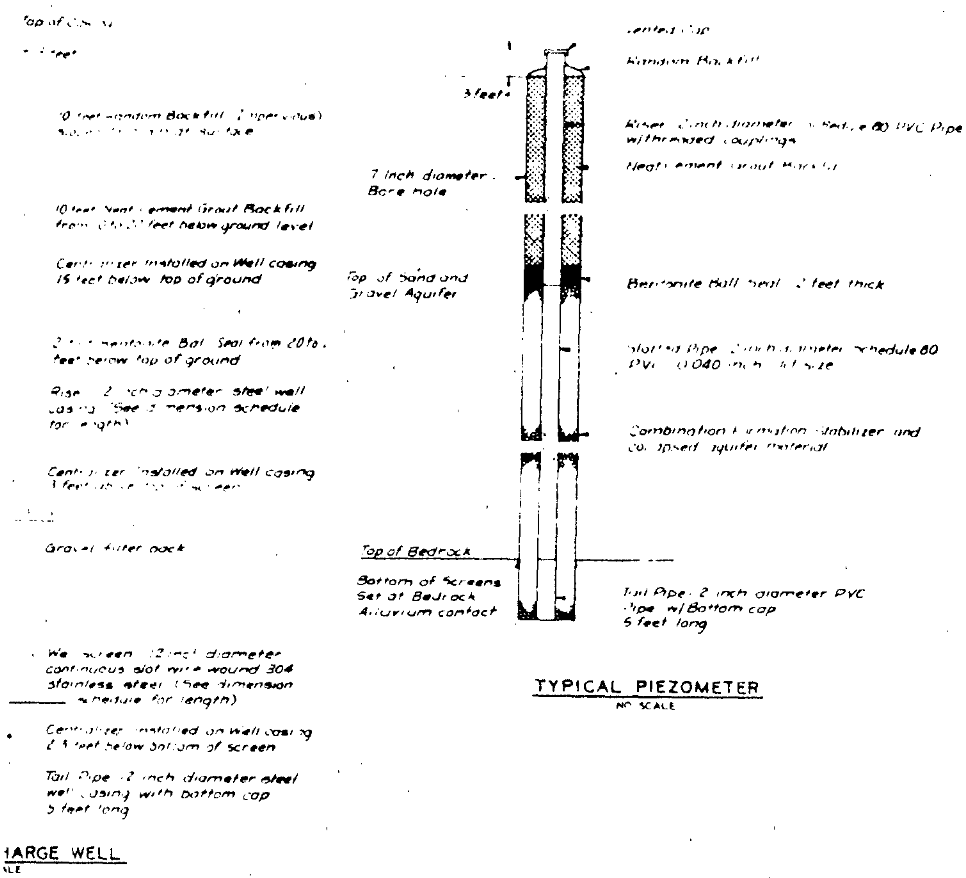
2



TYPICAL DISCHARGE WELL
NO SCALE



TYPICAL RECHARGE WELL
NO SCALE



TYPICAL PIEZOMETER

NO SCALE

HARGE WELL

DISCHARGE AND RECHARGE WE AND PIEZOMETER DIMENSION SCHEDULE

WELL NUMBER	STATION	DEPTH (FT)	SCREEN LENGTH (FT)	SCREEN DEPTH (FT)
DW-1	2+00	66	18	38.0-56.0
DW-2	3+00	65	21	32.0-55.0
DW-3	4+00	67	18	39.0-57.0
DW-4	5+00	69	17	42.0-59.0
DW-5	6+00	66	16	40.0-56.0
DW-6	7+00	54	17	37.0-54.0
DW-7	8+00	64	17	37.0-54.0
DW-8	9+00	64	18	36.0-54.0
DW-9	10+00	62	15	37.0-52.0
DW-10	11+00	60	8	42.0-50.0
DW-11	12+00	59	5	44.0-49.0
DW-12	14+00	56	5	41.0-46.0
DW-13	16+50	50	8	32.0-40.0
DW-14	19+00	58	7	41.0-48.0
DW-15	21+50	59	7	42.0-49.0
RW-1	2+00	59	21	33.0-54.0
RW-2	2+80	58	21	32.0-53.0
RW-3	3+60	57	21	30.0-51.0
RW-4	4+40	54	20	29.0-49.0
RW-5	5+20	55	20	30.0-50.0
RW-6	6+00	55.6	20	30.6-50.6
RW-7	6+80	57	19	33.0-52.0
RW-8	7+60	55	18	32.0-50.0
RW-9	8+40	49	15	29.0-44.0
RW-10	9+20	50	13	32.0-45.0
RW-11	10+00	48	11	32.0-43.0
RW-12	10+80	48	8	35.0-43.0
RW-13	11+60	49	10	34.0-44.0
RW-14	12+40	50	12	32.5-44.5
RW-15B	13+40	53	5.5	42.5-48.0
RW-16	15+40	50	8	37.0-45.0
RW-17	16+90	52	10	35.0-45.0
RW-18	18+40	49	8	38.0-46.0
RW-19	19+90	54	9	35.0-44.0
RW-20	21+40	54	9	40.0-49.0
RW-21	22+90	54	6	43.0-49.0
P-1	2+50	61	20	35.5-55.5
P-2	5+50	64	19	39.0-58.0
P-31	8+50	59.5	21	33.5-54.5
P-4	11+50	54	8	41.0-49.0
P-5	11+50	54	8	41.0-49.0
P-6	15+25	50	8	37.0-45.0
P-7	15+25	50	8	37.0-45.0
P-8	20+25	55	9	41.0-50.0
P-9	20+25	55	9	41.0-50.0
P-10	24+00	40	5	30.0-35.0
P-11	24+00	40	5	30.0-35.0
P-12	5+60	57	21	33.0-54.0
P-13	8+80	56	16	35.0-51.0
P-14	12+00	51	12	34.0-46.0
P-15	14+65	42	10	32.0-42.0
P-16	22+15	56	9	42.0-5[illegible].0
22-13	17+50	49	10	34.0-44.0

NOTES:

1. Well and Piezometer designs are based on existing subsurface data. Screen placements for all wells and piezometers shall be based on conditions observed at each well site during construction.
2. See Plates 12 through 16 for location of Discharge Wells, Recharge Wells and Piezometers.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

NORTHWEST BOUNDARY CONTAINMENT

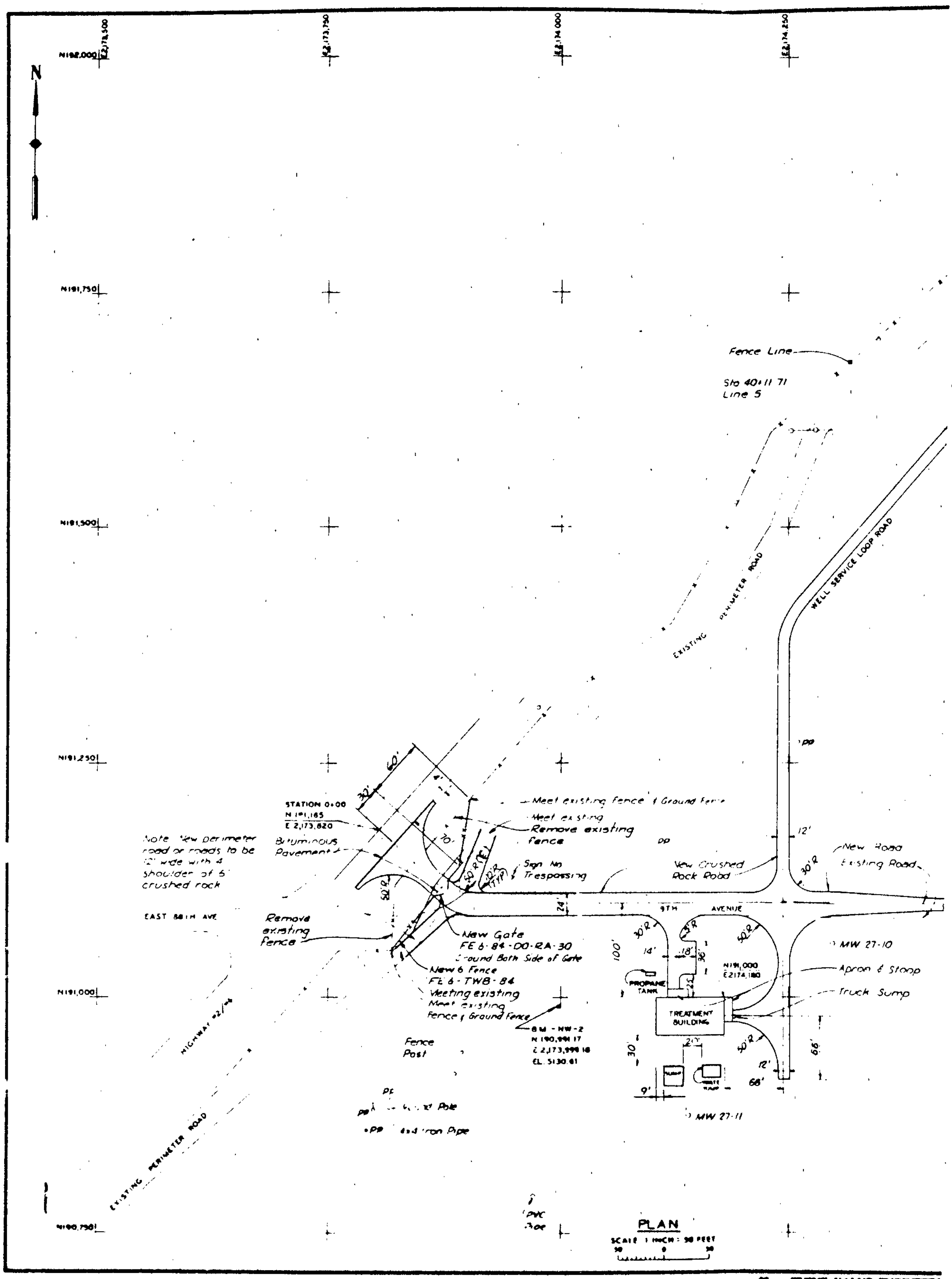
WELL AND PIEZOMETER DETAILS

FY 81 MCA PN 30.2

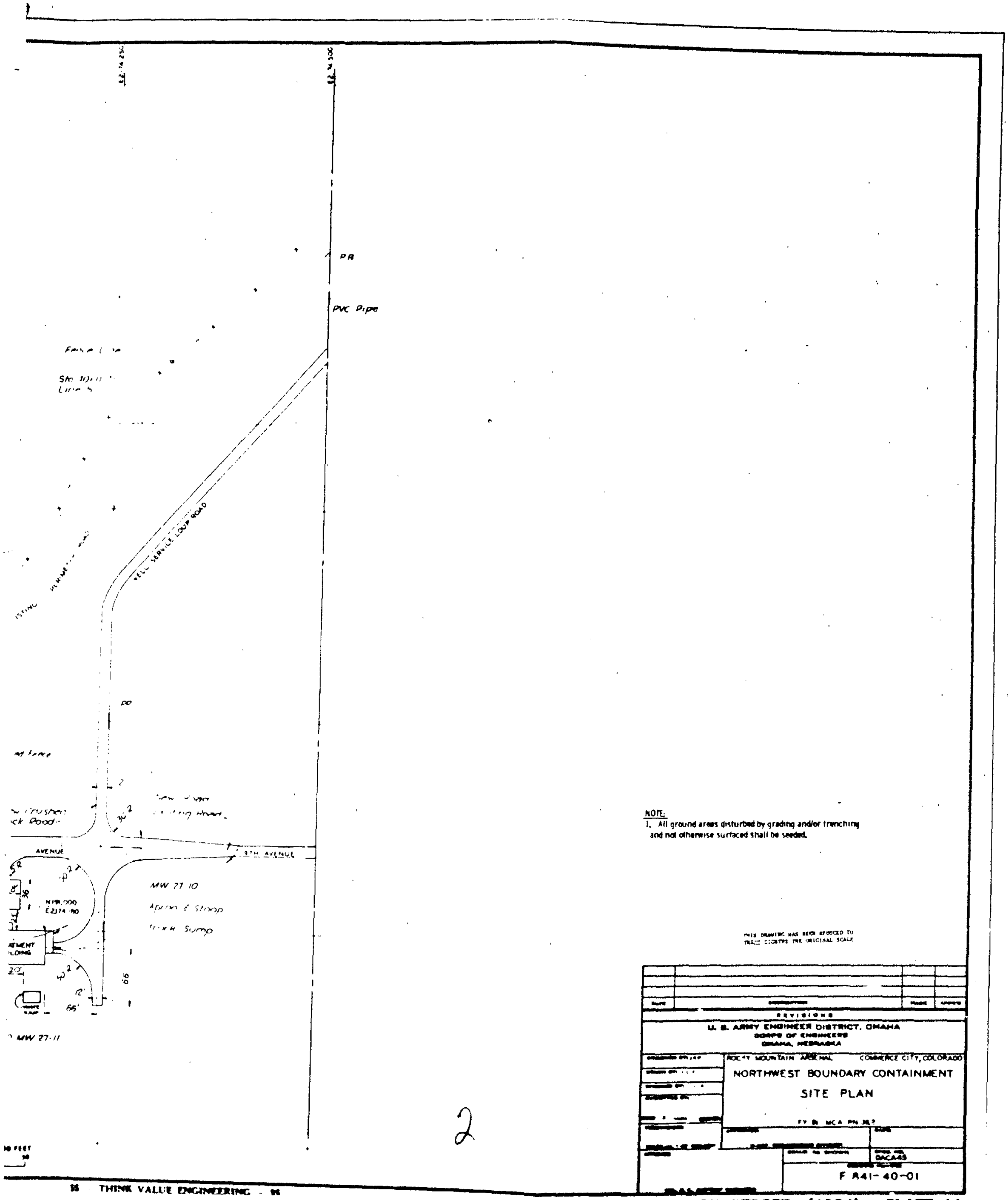
DACA45

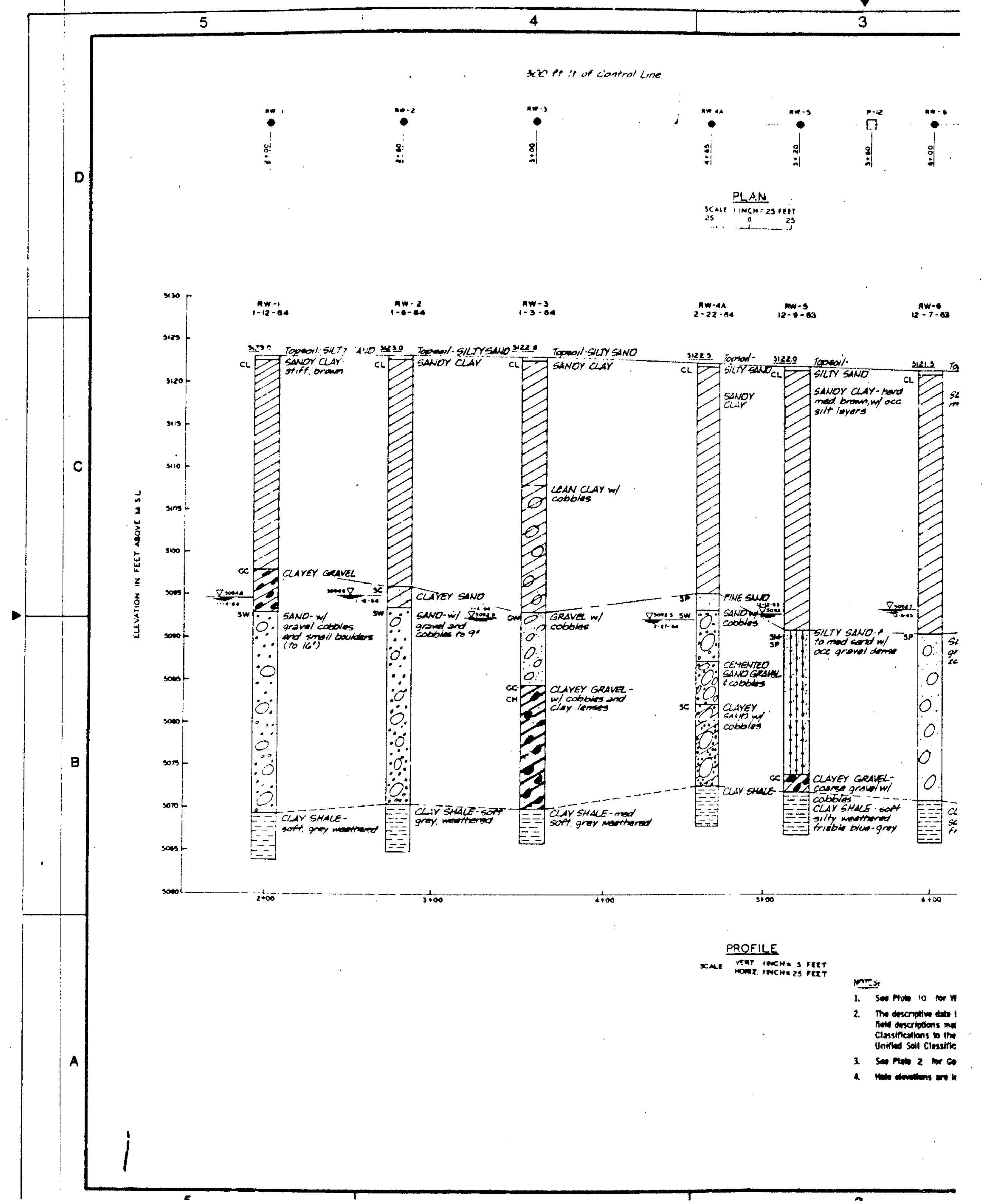
F 841-40-01

2

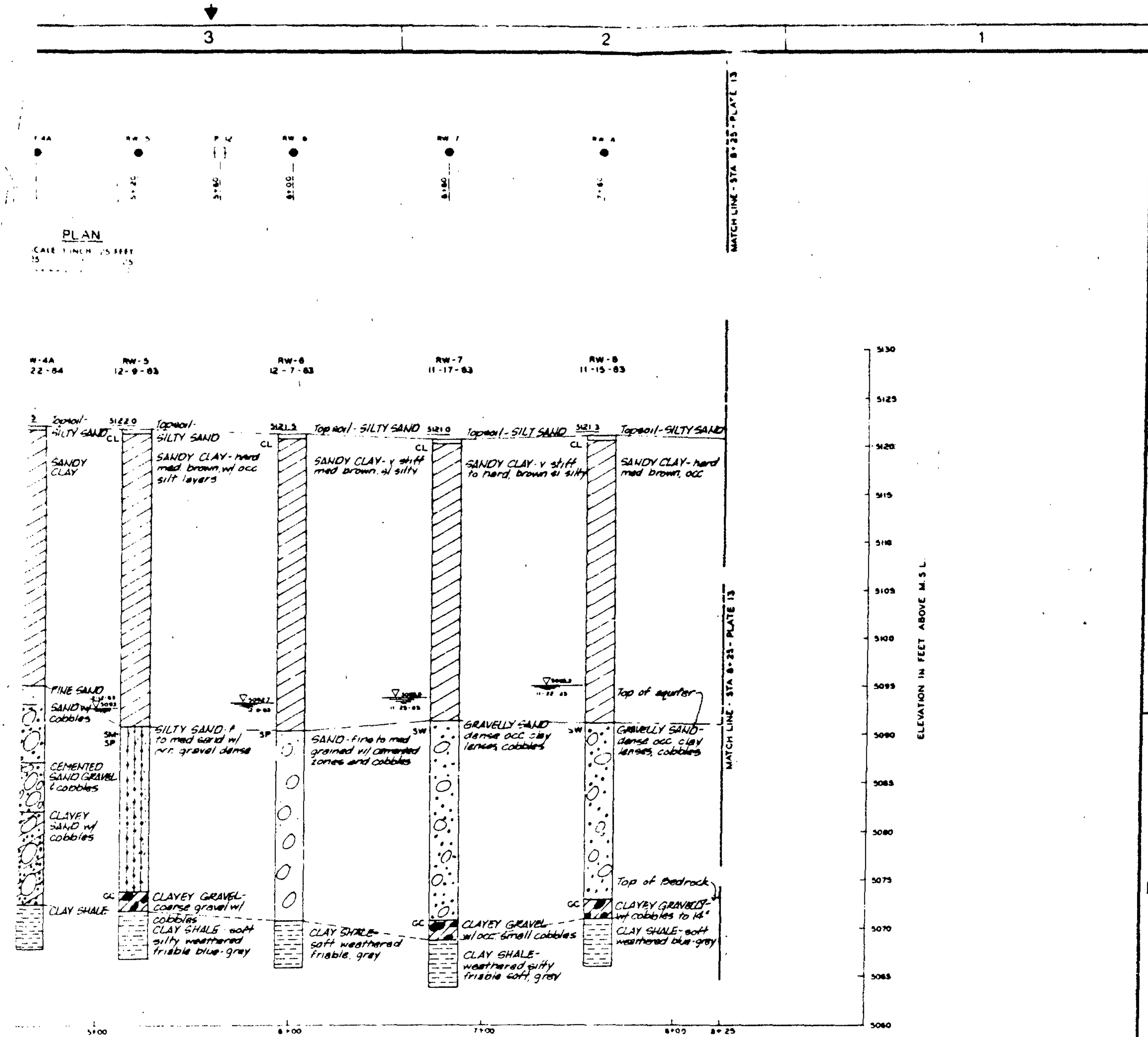


N
N192,000
E2,173,500
E2,173,750
E2,174,000
E2,174,250
N191,750
N191,500
N191,250
N191,000
N190,750
Fence Line
Sta 40+11 71
Line 5
EXISTING PERIMETER ROAD
WELL SERVICE LOOP ROAD
STATION 0+00
N 191,165
E 2,173,820
Meet existing Fence & Ground Fence
Meet existing
Remove existing fence
Bituminous Pavement
Sign No Trespassing
New Crushed Rock Road
New Road
Existing Road
Note: New perimeter road or roads to be 12' wide with 4' shoulder of 5' crushed rock
EAST 88TH AVE
9TH AVENUE
Remove existing fence
New Gate
FE 6-84-DO-RA-30
Ground Both Side of Gate
New 6' Fence
FE 6-TWB-84
Meeting existing
Meet existing
Fence & Ground Fence
BM-NW-2
N 190,991.17
E 2,173,999.18
EL. 5130.61
PROPANE TANK
TREATMENT BUILDING
N191,000
E2174,180
MW 27-10
Apron & Stoop
Truck Sump
MW 27-11
Fence Post
HIGHWAY #2
Iron Pipe
PVC Pipe
PLAN
SCALE 1 INCH = 50 FEET


PR
PVC Pipe
WELL SERVICE LOOP ROAD
9TH AVENUE
AVENUE
MW 27-10
MW 27-11
NOTE:
1. All ground areas disturbed by grading and/or trenching and not otherwise surfaced shall be seeded.
REVISIONS
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
ROCKY MOUNTAIN ARSENAL
COMMERCE CITY, COLORADO
NORTHWEST BOUNDARY CONTAINMENT
SITE PLAN
DACA45
F R41-40-01
2



5
4
3
D
C
B
A
300 ft lt of Control Line
RW-1
RW-2
RW-3
RW-4A
RW-5
P-12
RW-6
PLAN
SCALE 1 INCH = 25 FEET
RW-1 1-12-84
RW-2 1-6-84
RW-3 1-3-84
RW-4A 2-22-84
RW-5 12-9-83
RW-6 12-7-83
ELEVATION IN FEET ABOVE M S L
Topsoil-SILTY SAND
SANDY CLAY stiff, brown
CLAYEY GRAVEL
SAND- w/ gravel cobbles and small boulders (to 16")
CLAY SHALE- soft, grey weathered
Topsoil-SILTY SAND
SANDY CLAY
CLAYEY SAND
SAND- w/ gravel and cobbles to 9"
CLAY SHALE- soft grey, weathered
Topsoil-SILTY SAND
SANDY CLAY
LEAN CLAY w/ cobbles
GRAVEL w/ cobbles
CLAYEY GRAVEL- w/ cobbles and clay lenses
CLAY SHALE- med soft grey weathered
Topsoil-SILTY SAND
SANDY CLAY
FINE SAND
SAND w/ cobbles
CEMENTED SAND GRAVEL & cobbles
CLAYEY SAND w/ cobbles
CLAY SHALE
Topsoil-SILTY SAND
SANDY CLAY- hard med. brown, w/ occ silt layers
SILTY SAND- f to med sand w/ occ gravel dense
CLAYEY GRAVEL- coarse gravel w/ cobbles
CLAY SHALE- soft silty weathered friable blue-grey
PROFILE
SCALE VERT 1 INCH = 5 FEET
HORIZ. 1 INCH = 25 FEET
NOTES:
1. See Plate 10 for W
2. The descriptive data field descriptions ma Classifications to the Unified Soil Classific
3. See Plate 2 for Ge
4. Hole elevations are i



PROFILE

SCALE VERT 1 INCH = 5 FEET
HORIZ 1 INCH = 25 FEET

NOTES:

1. See Plate 10 for Well and Piezometer Dimension Schedule.
2. The descriptive data to the right of the logs are the results of field descriptions made by the driller at the time of drilling. Classifications to the left of the logs are in accordance with the Unified Soil Classification System TM3-357, May 1967.
3. See Plate 2 for Geotechnical Legend and Notes.
4. Hole elevations are interpolated.

$$ — THINK VALUE ENGINEERING — $$

Revisions			
Symbol	Descriptions	Date	Approved

U S ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
OMAHA, NEBRASKA

ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

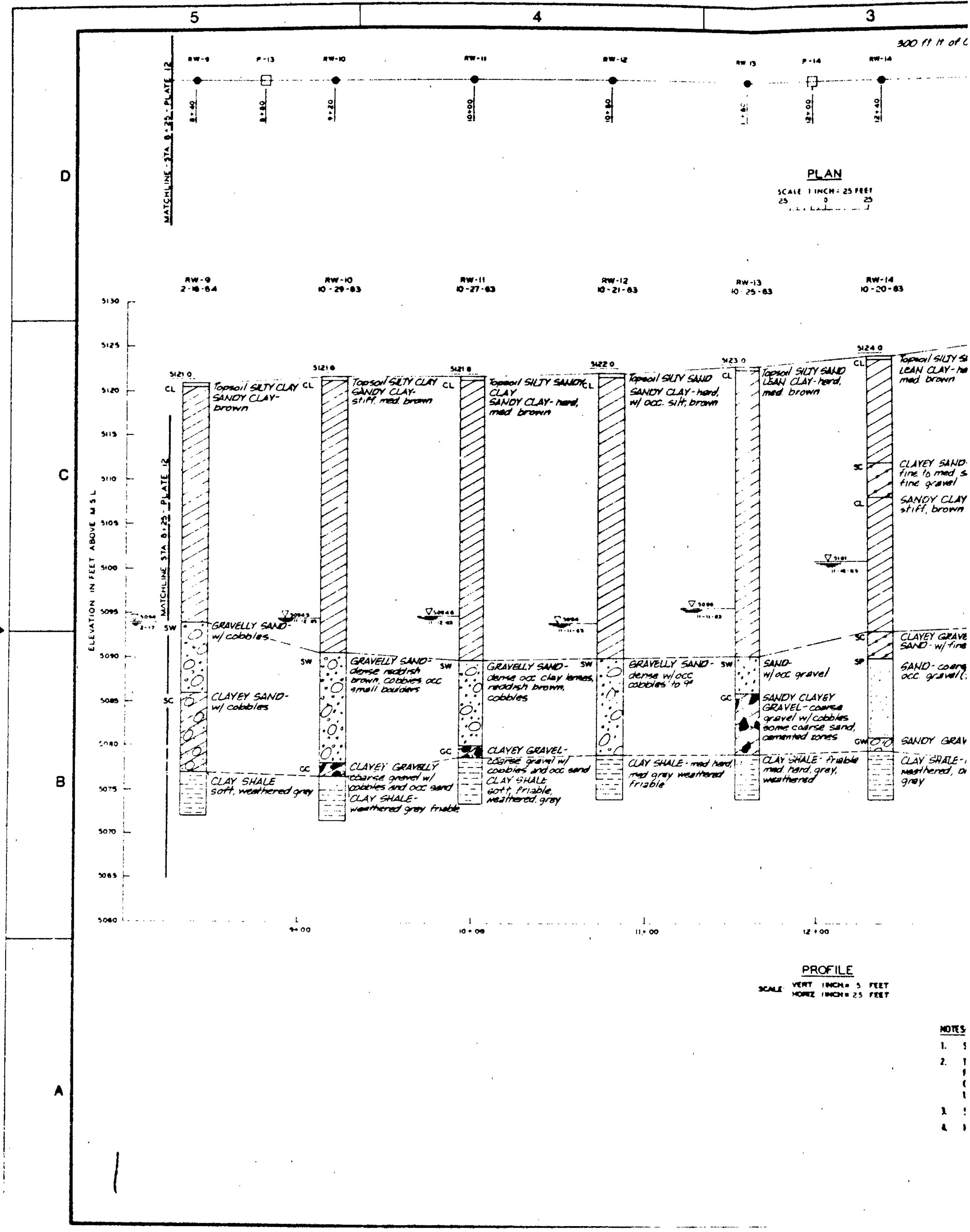
NORTHWEST BOUNDARY CONTAINMENT
PLAN AND PROFILE OF
RECHARGE LINE
LOG OF WELLS [illegible] RW-6

Designed by: L M H
Drawn by: M R A
Checked by: L M H

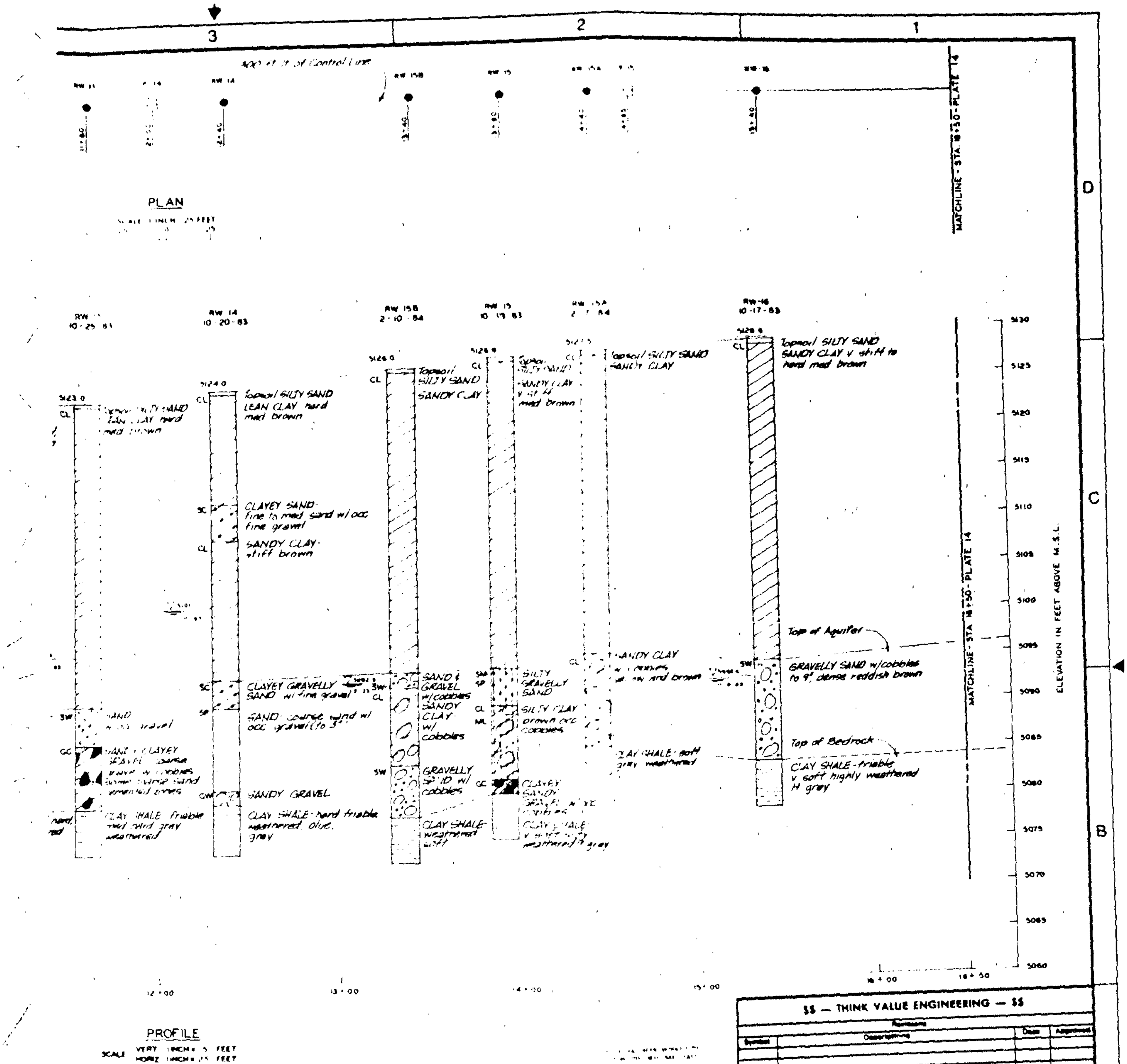
Scale: As Shown

Drawing Code: F 841-40-01

2



5
4
3
D
C
B
A
300 ft lt of C
MATCHLINE - STA 8+25 - PLATE 12
RW-9
P-13
RW-10
RW-11
RW-12
RW-13
P-14
RW-14
8+40
8+80
9+20
10+00
10+80
12+00
12+40
PLAN
SCALE 1 INCH = 25 FEET
RW-9 2-16-84
RW-10 10-29-83
RW-11 10-27-83
RW-12 10-21-83
RW-13 10-25-83
RW-14 10-20-83
ELEVATION IN FEET ABOVE M.S.L.
5130
5125
5120
5115
5110
5105
5100
5095
5090
5085
5080
5075
5070
5065
5060
5121.0
5121.6
5121.8
5122.0
5123.0
5124.0
Topsoil SILTY CLAY SANDY CLAY- brown
GRAVELLY SAND- w/ cobbles
CLAYEY SAND- w/ cobbles
CLAY SHALE soft, weathered grey
Topsoil SILTY CLAY SANDY CLAY- stiff, med. brown
GRAVELLY SAND- dense reddish brown, cobbles occ small boulders
CLAYEY GRAVELLY coarse gravel w/ cobbles and occ sand
CLAY SHALE- weathered grey friable
Topsoil SILTY SANDY CLAY SANDY CLAY- hard, med. brown
GRAVELLY SAND- dense occ. clay lenses, reddish brown, cobbles
CLAYEY GRAVEL- coarse gravel w/ cobbles and occ sand
CLAY SHALE soft, friable, weathered, grey
Topsoil SILTY SAND SANDY CLAY- hard, w/ occ. silt, brown
GRAVELLY SAND- dense w/ occ cobbles to 9"
CLAY SHALE - med hard, med grey weathered friable
Topsoil SILTY SAND LEAN CLAY- hard, med. brown
SAND- w/ occ gravel
SANDY CLAYEY GRAVEL- coarse gravel w/ cobbles some coarse sand, cemented zones
CLAY SHALE- friable med. hard, grey, weathered
CLAYEY SAND- fine to med. s fine gravel
SANDY CLAY stiff, brown
CLAYEY GRAVE SAND- w/ fine
SAND- coars occ. gravel
SANDY GRAV
CLAY SHALE- weathered, gray
CL
SW
SC
GC
SP
GW
9+00
10+00
11+00
12+00
PROFILE
SCALE: VERT 1 INCH = 5 FEET HORIZ 1 INCH = 25 FEET
NOTES:



NOTES:

1. See Plate 10 for Well and Piezometer Dimension Schedule
2. The descriptive data to the right of the logs are the results of field descriptions made by the driller at the time of drilling. Classifications to the left of the logs are in accordance with the Unified Soil Classification System TM3 357 May 1967
3. See Plate 2 for Geotechnical Legend and Notes
4. Hole elevations are interpolated

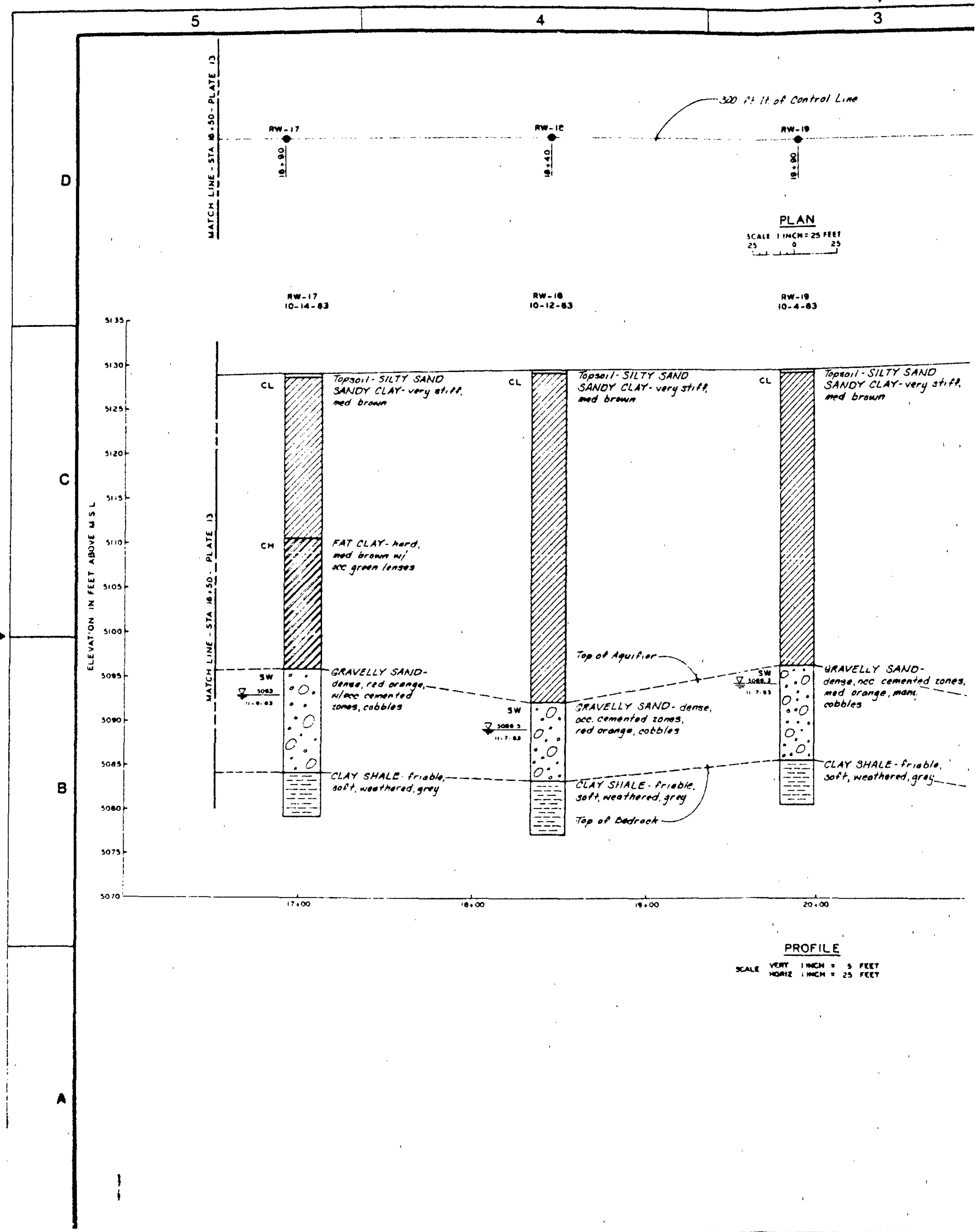
$$ — THINK VALUE ENGINEERING — $$

Symbol	Description	Date	Approved

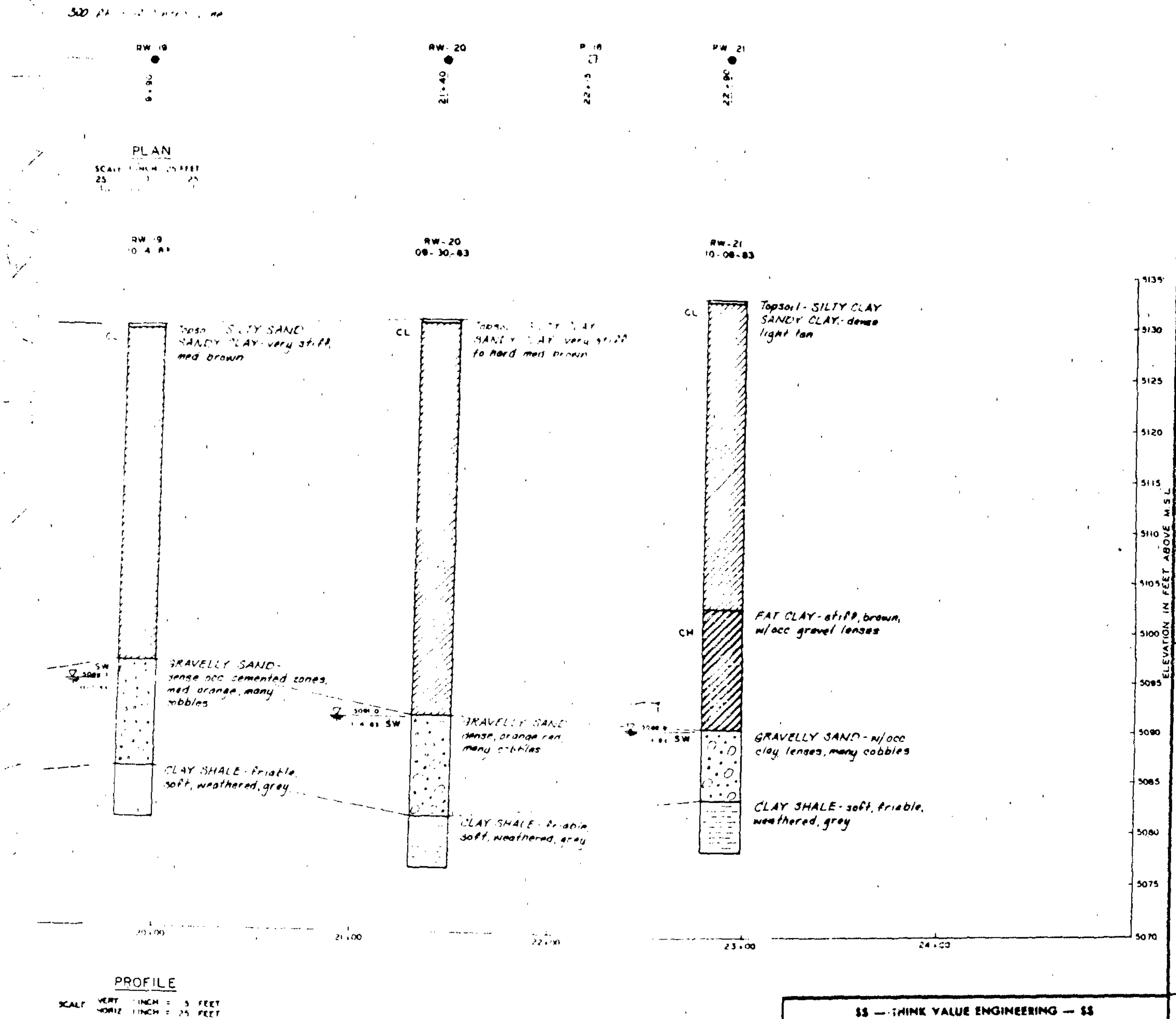
U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
OMAHA, NEBRASKA

ROCKY MOUNTAIN ARSENAL — COMMERCE CITY COLORADO

NORTHWEST BOUNDARY CONTAINMENT
PLAN AND PROFILE OF
RECHARGE LINE
LOG OF WELLS RW-9 THRU RW-16



5
4
3
D
C
B
A
MATCH LINE - STA 16+50 - PLATE 13
320 Ft It of Control Line
RW-17
RW-18
RW-19
16+90
18+40
19+90
PLAN
SCALE 1 INCH = 25 FEET
25 0 25
RW-17
10-14-83
RW-18
10-12-83
RW-19
10-4-83
ELEVATION IN FEET ABOVE M S L
5135
5130
5125
5120
5115
5110
5105
5100
5095
5090
5085
5080
5075
5070
CL
Topsoil - SILTY SAND
SANDY CLAY - very stiff, med brown
CH
FAT CLAY - hard, med brown w/ occ green lenses
SW
GRAVELLY SAND - dense, red orange, w/occ cemented zones, cobbles
5093
CLAY SHALE - friable, soft, weathered, grey
Top of Aquifier
GRAVELLY SAND - dense, occ. cemented zones, red orange, cobbles
Top of Bedrock
GRAVELLY SAND - dense, occ cemented zones, med orange, mani. cobbles
17+00
18+00
19+00
20+00
PROFILE
SCALE VERT 1 INCH = 5 FEET
HORIZ 1 INCH = 25 FEET



NOTES:

1. See Plate 10 for Well and Piezometer Dimension Schedule
2. The descriptive data to the right of the logs are the results of field descriptions made by the driller at the time of drilling. Classifications to the left of the logs are in accordance with the Unified Soil Classification System TM3-357 May 1967
3. See Plate 2 for Geotechnical Legend and Notes
4. Hole elevations are interpolated

$$ — THINK VALUE ENGINEERING — $$

Symbol	Descriptions	Date	Approved

U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
OMAHA, NEBRASKA

ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

NORTHWEST BOUNDARY CONTAINMENT

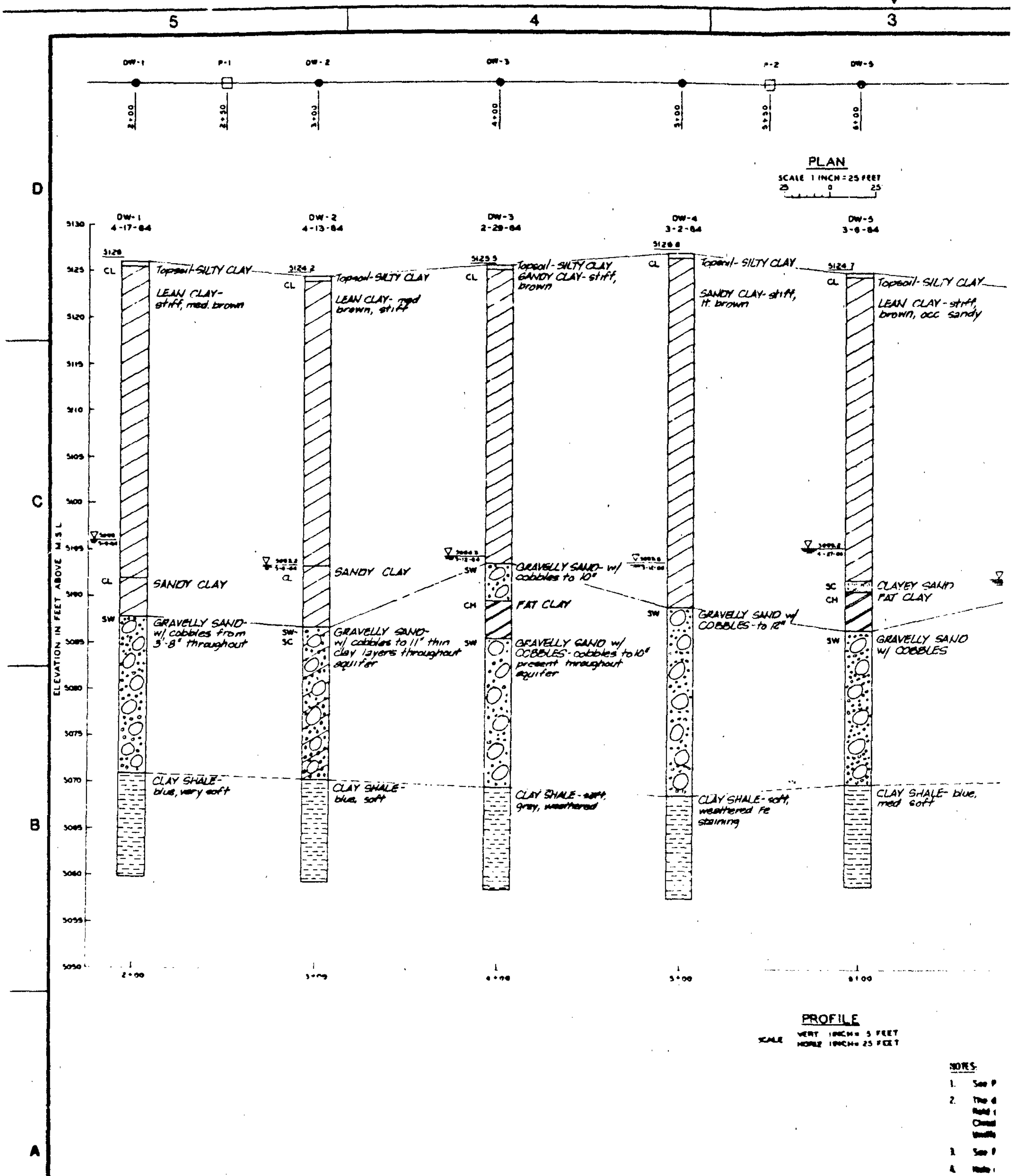
PLAN AND PROFILE OF RECHARGE LINE

LOG OF WELLS - RW-17 THRU RW-21

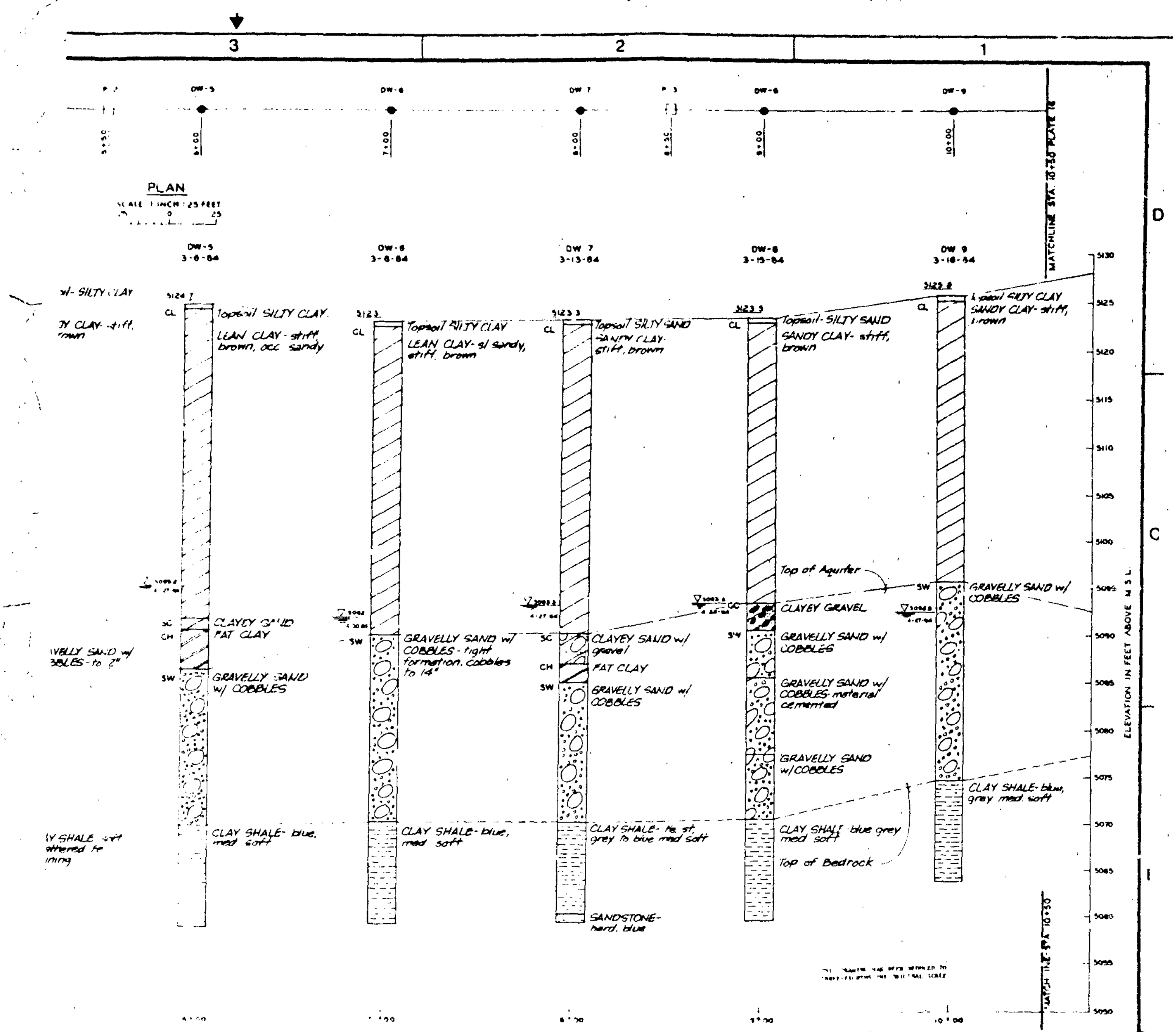
Designed by L.M.H.
Drawn by M.R.A.
Checked by L.M.H.

Scale: As Shown

... REPORT (1984) PLATE 14

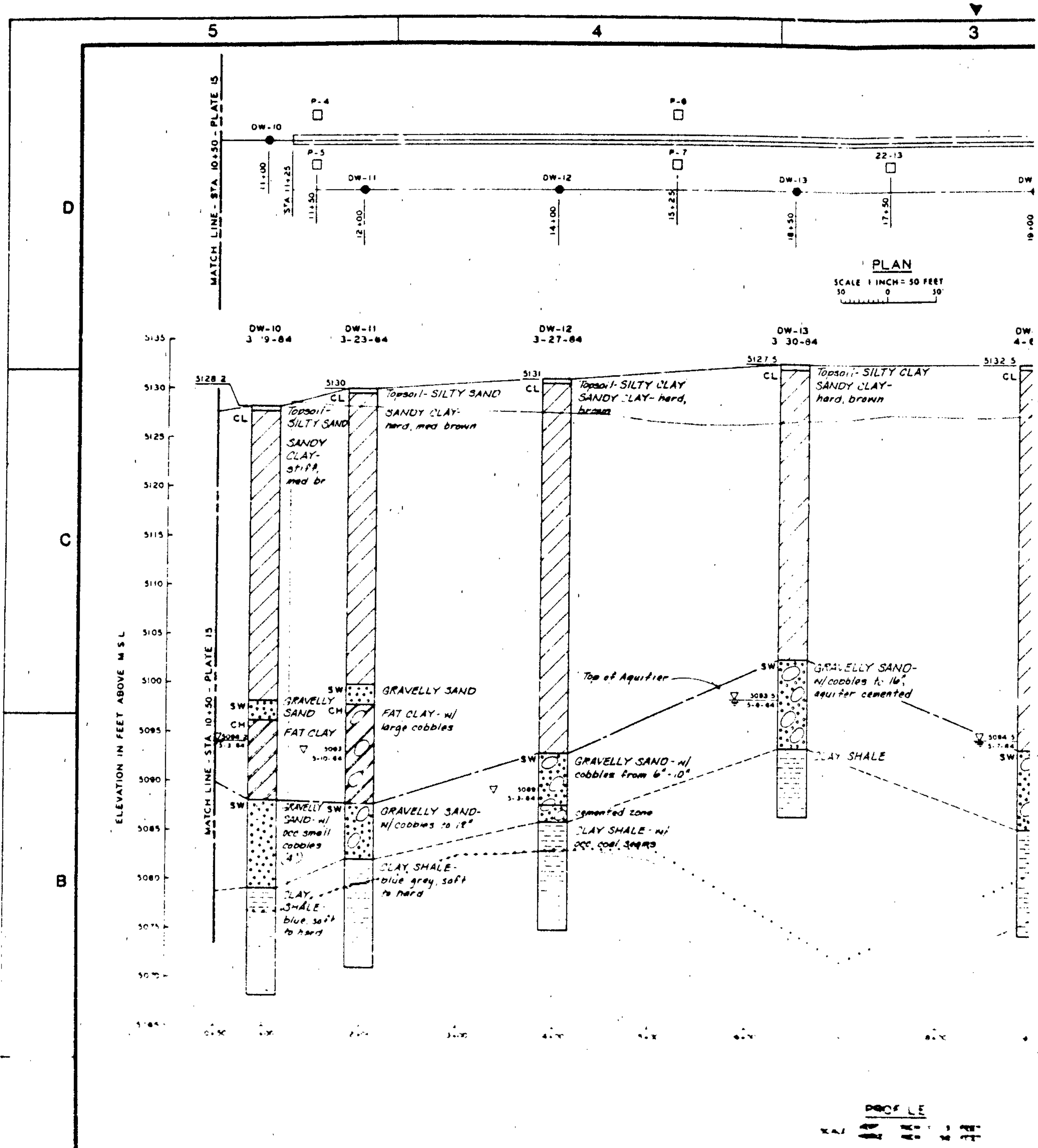


5
4
3
D
C
B
A
DW-1
P-1
DW-2
DW-3
P-2
DW-5
2+00
2+50
3+00
4+00
5+00
5+50
6+00
PLAN
SCALE 1 INCH = 25 FEET
DW-1 4-17-84
DW-2 4-13-84
DW-3 2-29-84
DW-4 3-2-84
DW-5 3-6-84
ELEVATION IN FEET ABOVE M.S.L.
5130
5125
5120
5115
5110
5105
5100
5095
5090
5085
5080
5075
5070
5065
5060
5055
5050
5129
5124.2
5125.5
5126.8
5124.7
Topsoil-SILTY CLAY
LEAN CLAY-stiff, med. brown
SANDY CLAY
GRAVELLY SAND-w/ cobbles from 3"-8" throughout
CLAY SHALE-blue, very soft
Topsoil-SILTY CLAY
LEAN CLAY-med brown, stiff
SANDY CLAY
GRAVELLY SAND-w/ cobbles to 11" thin clay layers throughout aquifer
CLAY SHALE-blue, soft
Topsoil-SILTY CLAY
SANDY CLAY-stiff, brown
GRAVELLY SAND-w/ cobbles to 10"
FAT CLAY
GRAVELLY SAND w/ COBBLES-cobbles to 10" present throughout aquifer
CLAY SHALE-soft, gray, weathered
Topsoil-SILTY CLAY
SANDY CLAY-stiff, lt. brown
GRAVELLY SAND w/ COBBLES-to 12"
CLAY SHALE-soft, weathered Fe staining
Topsoil-SILTY CLAY
LEAN CLAY-stiff, brown, occ sandy
CLAYEY SAND
FAT CLAY
GRAVELLY SAND w/ COBBLES
CLAY SHALE-blue, med soft
CL
SW
SW-SC
CH
SC
PROFILE
SCALE VERT 1 INCH = 5 FEET
HORIZ 1 INCH = 25 FEET
NOTES:

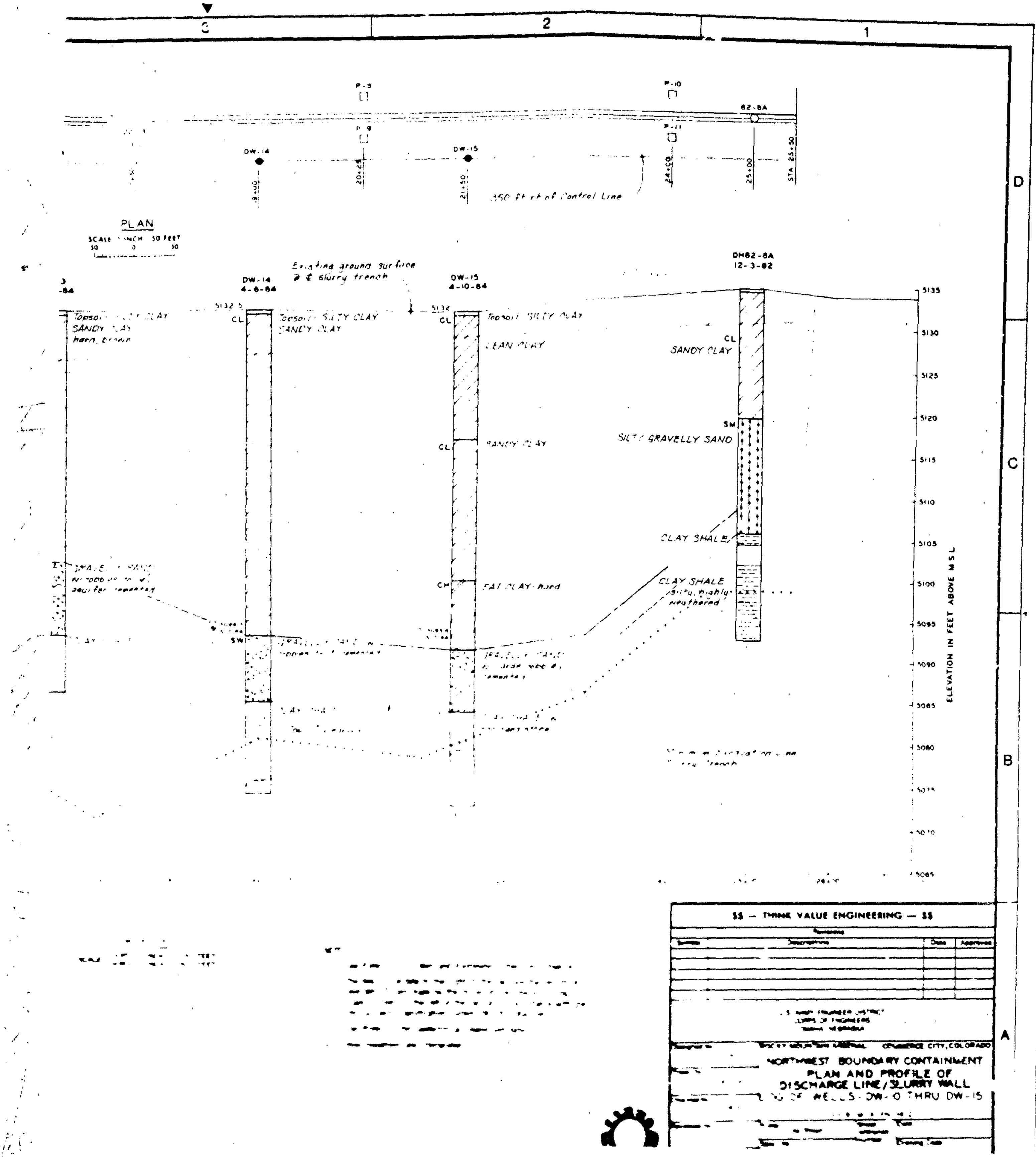


NOTES

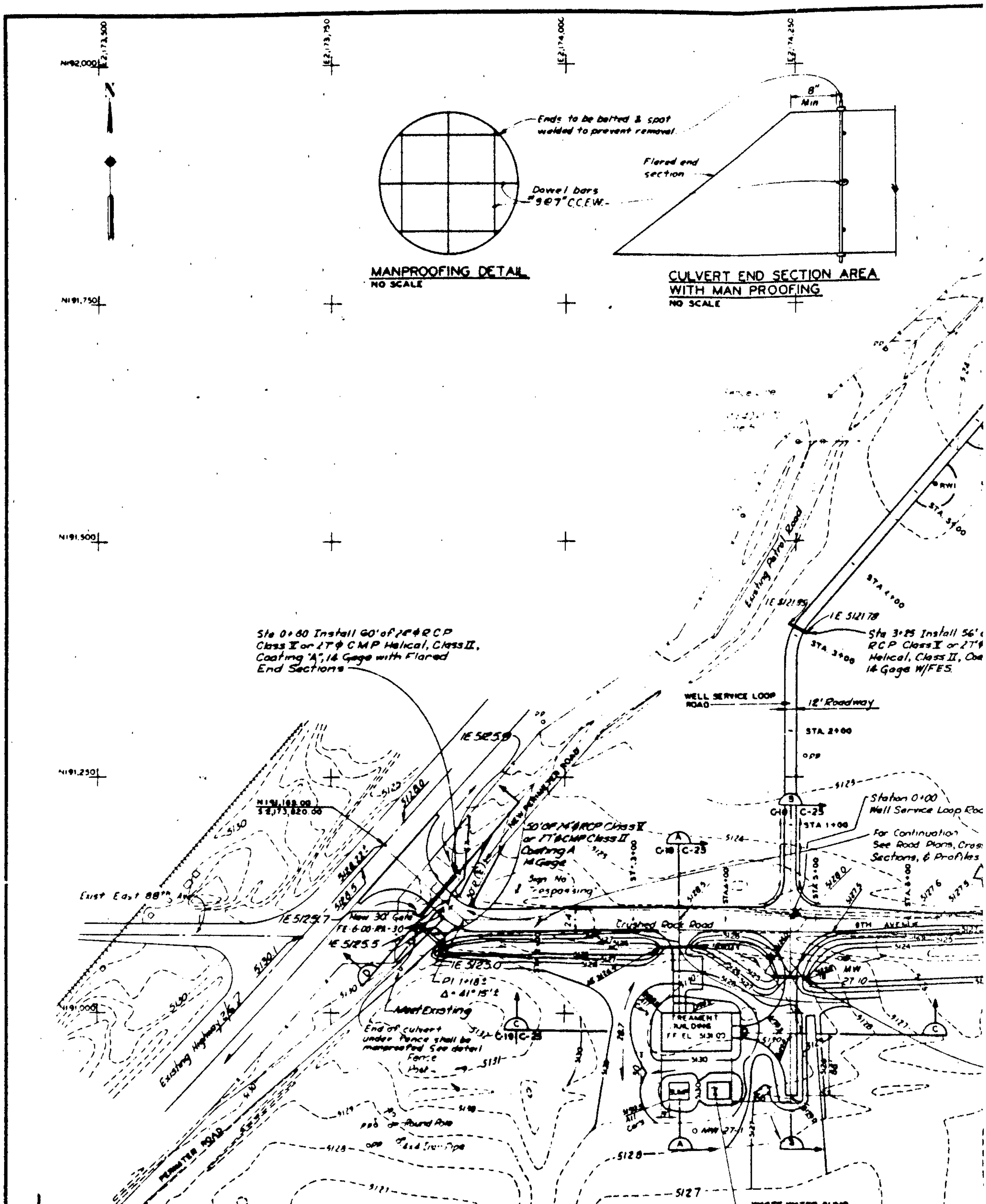
$$ — THINK VALUE ENGINEERING — $$



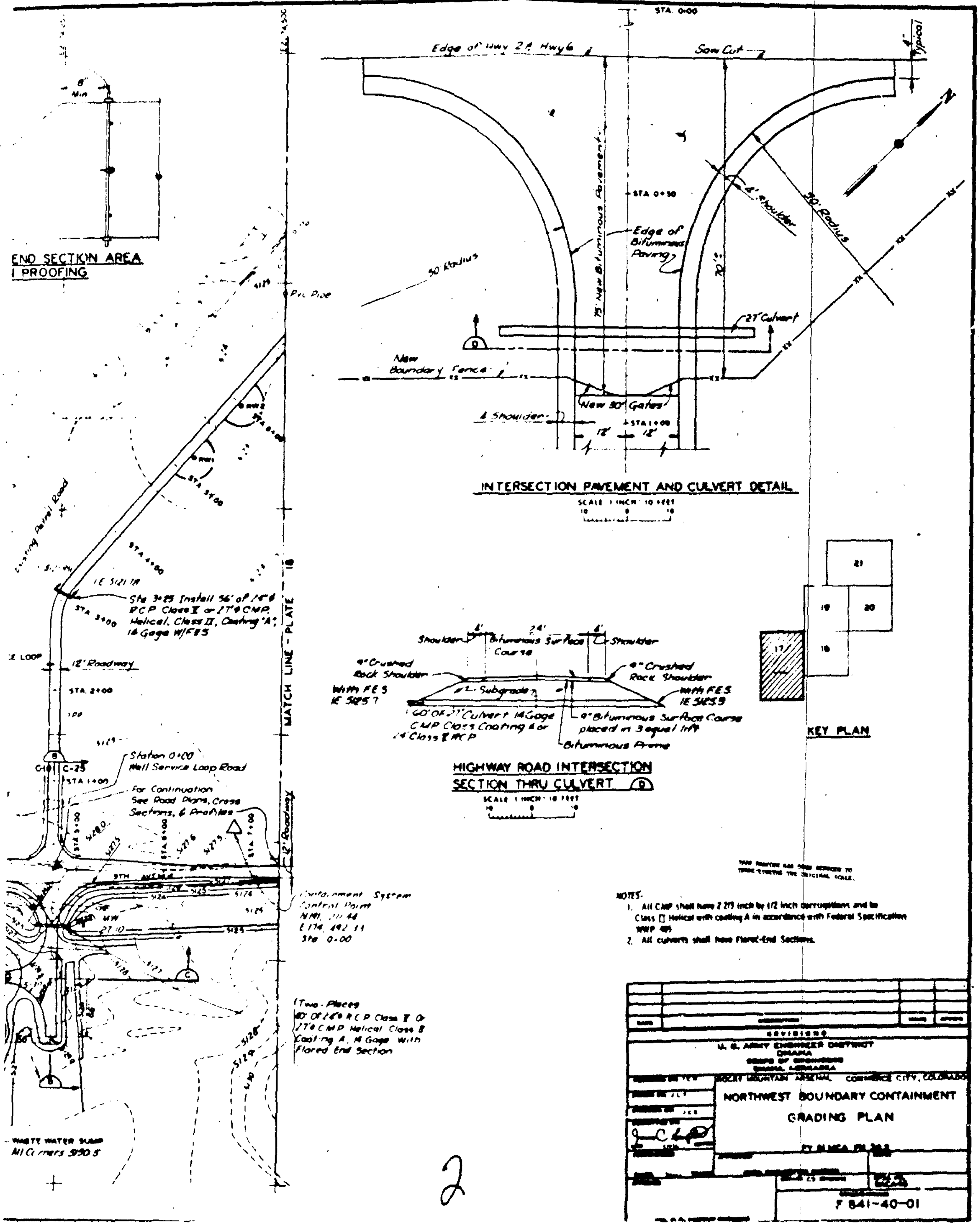
5
4
3
D
C
B
A
MATCH LINE - STA 10+50 - PLATE 15
DW-10
DW-11
DW-12
DW-13
P-4
P-5
P-6
P-7
22-13
11+00
STA 11+25
11+50
12+00
14+00
15+25
16+50
17+50
19+00
PLAN
SCALE 1 INCH = 50 FEET
ELEVATION IN FEET ABOVE M S L
DW-10 3-19-84
DW-11 3-23-84
DW-12 3-27-84
DW-13 3-30-84
5128.2
5130
5131
5127.5
5132.5
Topsoil-SILTY SAND
SANDY CLAY-stiff, med br
Topsoil-SILTY SAND
SANDY CLAY-hard, med brown
Topsoil-SILTY CLAY
SANDY CLAY-hard, brown
Topsoil-SILTY CLAY
SANDY CLAY-hard, brown
GRAVELLY SAND
FAT CLAY
GRAVELLY SAND
FAT CLAY-w/ large cobbles
GRAVELLY SAND-w/ occ small cobbles (4")
GRAVELLY SAND-w/ cobbles to 12"
CLAY SHALE-blue grey, soft to hard
CLAY SHALE-blue, soft to hard
GRAVELLY SAND-w/ cobbles from 6"-10"
cemented zone
CLAY SHALE-w/ occ. coal seams
Top of Aquifer
GRAVELLY SAND-w/cobbles to 16", aquifer cemented
CLAY SHALE
CL
SW
CH
PROFILE



3
2
1
D
C
B
A
P-9
P-10
P-11
82-8A
DW-14
DW-15
20+25
21+50
24+00
25+00
STA 25+50
350 ft ± of Control Line
PLAN
SCALE 1 INCH = 50 FEET
Existing ground surface @ ℄ slurry trench
DW-14
4-6-84
DW-15
4-10-84
DH82-8A
12-3-82
5132.5
CL
SW
CH
SM
Topsoil SILTY CLAY
SANDY CLAY
hard, brown
LEAN CLAY
SANDY CLAY
FAT CLAY hard
SILTY GRAVELLY SAND
CLAY SHALE
CLAY SHALE
silty, highly weathered
5135
5130
5125
5120
5115
5110
5105
5100
5095
5090
5085
5080
5075
5070
5065
ELEVATION IN FEET ABOVE M S L
$$ — THINK VALUE ENGINEERING — $$
Revisions
Symbol
Description
Date
Approved
ROCKY MOUNTAIN ARSENAL
COMMERCE CITY, COLORADO
NORTHWEST BOUNDARY CONTAINMENT
PLAN AND PROFILE OF
DISCHARGE LINE/SLURRY WALL
OF WELLS DW-0 THRU DW-15

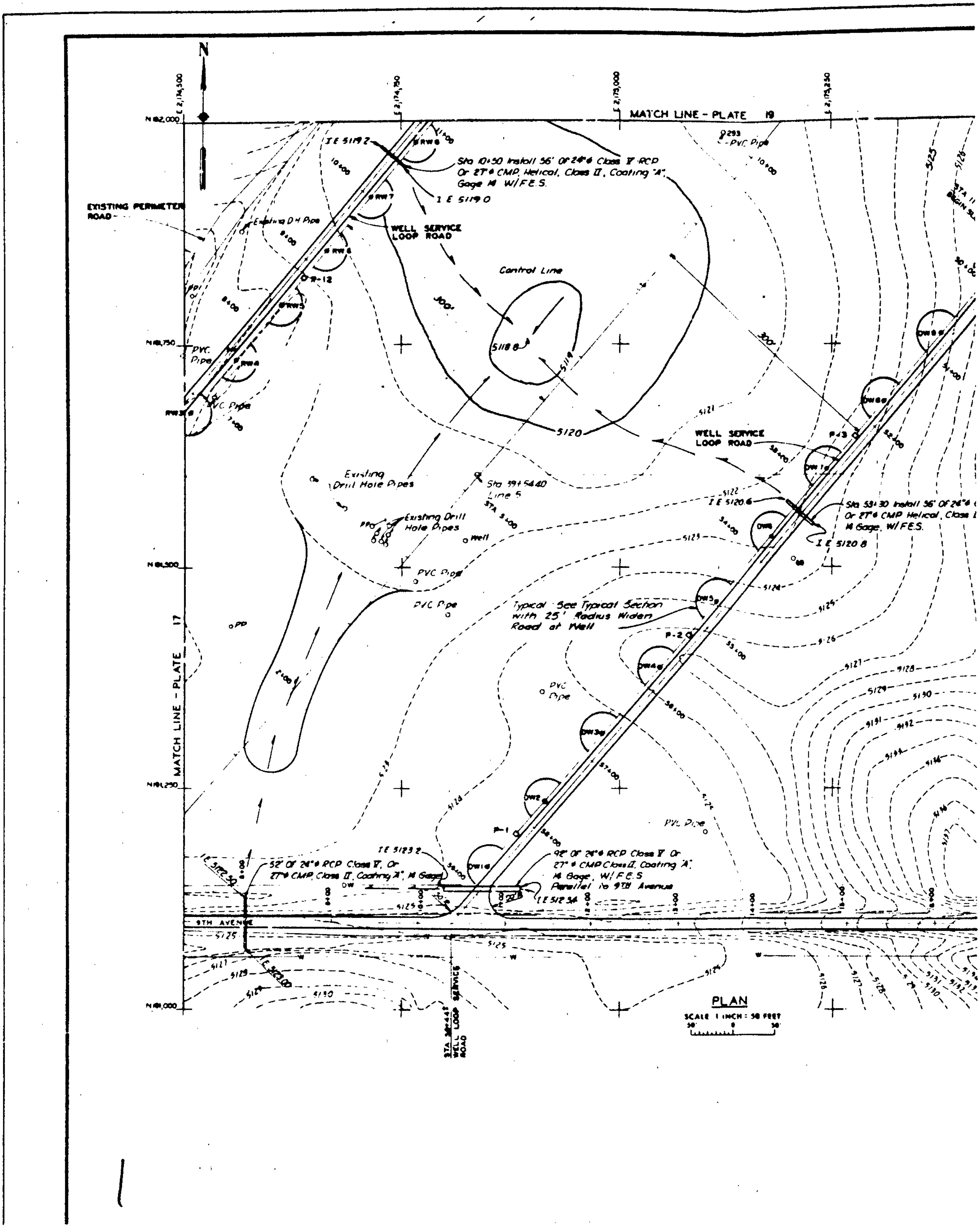


MANPROOFING DETAIL
NO SCALE
Ends to be bolted & spot welded to prevent removal
Dowel bars
CULVERT END SECTION AREA WITH MAN PROOFING
NO SCALE
Flared end section
8" Min
Sta 0+60 Install 60' of 24"Ø RCP Class V or 27"Ø CMP Helical, Class II, Coating "A", 14 Gage with Flared End Sections
Sta 3+25 Install 56'
Helical, Class II
14 Gage W/FES
WELL SERVICE LOOP ROAD
12' Roadway
STA 2+00
STA 1+00
Station 0+00 Well Service Loop Road
For Continuation See Road Plans, Cross Sections, & Profiles
Existing Patrol Road
Crushed Rock Road
8TH AVENUE
Exist East 88th Ave
Existing Highway 2&7
PERIMETER ROAD
NEW PERIMETER ROAD
New 30' Gate
Meet Existing
End of culvert under fence shall be manproofed See detail
Fence Post
Round Pole
4x4 Iron Pipe
TREATMENT BUILDING
WASTE WATER SUMP
All Corners 5130.5
5128
5127
PLAN
SCALE 1 INCH = 50 FEET

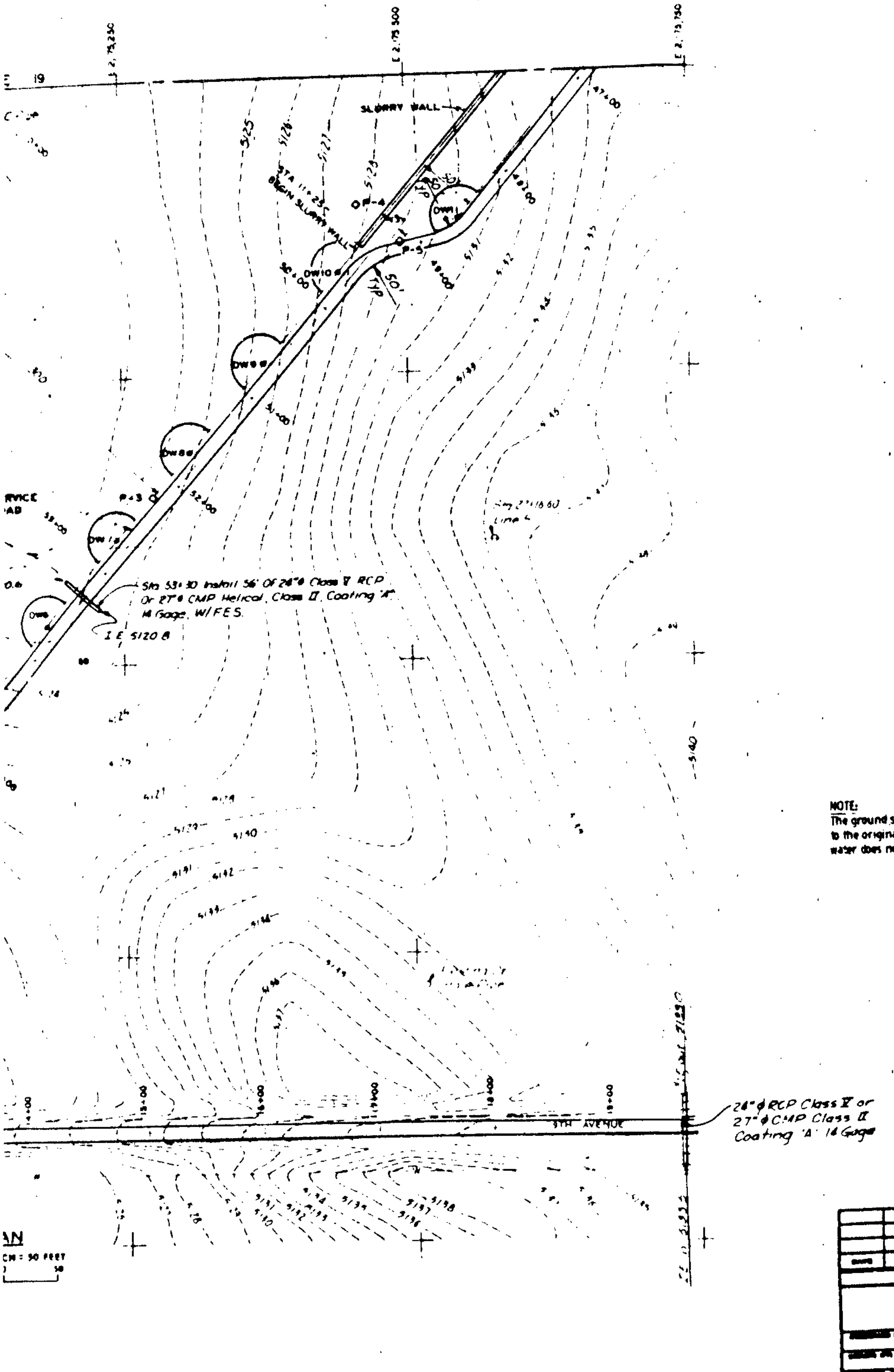


END SECTION AREA
I PROOFING
STA 0+00
Edge of Hwy 2 & Hwy 6
Saw Cut
4' Typical
75' New Bituminous Pavement
STA 0+50
Edge of Bituminous Paving
4' Shoulder
30' Radius
30' Radius
70'
27" Culvert
New Boundary Fence
New 30' Gates
4 Shoulder
STA 1+00
12'
12'
INTERSECTION PAVEMENT AND CULVERT DETAIL
SCALE 1 INCH = 10 FEET
Shoulder
Bituminous Surface Course
Shoulder
24'
4'
4'
4" Crushed Rock Shoulder
4" Crushed Rock Shoulder
With F.E.S. IE 5125.7
With F.E.S. IE 5125.9
2% Subgrade
60' OF 27" Culvert 14 Gage CMP Class Coating A or 24" Class II RCP
4" Bituminous Surface Course placed in 3 equal lifts
Bituminous Prime
HIGHWAY ROAD INTERSECTION
SECTION THRU CULVERT D
SCALE 1 INCH = 10 FEET
KEY PLAN
21
19
20
17
18
MATCH LINE - PLATE 18
Existing Patrol Road
IE 5121.78
Sta 3+25 Install 56' of 18" Ø RCP Class II or 21" Ø CMP, Helical, Class II, Coating "A", 14 Gage W/FES
12' Roadway
STA 2+00
STA 3+00
STA 4+00
STA 5+00
STA 6+00
Pvc Pipe
Station 0+00 Well Service Loop Road
For Continuation See Road Plans, Cross Sections, & Profiles
12' Roadway
Containment System Control Point
Sta 0+00
(Two Places)
40' Of 24" Ø R.C.P. Class II Or 27" Ø C.M.P. Helical Class II Coating A, 14 Gage With Flared End Section
WASTE WATER SUMP
All Corners 5130.5
THIS DRAWING HAS BEEN REDUCED TO ONE-FOURTH THE ORIGINAL SCALE.
NOTES:
1. All CMP shall have 2 2/3 inch by 1/2 inch corrugations and be Class II Helical with coating A in accordance with Federal Specification WWP 405
2. All culverts shall have Flared-End Sections.
REVISIONS
U. S. ARMY ENGINEER DISTRICT
OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO
NORTHWEST BOUNDARY CONTAINMENT
GRADING PLAN
F 841-40-01

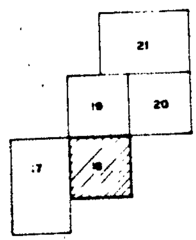
2



N
MATCH LINE - PLATE 19
MATCH LINE - PLATE 17
EXISTING PERIMETER ROAD
Sta 10+50 Install 56' Of 24"ϕ Class V RCP Or 27"ϕ CMP, Helical, Class II, Coating "A", Gage 14 W/F.E.S.
I E 5119.2
I E 5119.0
WELL SERVICE LOOP ROAD
Control Line
Existing Drill Hole Pipes
Sta 39+54.40 Line 5
Existing Drill Hole Pipes
Well
PVC Pipe
Typical See Typical Section with 25' Radius Widen Road at Well
Sta 53+30 Install 56' Of 24"ϕ Or 27"ϕ CMP Helical, Class 14 Gage, W/F.E.S.
I E 5120.6
I E 5120.8
52' Of 24"ϕ RCP Class V, Or 27"ϕ CMP, Class II, Coating "A", 14 Gage
92' Of 24"ϕ RCP Class V Or 27"ϕ CMP Class II, Coating "A", 14 Gage, W/F.E.S. Parallel to 9TH Avenue
I E 5123.2
I E 5123.4
9TH AVENUE
STA 30+44.5 WELL LOOP SERVICE ROAD
PLAN
SCALE 1 INCH = 50 FEET



NOTE:
The ground surface over the completed slurry wall shall be restored to the original ground elevations and contours, and graded so that water does not pond on or adjacent to the slurry wall.



KEY PLAN

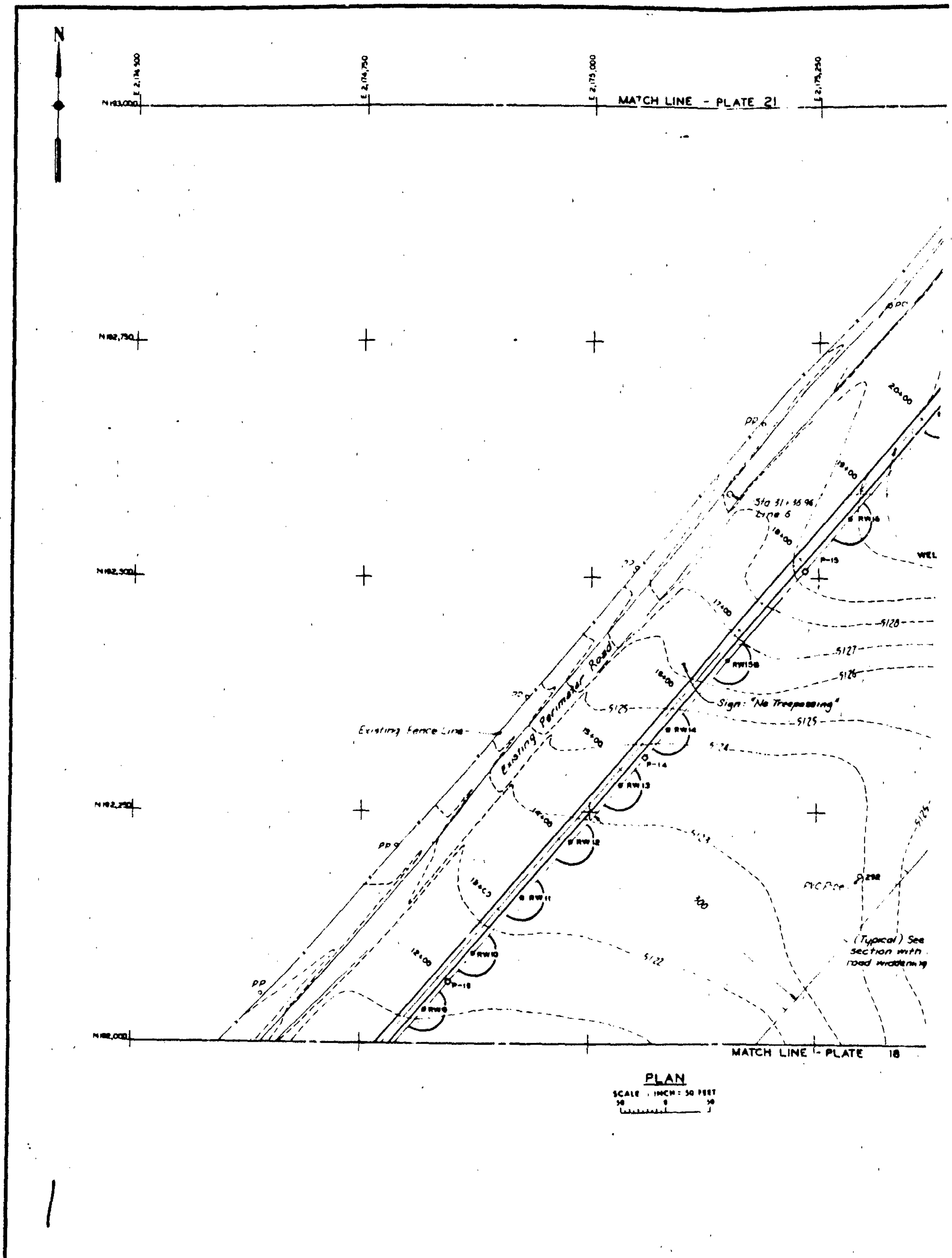
U. S. ARMY ENGINEER DISTRICT
OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

NORTHWEST BOUNDARY CONTAINMENT
WELL SERVICE LOOP ROAD
GRADING PLAN

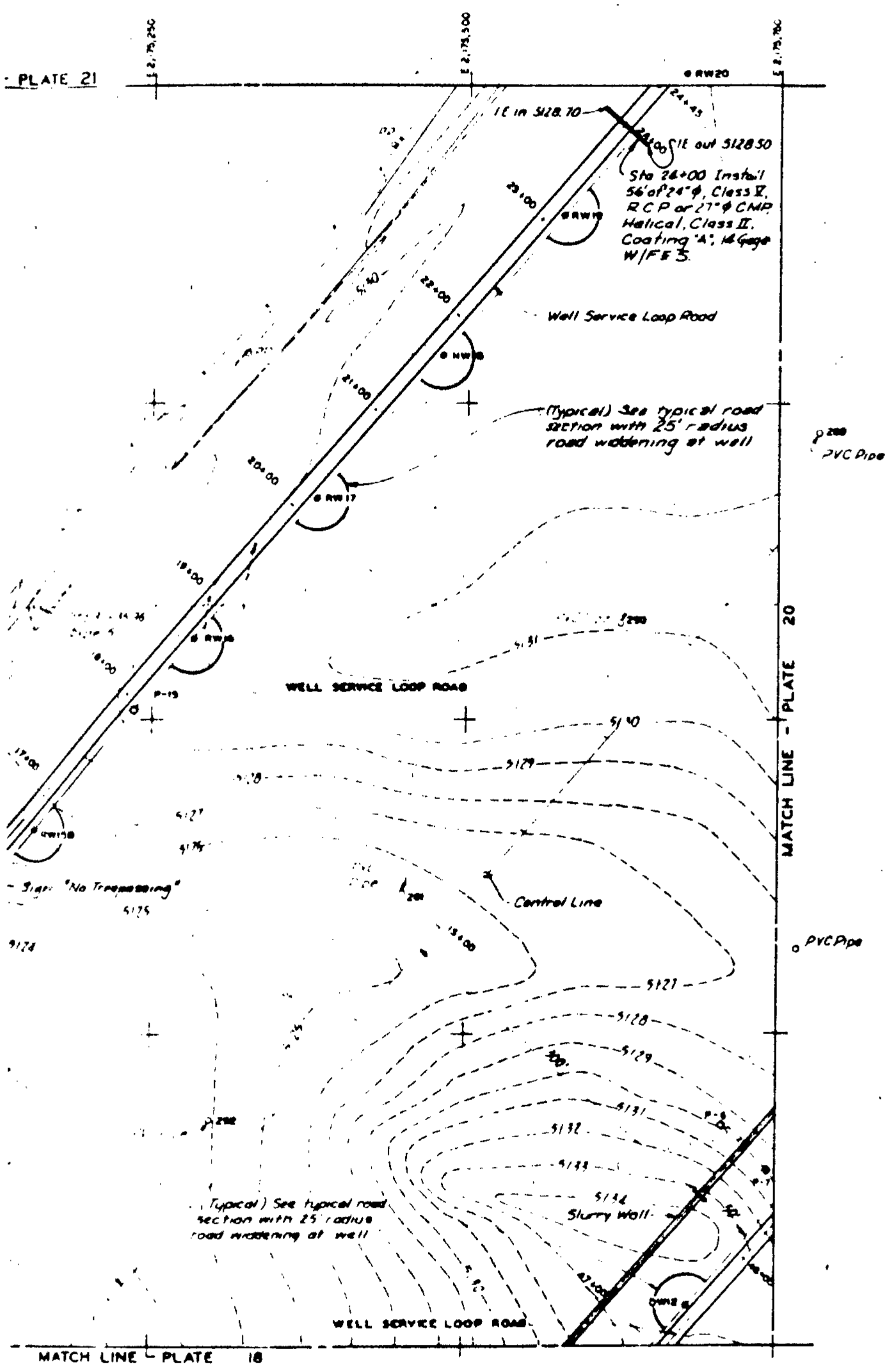
F 841-40-01

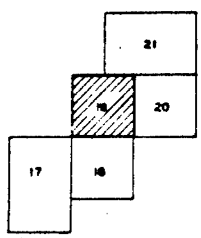
2



PLAN

SCALE 1 INCH = 50 FEET





KEY PLAN

NOTE:
The ground surface over the completed slurry wall shall be restored to the original ground elevations and contours, and graded so that water does not pond on or adjacent to the slurry wall.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

REVISIONS

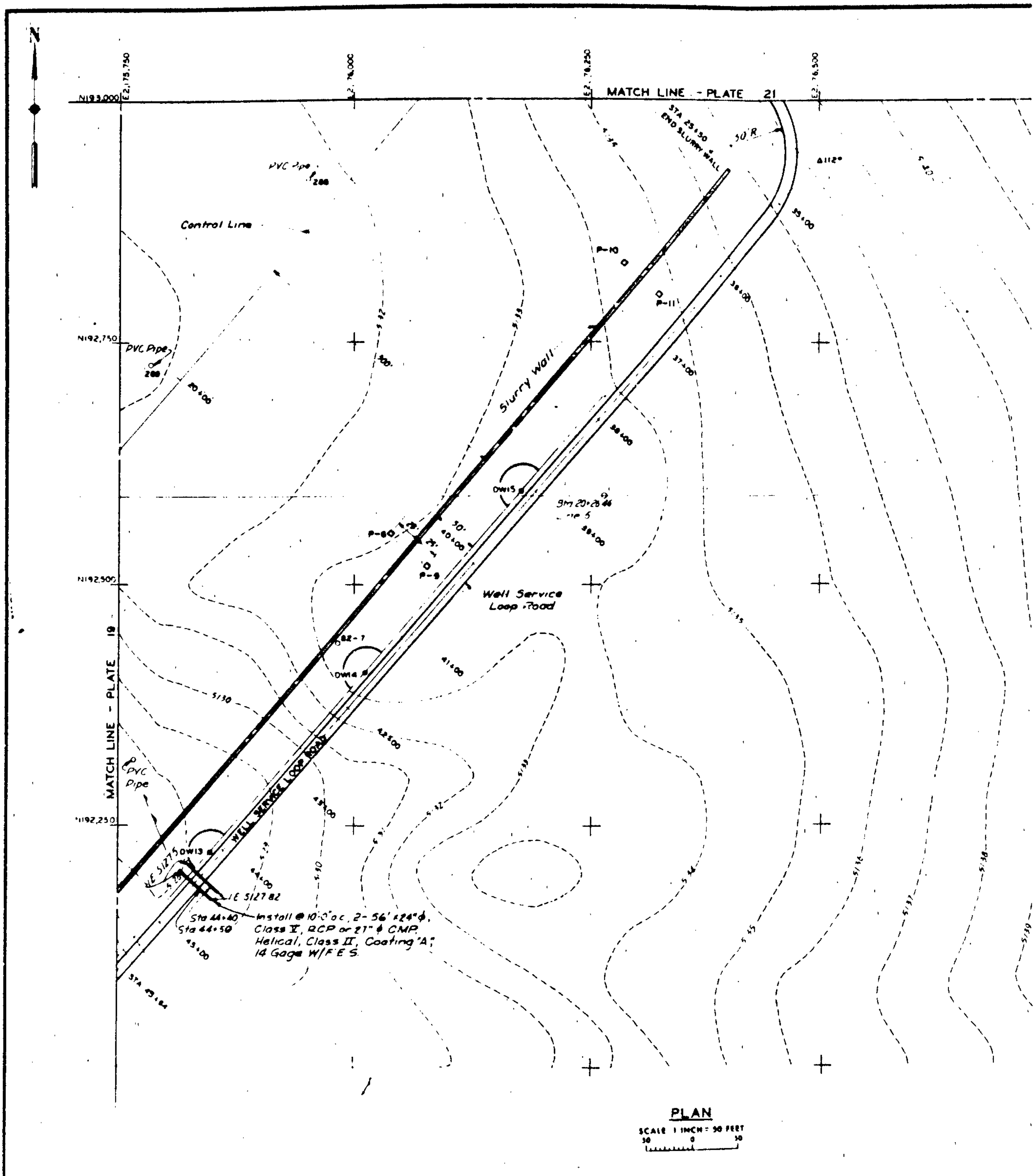
U. S. ARMY ENGINEER DISTRICT
OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

NORTHWEST BOUNDARY CONTAINMENT
WELL SERVICE LOOP ROAD
GRADING PLAN

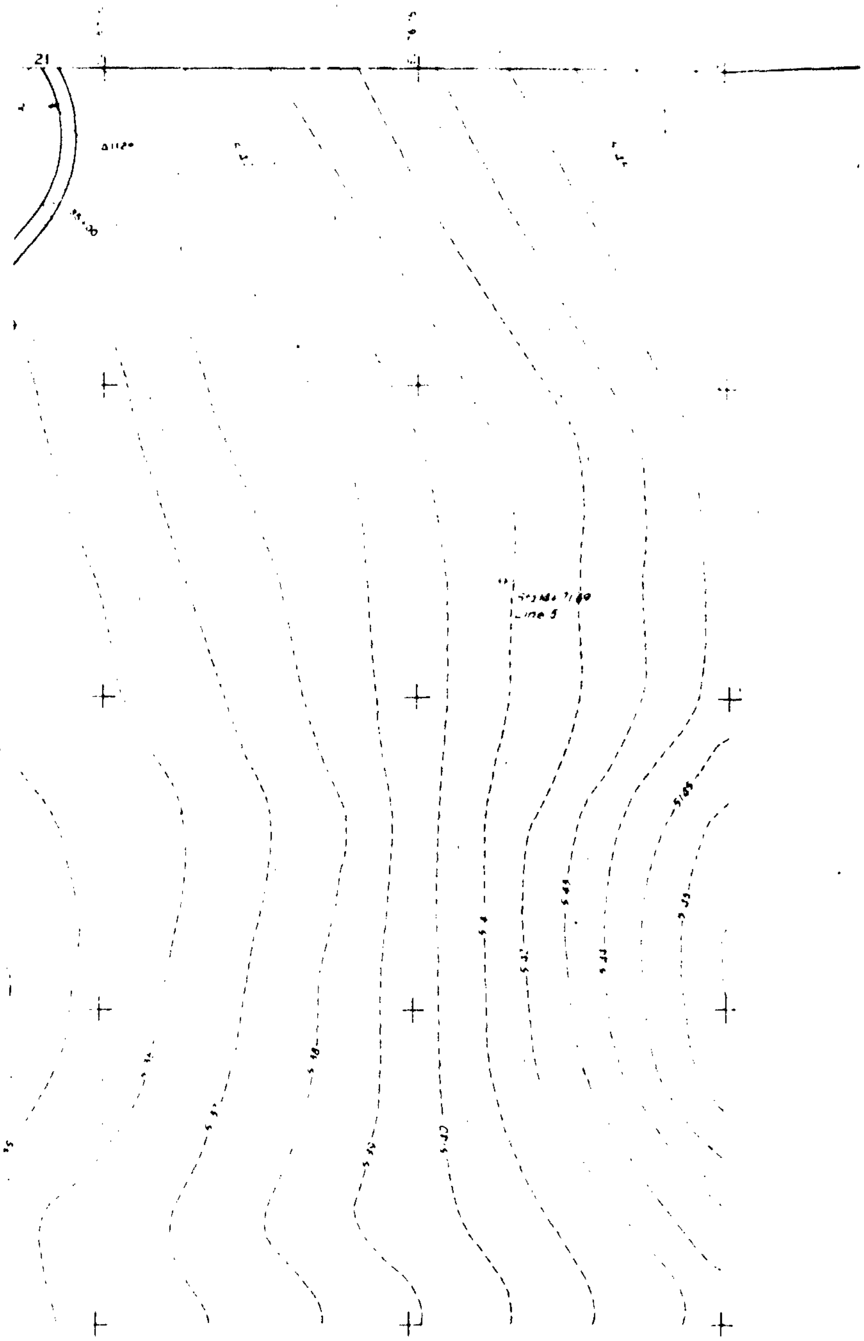
P 841-40-01

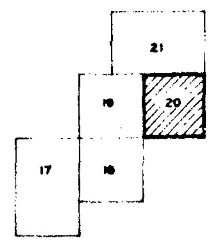
2



PLAN

SCALE 1 INCH = 50 FEET





KEY PLAN

NOTE:
The ground surface over the completed slurry wall shall be restored to the original ground elevations and contours, and graded so that water does not pond on or adjacent to the slurry wall.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE

REVISIONS

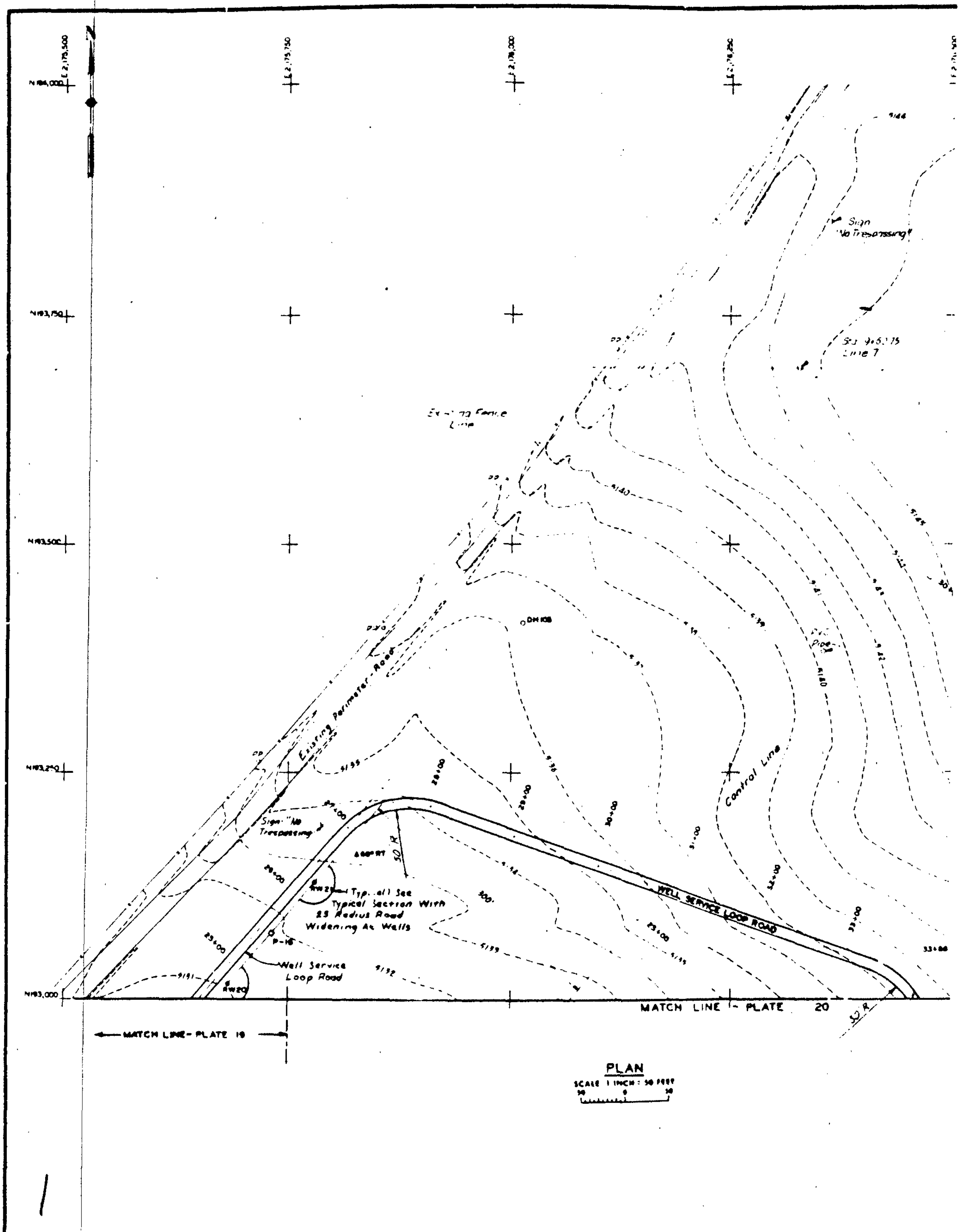
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

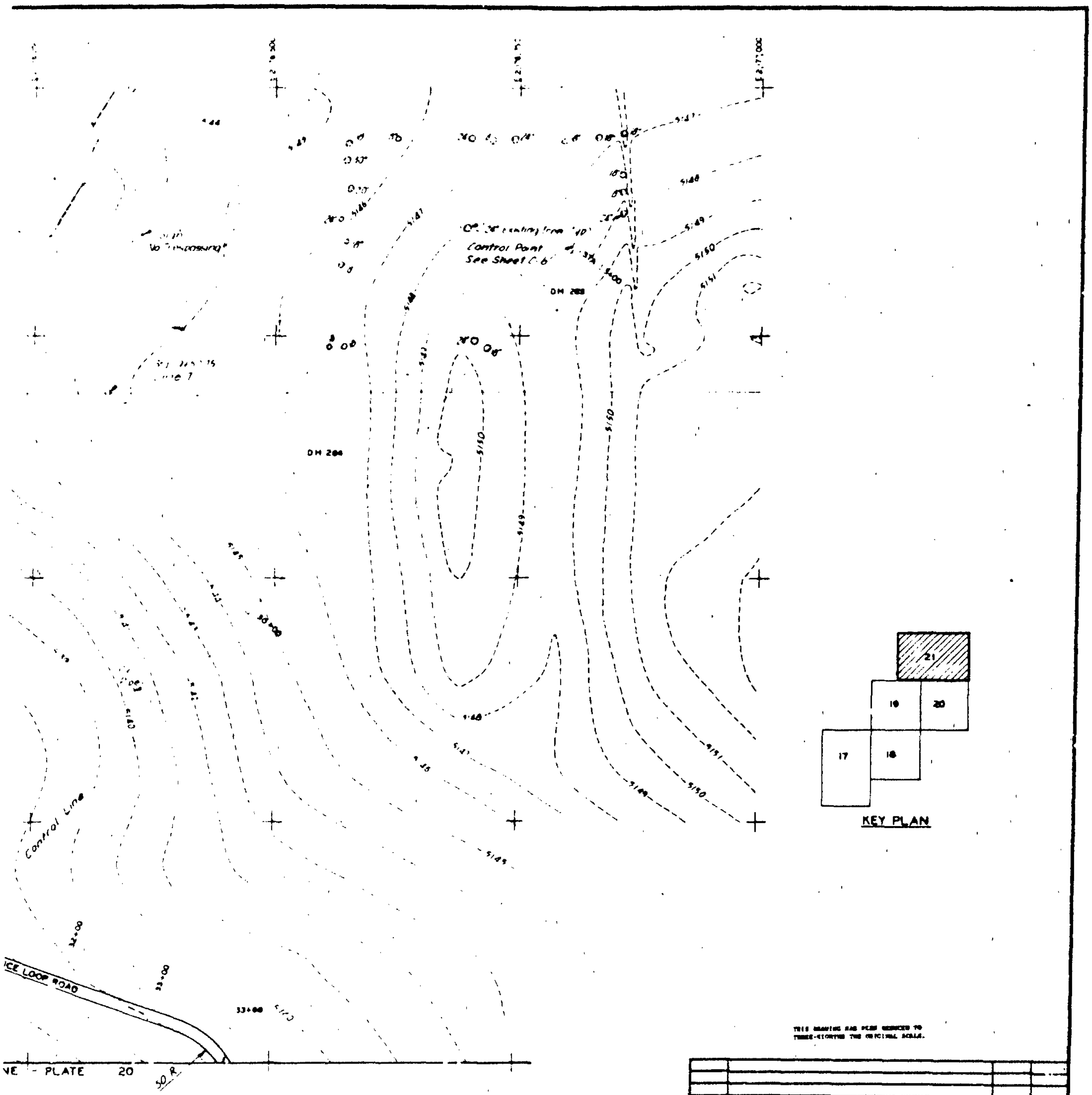
NORTHWEST BOUNDARY CONTAINMENT
WELL SERVICE LOOP ROAD
GRADING PLAN

DACA45

2



N193,750
N193,500
N193,250
N193,000
Existing Fence Line
Sign "No Trespassing"
Existing Perimeter Road
Sign "No Trespassing"
Control Line
WELL SERVICE LOOP ROAD
Typical See Typical Section With 25 Radius Road Widening At Wells
Well Service Loop Road
DH 108
P-16
RW20
50 R
MATCH LINE - PLATE 20
MATCH LINE - PLATE 19
PLAN
SCALE 1 INCH = 50 FEET



THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

REVISIONS

U. S. ARMY ENGINEER DISTRICT
OMAHA
CORPS OF ENGINEERS
OMAHA NEBRASKA

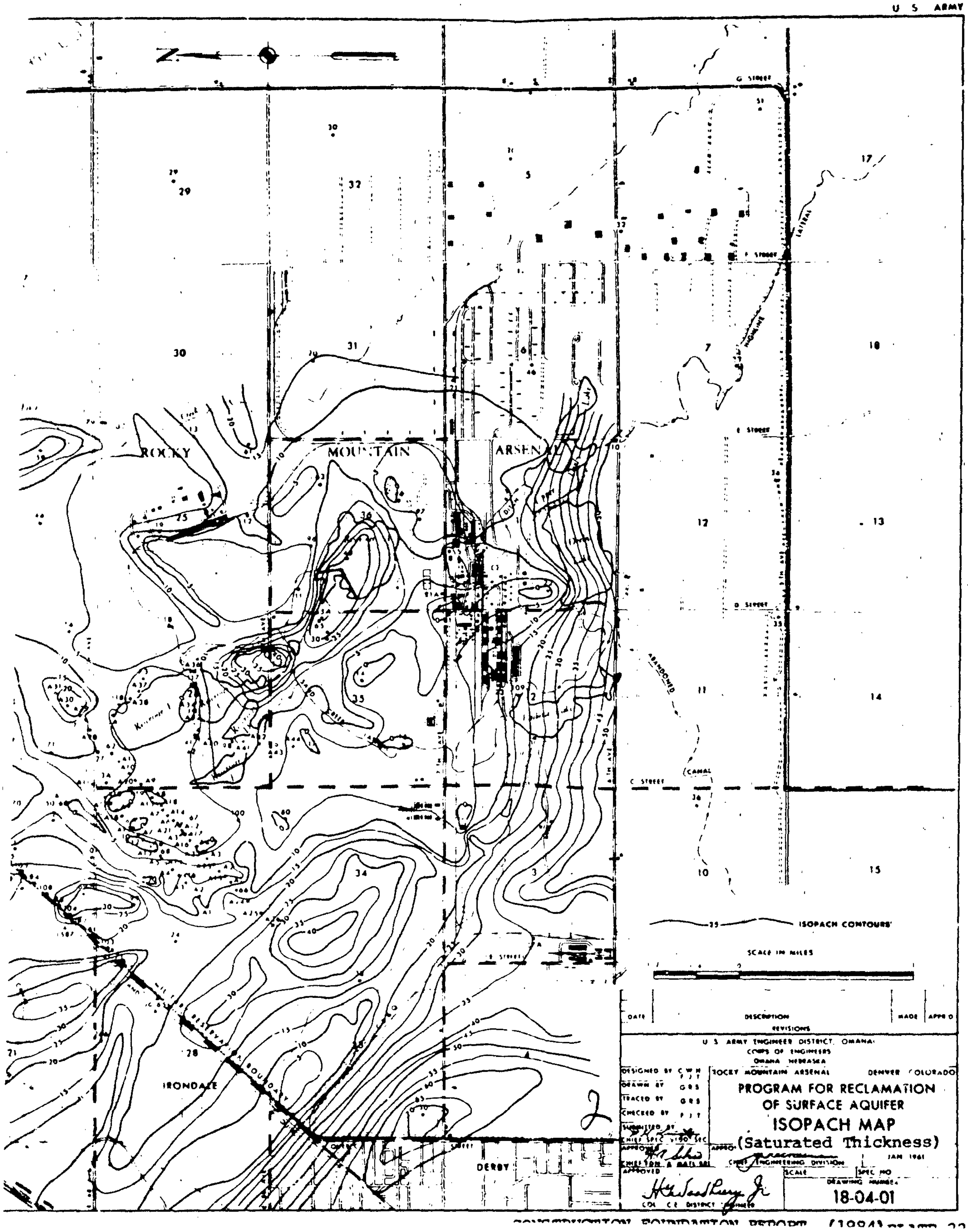
ROCKY MOUNTAIN ARSENAL COMMERCE CITY, COLORADO

NORTHWEST BOUNDARY CONTAINMENT
WELL SERVICE LOOP ROAD
GRADING PLAN

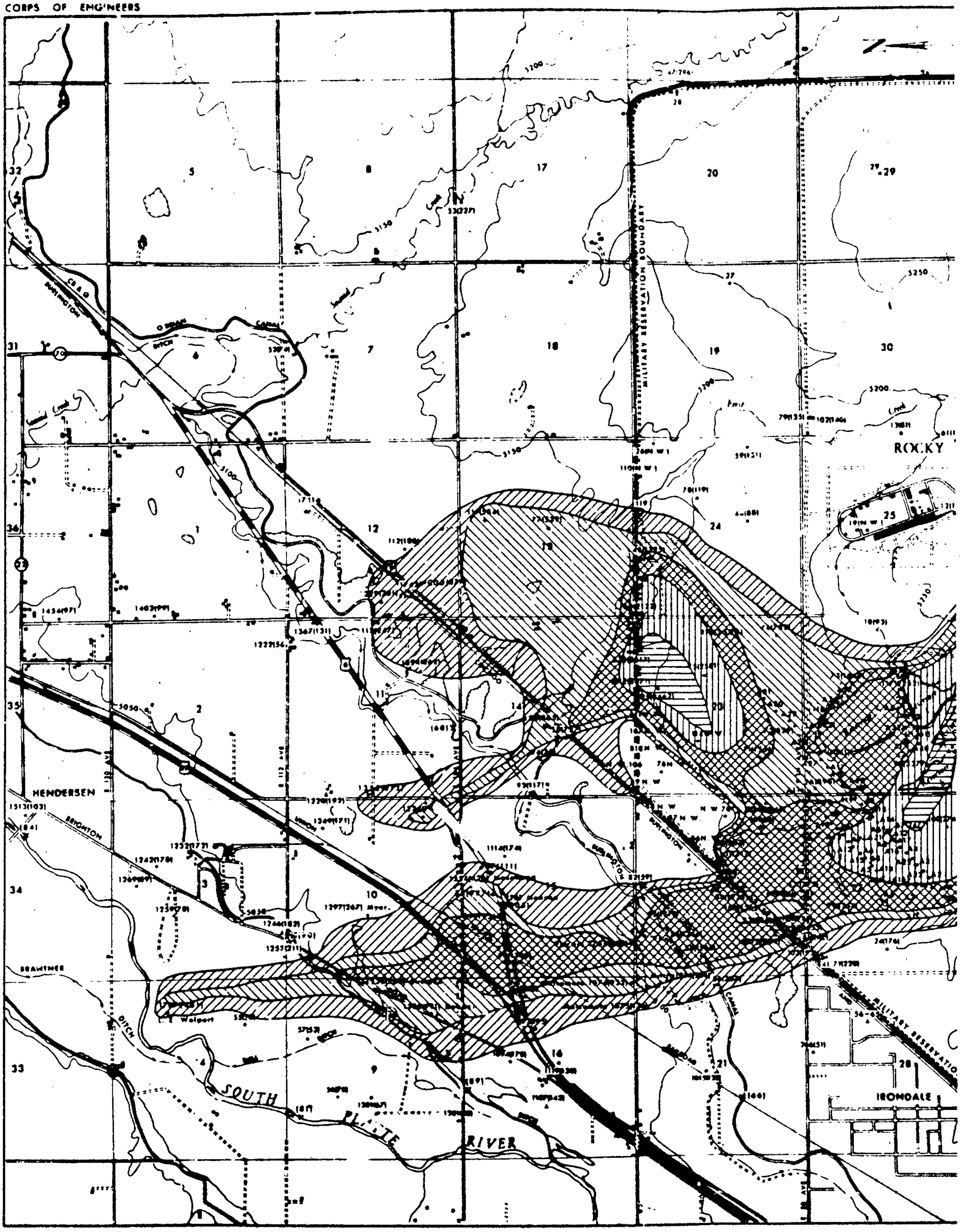
F 841-40-01

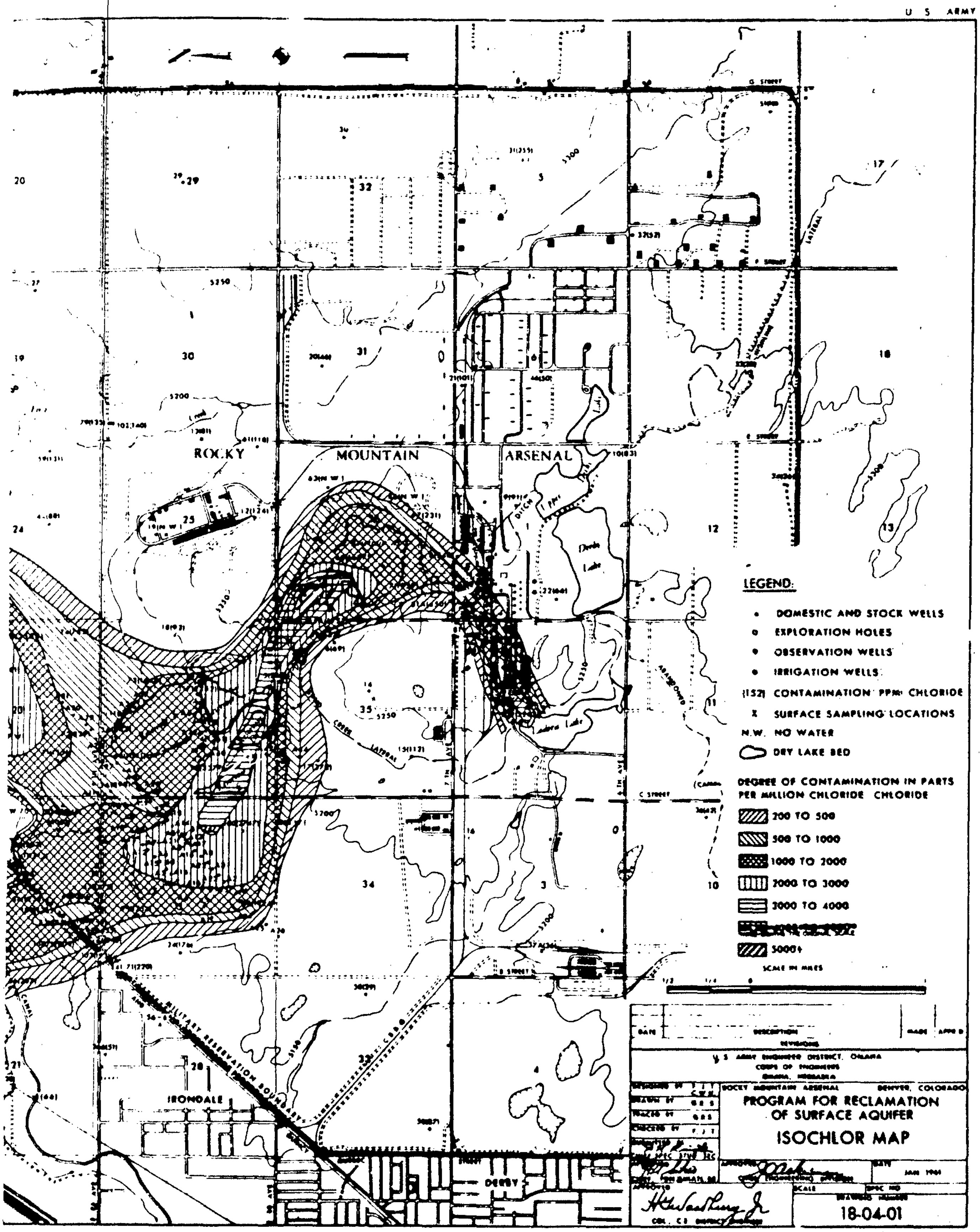
2

CORPS OF ENGINEERS

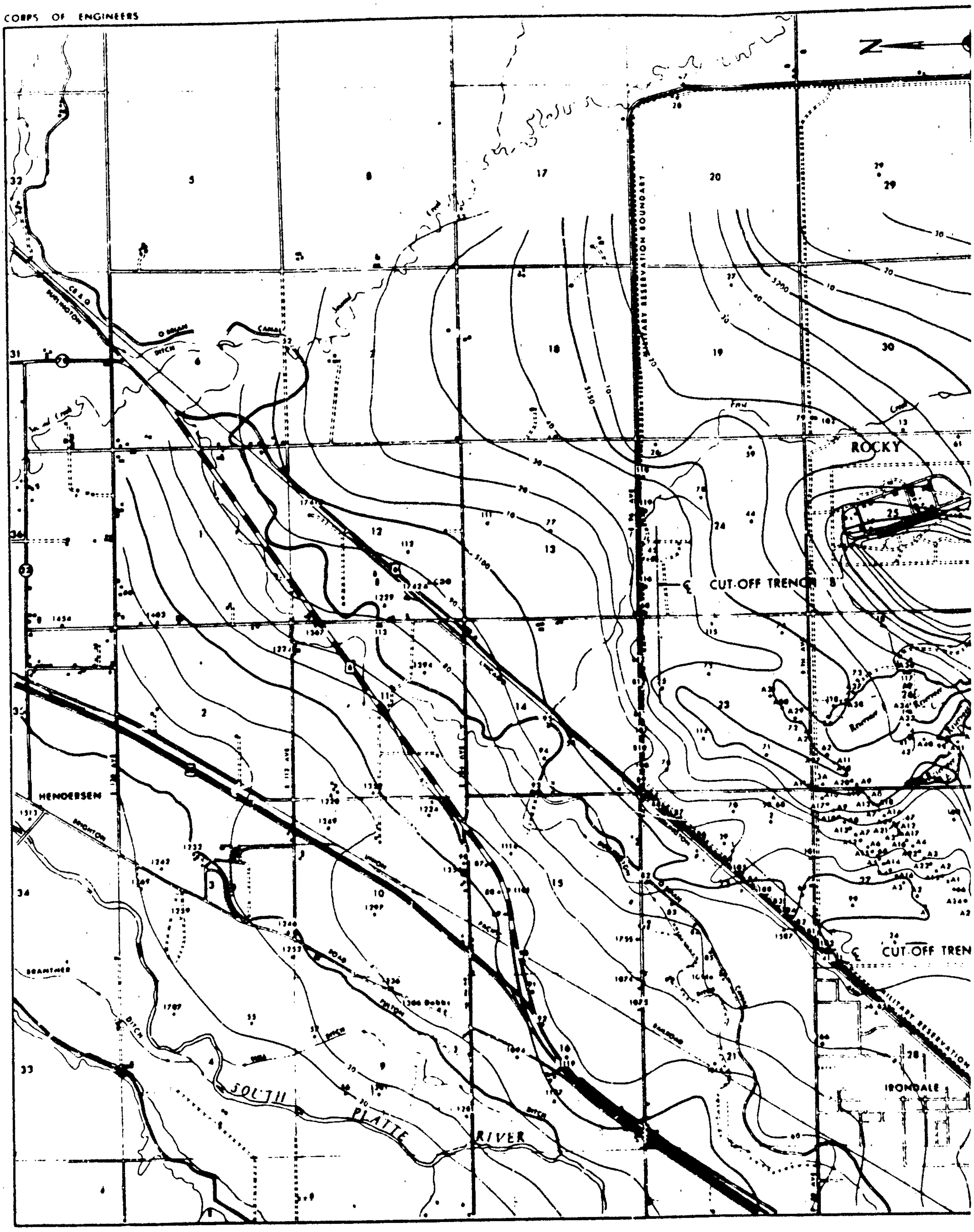

U S ARMY
ROCKY
MOUNTAIN
ARSENAL
G STREET
F STREET
E STREET
D STREET
C STREET
IRONDALE
DERBY
ABANDONED
CANAL
LATERAL
ISOPACH CONTOURS
SCALE IN MILES
DATE
DESCRIPTION
REVISIONS
MADE
APPR'D
U S ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA NEBRASKA
ROCKY MOUNTAIN ARSENAL
DENVER COLORADO
PROGRAM FOR RECLAMATION
OF SURFACE AQUIFER
ISOPACH MAP
(Saturated Thickness)
JAN 1961
DESIGNED BY
DRAWN BY
TRACED BY
CHECKED BY
SUBMITTED BY
APPROVED
CHIEF ENGINEERING DIVISION
SCALE
SPEC NO
DRAWING NUMBER
18-04-01
COL CE DISTRICT ENGINEER
2

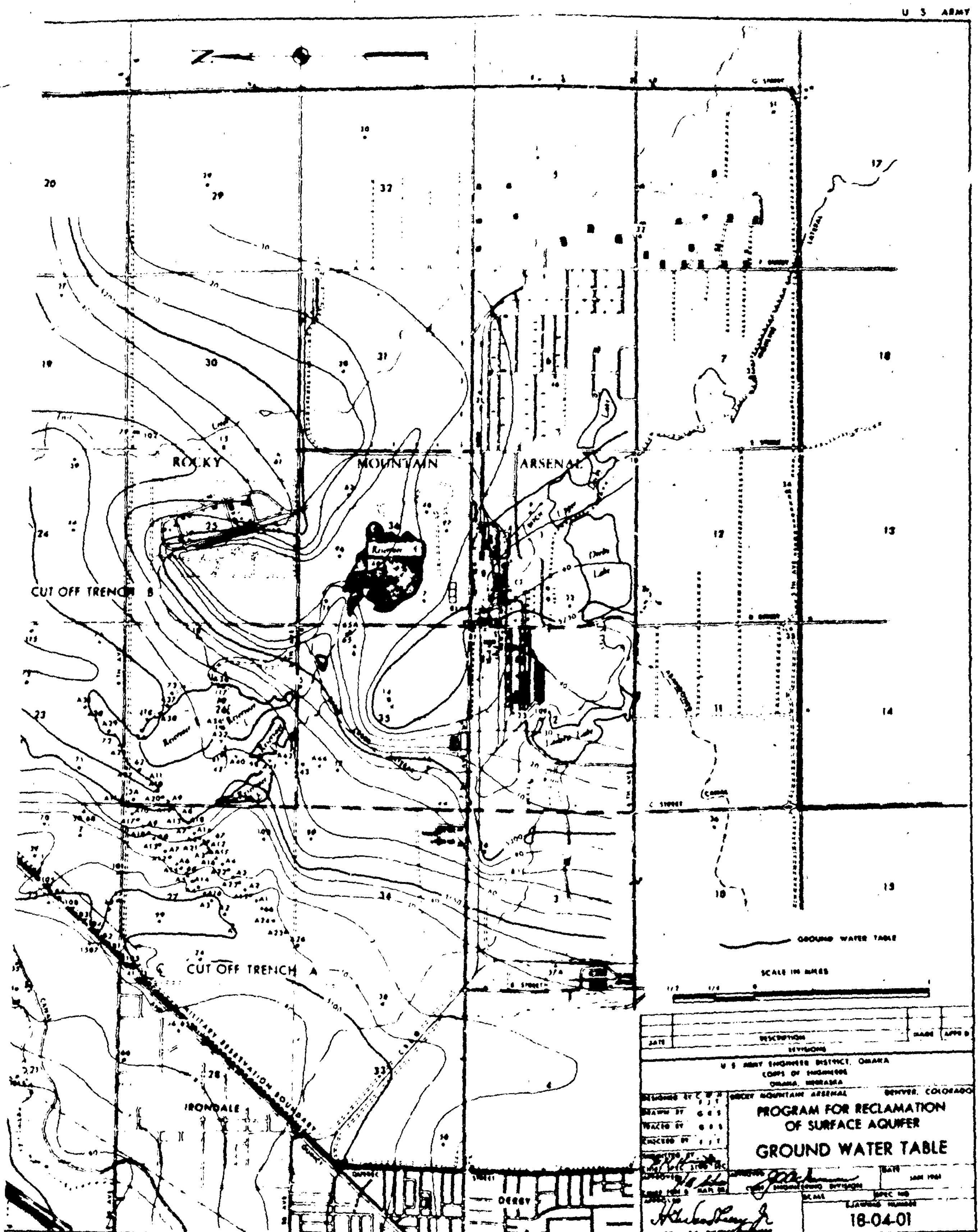
CORPS OF ENGINEERS




U S ARMY
ROCKY
MOUNTAIN
ARSENAL
IRONDALE
DERBY
LEGEND:
DOMESTIC AND STOCK WELLS
EXPLORATION HOLES
OBSERVATION WELLS
IRRIGATION WELLS
(152) CONTAMINATION PPM CHLORIDE
X SURFACE SAMPLING LOCATIONS
N.W. NO WATER
DRY LAKE BED
DEGREE OF CONTAMINATION IN PARTS PER MILLION CHLORIDE CHLORIDE
200 TO 500
500 TO 1000
1000 TO 2000
2000 TO 3000
3000 TO 4000
5000+
SCALE IN MILES
DESCRIPTION
REVISIONS
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
ROCKY MOUNTAIN ARSENAL DENVER, COLORADO
PROGRAM FOR RECLAMATION
OF SURFACE AQUIFER
ISOCHLOR MAP
JAN 1961
18-04-01

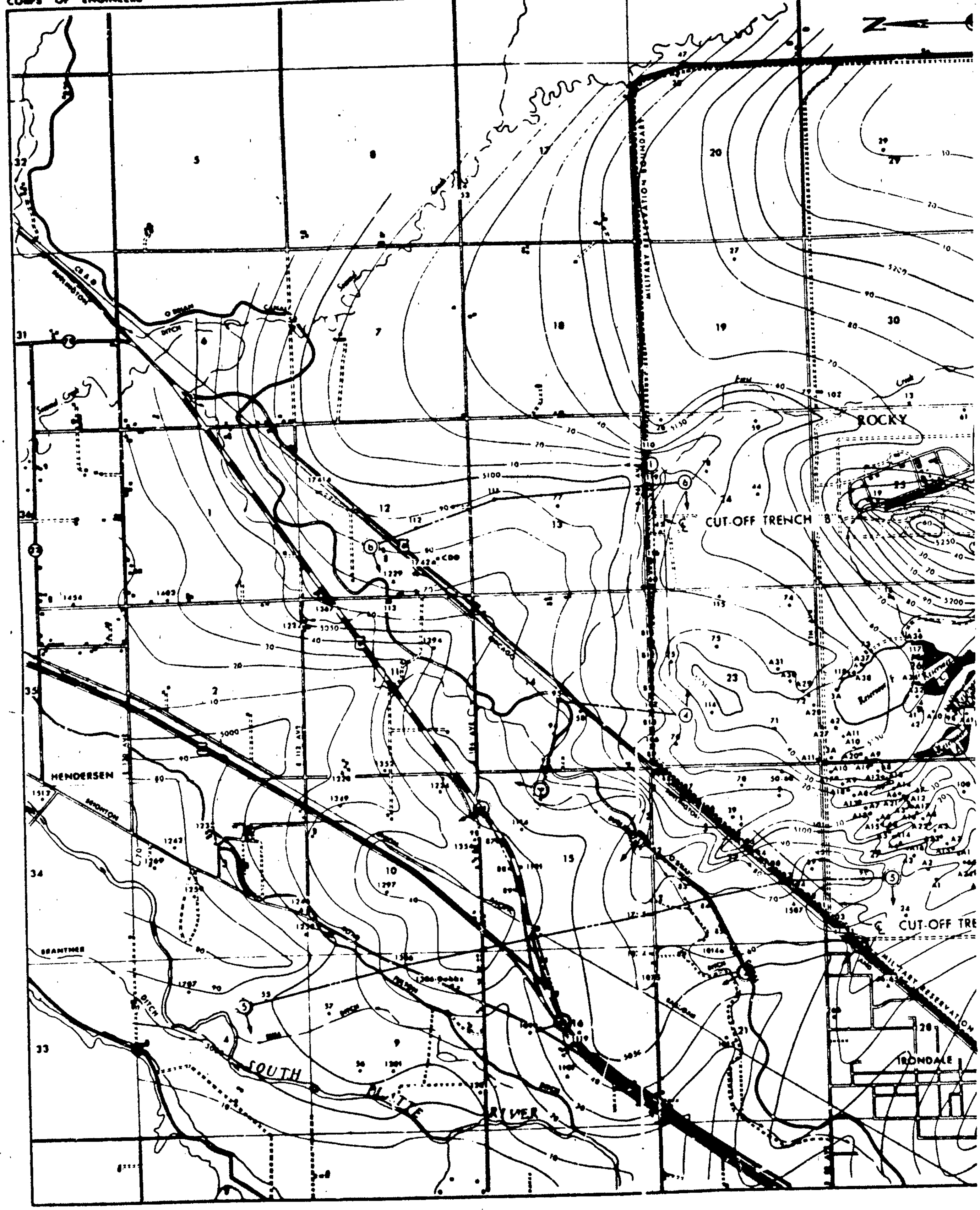
CORPS OF ENGINEERS

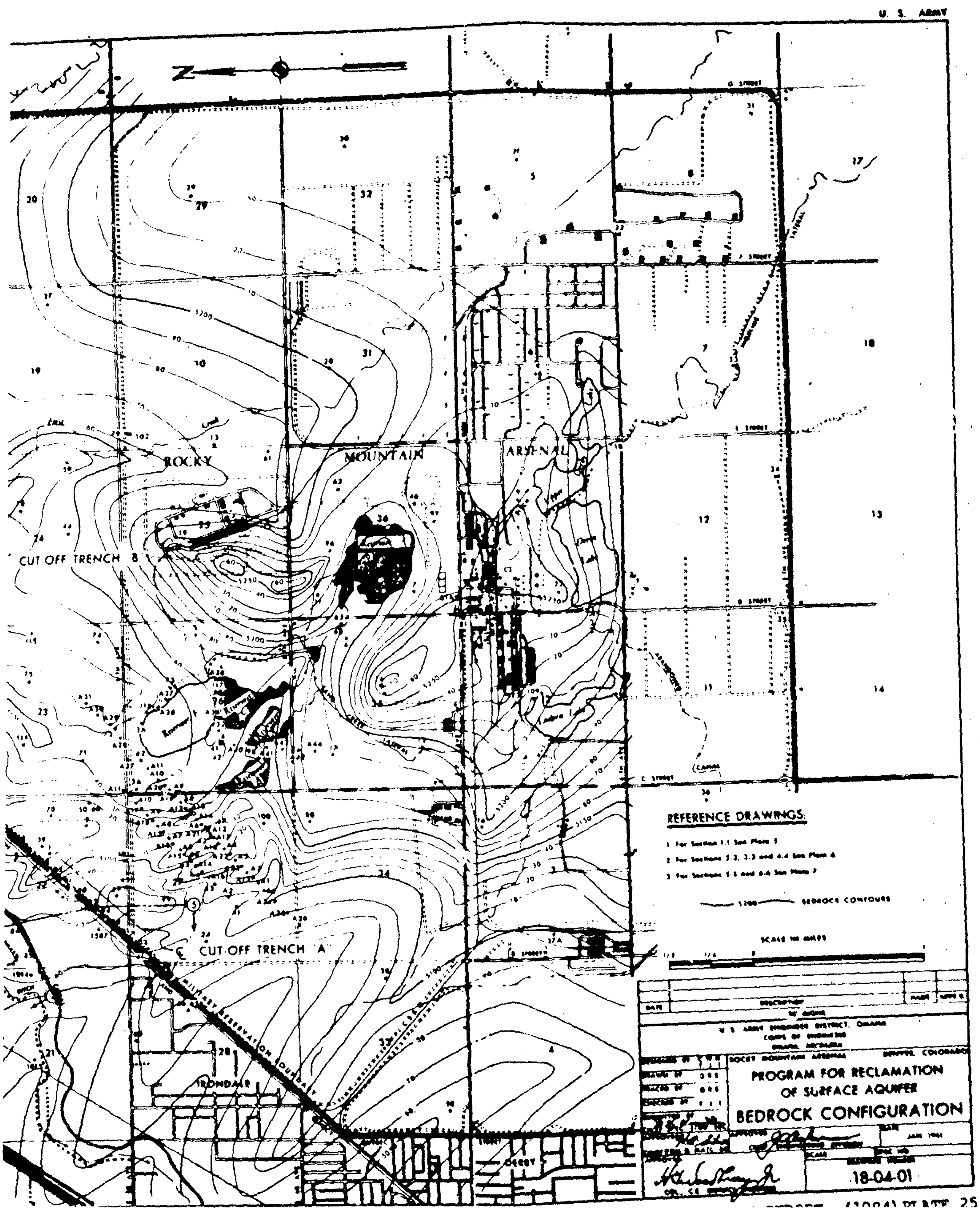




FOUNDATION REPORT (1984) PLATE 24

CORPS OF ENGINEERS





(1984) PLATE 25