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THE STATE OF WYOMING

ED HERSCHLER
GOVERNOR

Department of Environmental Quality

LAND QUALITY DIVISION

HERSCHLER BLDG. - THIRD FLOOR
122 WEST 25TH

TELEPHONE 307-777-7756

CHEYENNE, WYOMING 82002

December 11, 1985

Mr. Truman E. Louderback
Cleveland-Cliffs, Inc.
818 Taughenbaugh Boulevard
Rifle, CO 81650-2730

RE: Collins Draw Uranium ISL Project, Research and Development
License No. 3RD

Dear Mr. Louderback:

This letter is in response to your letter of November 27, 1985, in which you stated that excursion monitoring should not be required of Cleveland-Cliffs Inc. (CCI) even though numerous excursions had been noted at the Collins Draw site for months.

In your November 27, 1985, letter you made reference to the Land Quality Division's (LQD) letter of October 18, 1983, where Cleveland-Cliffs' use of Best Practicable Technology (BPT) was discussed. Mr. Randen's October 18, 1983, letter states that:

1) CCI had used Best Practicable Technology (BPT) at the Collins Draw Project with the qualifications that,

   - groundwater restoration would continue as previously agreed, and

   - the BPT used for the Research and Development Project would not constitute BPT for a commercial project;

2) CCI would not be released from liability until all items outlined in Mr. Chancellor's letter of June 17, 1983, and Messers. Sundin and Shaffer's letter of August 12, 1983, were completed.

The August 12, 1983, letter indicated that the Division would need to know what the maximum concentrations of parameters of concern would be in the wellfield area. It was indicated that a monitoring plan could be established following the last phase of restoration to provide this information. In a memo to file from Kathy Ogle dated August 5, 1983, and referenced in the August 12, 1983, letter, it was recommended that CCI continue monitoring the B-Field until stability occurs. Parameters of particular concern were uranium and selenium.

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The June 17, 1983, letter from Richard Chancellor outlined additional restoration activity that was to take place following a six month stabilization period. Upon review of the Land Quality Division files, it appears this additional restoration was never performed at the Collins Draw site. This was so stated by CCI at a meeting in Denver with the Nuclear Regulatory Commission on November 14, 1985.

It is also clear from the above sequence of events and the staff review of the files that the Land Quality Division required monitoring following the LQD's BPT determination of October 18, 1983, because of concerns over the geochemical stability of the wellfield.

Monitoring during a stability period is a normal requirement for other Research and Development groundwater evaluations. Throughout the entire period of the active license, the operator is liable for controlling fluids and maintaining the site on a non-excursion status. Therefore, CCI was required to monitor for excursions during the stability period.

The Land Quality Division made the original determination of BPT with qualifications. Since CCI never completed those qualifying practices, the LQD's position is that CCI never implemented BPT.

Cleveland-Cliffs Inc. is hereby informed that:

1. Cleveland-Cliffs is liable for excursions throughout the period of an active permit/license and must continue to monitor for the possibility of such excursions on the same schedule as written in Research and Development License No. 3, i.e. once every two (2) weeks.

   Your letter of September 25, 1985, wherein you requested a reduction in the current monitoring interval of every two weeks to a twice a year interval is being reviewed. You should receive a response to the September 25, 1985 letter in the near future.

2. Since the previously agreed upon restoration as a qualification for the Land Quality Division's determination of Best Practicable Technology was never performed by CCI, the Land Quality Division's determination of BPT has not been finalized.

3. CCI, prior to release from liability at the Collins Draw site, must demonstrate that BPT has been employed. CCI should submit a plan for LQD approval to conduct further active restoration. The further use of reverse osmosis and/or the injection of a reductant should be considered by CCI in the restoration plan.

If you have any questions, please do not hesitate to call.

Sincerely,

Roger Shaffer
Land Quality Administrator

William Garland
Water Quality Administrator

cc. Bill Kearney
Susan Hogg
District III

Memorandum

TO FILE: Cleveland Cliffs R & D No. 3

FROM: Susan Hogg, Chief Hydrologist

DATE: December 3, 1985

SUBJECT: Monitoring and Determination of Use of Best Practicable Technology (BPT)

Introduction

This memo is in response to CCIC's letter of November 19, 1985. In that letter CCIC requested an explanation of why they have been required to perform excursion monitoring every two weeks since the Land Quality Division determination of best practicable technology was made (October 18, 1983).

Discussion

In the October 18, 1983 letter from LQD it was stated that best practicable technology (BPT) had been used at the Collins Draw Site with the following qualifications.

(1) The previously agreed upon additional restoration will be completed,

(2) and although BPT for a Research and Development site, this technology would not be considered BPT for a commercial permit.

It was also stated in the October 18, 1983 letter that for CCIC to be released from liability all items outlined in Mr. Chancellor's June 17, 1983 letter and Mr. Sundin's/Mr. Shaffer's August 12, 1983 letters need to be completed.

The August 12, 1983 letter indicated that the agency would need to know what the maximum concentrations of parameters of concern will be in the well field area. It was indicated that a monitoring plan could be established following the last phase of restoration to provide this information. In a memo to file from Kathy Ogle dated August 5, 1983, it was recommended that CCIC continue monitoring the B-field until stability occurs. Parameters of particular concern at this time were uranium and selenium.

The June 17, 1983 letter outlined additional restoration activity that was to take place following a six month stabilization period. Upon review of Land Quality Division files it appears that this additional restoration was never performed at the CCIC Collins Draw site. This was so stated by CCIC at a meeting in Denver with the Nuclear Regulatory Commission, November 14, 1985.

It is clear from the above discussion and my review of the CCIC files that monitoring was required following the Land Quality Division BPT determination made October 18, 1983, because of concerns with the geochemical stability of the well field. Monitoring during a stability period is a normal requirement for other Research and Development groundwater restoration evaluations. Throughout the entire period of the active permit, the operator is liable for controlling fluids and maintaining the site on a non-excursion status. Therefore, CCIC was required to monitor for excursions during the stability period.

When the BPT determination was made (October 18, 1983), however, it was made with the qualification that previously agreed upon additional restoration would be completed. Since the requirement for additional restoration as outlined in the June 17, 1983 letter was never fulfilled by CCIC, it follows that the Land Quality Division determination of BPT as transmitted in the October 18, 1983 letter should now be withdrawn.

It is clear that the B well field is not stable (see letter to CCIC, October 9, 1985). This situation, in conjunction with the fact that the agreed upon additional restoration was not performed indicates that the earlier determination of BPT made by Land Quality Division should be withdrawn.

Conclusions and Recommendations

The following actions are recommended:

1. CCIC should be informed that throughout the period of an active permit/license, the operator is liable for excursions and, therefore, excursions should be monitored for.

2. Since the previously agreed upon restoration that was a qualification for the Land Quality Division's determination of BPT was never performed by CCIC, the Land Quality Division should withdraw their determination of BPT having been employed.

3. CCIC, prior to release from liability at the Collins Draw site, must demonstrate that BPT has been employed.

SH:lg

cc: Glenn Mooney
Rick Engelmann
✓Bill Kearney for NRC
Hydrology File

REVIEW OF

"ENVIRONMENTAL REPORT ON THE COLLINS DRAW PROJECT CAMPBELL COUNTY, WYOMING"

A RESPONSE TO TASK ORDER NO. 002, CONTRACT NO. NRC-RG4-84-501

Background

This document constitutes a review of the report entitled "Environmental Report on the Collins Draw Project, Campbell County, Wyoming" by Cleveland Cliffs Iron Company (1986). The report presents no significant field data or revelations beyond that which have been presented in earlier reports in support of Cleveland-Cliffs' (CCIC) restoration efforts. The report presents a discussion of Research and Development (R and D) operations conducted at the Collins Draw Project site plus a discussion of evidence intended to justify the termination of restoration activities at the site. According to the report,

> This document has been prepared by Cleveland-Cliffs in order to provide evidence of the restoration activities that have been conducted at the project site; to analyze project impacts to the groundwater resource; and to identify and compare all options to verify that final termination of the restoration activities is the most appropriate course of action for the project.

The report is divided into ten sections. Section 1 consists of an introduction. Section 2 (Affected Environment) describes the history of R and D operations conducted at the site, and the project impacts that have resulted from operation of the project. Section 3 presents a discussion of proposed activities associated with the termination of restoration and with the reclamation and abandonment of the project site. Section 4 presents a discussion of alternative options to the proposed termination of

restoration activities. Section 5 discusses the potential impacts of the proposed final termination of restoration activities. Section 6 discusses the potential impacts of alternative options to the proposed termination of the restoration activities. Section 7 presents a summary and a comparison of the potential positive and negative impacts of further restoration versus final termination of restoration activities. Section 8 discusses the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity. Section 9 discusses the irreversible and irretrievable commitments of the groundwater resources until the groundwater quality is restored by natural processes or further groundwater restoration. Section 10 discusses the compliance with applicable federal, state, and local laws, rules, regulations, and license requirements for final termination of restoration activities and further restoration activities.

The primary purpose of the report is to justify the final termination of restoration activities at the Collins Draw Project site. The report downplays the significance of the various dissolved solids remaining in the groundwater as a result of in-situ uranium mining. Appendix A of the report presents an analysis of groundwater restoration at the Collins Draw Project site by the consulting firm of Ledbetter, Liljestrand, and Charbeneau (1986). The basic conclusions of this report are: 1) that the pre-mining water quality is marginal, 2) that substantial efforts have been made toward restoration of water quality, and 3) that mining operations have not seriously degraded the water. The consulting firm's report

recommends that no further restoration activities be conducted at the Collins Draw Project site.

In addition to downplaying the significance of groundwater quality degradation that has occurred at the Collins Draw Project site as a consequence of in-situ mining, the report downplays the significance of the potential improvements in water quality that could be achieved by further restoration activities. Williams and Associates, Inc. does not agree with the conclusion by Ledbetter, Liljestrand and Charbeneau (1986) that because the pre-mining water quality is relatively poor further restoration would not achieve significant results. This position has been supported in earlier documents presented to the NRC. The consultant's report appears to be factual and accurate with respect to the estimated effectiveness of further restoration activities; however, these conclusions are based on the presumption that the water quality data collected at the site reflect accurately the true water quality in the vicinity of the well fields. The subject environmental report by CCIC does not address the concerns described by Williams and Associates, Inc. (1985) with respect to water quality degradation beyond the well fields. Appendix 1 attached hereto summarizes the results of a mathematical model presented in Williams and Associates, Inc. (1985). The results of the subject mathematical model constitute the primary basis for our concern about the true distribution of the remnants of lixiviant at the site.

The basic problems with groundwater restoration at the Collins Draw Project site stem from the fact that no waste disposal ponds were constructed at

the site to contain waste water. According to the report (p. 39), "Due to the environmental problems associated with temporary waste disposal in evaporation ponds, Cleveland-Cliffs decided not to construct and use evaporation ponds to dispose of process waste water." The history behind this decision is not clear to us; however, it appears that CCIC decided to gamble on the presumption that the groundwater quality in the mined aquifer could be restored to pre-mining quality by using a balanced operation.

Shortly after restoration efforts at the Collins Draw Project site were initiated, CCIC realized that adequate aquifer restoration could not be achieved without some type of waste water disposal facility. Because of this fact, CCIC had to obtain an NPDES discharge permit to dispose of waste water. It was necessary also for CCIC to obtain a license for an industrial waste water leach field to dispose of treated waste water. However, the effectiveness of restoration still was hampered by stringent controls on the concentrations of certain contaminants such as radium-226 that could be disposed in the leach field or by surface discharge. This limitation would not have existed had an evaporation pond been constructed at the site prior to mining.

Regardless of the history behind the decision to conduct an in-situ leaching operation without the use of evaporation ponds, it is obvious that CCIC pumped and treated large volumes of groundwater in an attempt to restore the aquifer. However, the limitation (imposed by the absence of evaporation ponds) on the volume of groundwater that could be disposed precluded the use of state-of-the-art restoration technology to restore the

aquifer. The restoration criteria which CCIC agreed to in their license to conduct an R and D in-situ uranium mine forced them to use a complex pumping and injection scheme in an attempt to restore the aquifer. CCIC also tried to use dilution to reduce lixiviant based contaminates in the ore zone aquifer.

While dilution has been used successfully to reduce concentrations of contaminants in surface water, dilution of contaminants in an aquifer is ineffective. The injection of "clean" water into an aquifer tends to displace the existing groundwater in the immediate vicinity of the injection well. Mixing of the groundwater and the dilution of contaminants takes place only by the process of hydrodynamic dispersion. The result of the modeling effort by Williams and Associates, Inc. (1985) illustrates that the injection of "clean" water tends to push groundwater contaminants away from the well field (see Appendix 1). It is not clear whether CCIC realized the effects that the injection of clean water and the concomitant complex pumping and injection scheme would have on the displacement of contaminants toward the outside of the well fields. However, we do not believe that clean water injection constitutes the Best Practicable Technology currently available.

Williams and Associates, Inc. is in basic agreement with those portions of the conclusions presented in the report under review that describe the potential advantages and disadvantages of further restoration versus termination of restoration activities (Table 1). However, this agreement is in principle only, because it must be based on the presumption that the

TABLE 1
IMPACT SUMMARY AND COMPARISON (AFTER CLEVELAND CLIFFS-IRON COMPANY, 1986)

	Positive Impacts	Negative Impacts
Proposed Termination of Restoration Activities	Natural groundwater restoration. Eliminate wells accessing production zone. Decrease potential appropriation and use of production zone groundwater. Near term decontamination and reclamation of project site allowing other uses.	No adverse environmental or financial impacts.
Groundwater Recirculation with Reverse Osmosis Treatment (58 gpm, 6 mo)	Reduction in TDS concentration.	Removal of 3.1 million gallons of groundwater. Approximately 3.2 acres surface impacts. Increased potential air quality, surface water quality, and radiological impacts. Very significant financial impacts (in excess of $850,000). Delay decontamination, reclamation, and other beneficial uses of the project site approximately 2 years.
Groundwater Sweep (45 gpm, 6 mo)	Reduction in TDS concentration.	Interrupt flow of artesian stockwater well. Removal of approximately 14.2 million gallons of groundwater. Approximately 10.9 acres surface impacts. Increased potential air quality, surface water quality and radiological impacts. Very significant financial impacts (approximately $1,850,000). Delay decontamination, reclamation, and other beneficial uses of the project site approximately 2 years.
No Action	Insignificant impacts.	Would draw well field groundwater to monitor wells. Delay other beneficial uses of the project area for indefinite period. Monitoring, security and maintenance costs continue.
Open Pit or Underground Mine the Production Zone	Total removal of production zone.	Not technically or financially feasible or environmentally reasonable. Very significant adverse, environmental, health and safety, water quantity, and financial impacts.
Isolation of Production Zone by Grout Curtain		Not technically or financially feasible.
Isolation of Production Zone by Chemical Substance		Most substances toxic and/or carcinogenic. Adequate isolation not feasible.
Oxidative Destruction of Residual Ammonia by Chlorine.		Technology not sufficiently developed. Increased groundwater quality impacts.

water quality data collected for the A and B well fields reflect accurately the true water quality in the vicinity of the well fields. Our mathematical modeling efforts (see Williams and Associates, 1985, and Appendix 1) suggest that this presumption is not valid. The results of this modeling suggest that the highest concentrations of contaminants were displaced toward the outside of the well fields. Unless at least 3 new monitor wells are installed, the actual effectiveness of the restoration activities conducted by CCIC cannot be evaluated adequately.

Conclusions

Field data currently available suggest that post-restoration water quality within well fields A and B at the CCIC site is comparable to pre-mining water quality it terms of potential water use. According to Ledbetter, Liljestrand and Charbeneau (1986, p. 2),

> Both the pre-mining and post-restoration concentrations indicate that this groundwater was and still is unfit for drinking by people, marginally acceptable for livestock, undesirable for irrigation, unsuitable for aquatic life for reasons other than ammonia, and inappropriate for many industries. In general in-situ mining has not seriously degraded the water for these purposes. The most serious degradations appear to have been the changes in the concentrations of uranium and selenium for actual potential uses of the water.

Williams and Associates, Inc. agrees with the statement quoted above if only the field data available currently are considered as a basis for decision making.

As stated in the report under review, the water quality in the A and B well fields can be improved by further restoration. With the exception of NH^+_4, and possibly uranium, radium and selenium, elevated concentrations of most constituents probably could be reduced to approximately pre-mining levels with a reasonable amount of additional restoration. This conclusion assumes that the available water quality data reflect accurately the water quality in the vicinity of the well fields.

Data available currently are inadequate to evaluate the quality of ground water beyond the well fields. Mathematical model simulations performed by Williams and Associates, Inc. (1985) (which were not addressed in the report under review) suggest that the restoration scheme used by CCIC pushed contaminants beyond the well fields. This result suggests that significantly higher concentrations of contaminants are present within a halo around the well fields than within the well fields (where data are available).

Recommendations

Williams and Associates, Inc. recommends that the NRC require CCIC to construct at least three new monitor wells to evaluate the post-restoration water quality in suspect areas beyond the well fields. The locations for these wells should be based on the results of the mathematical simulations presented by Williams and Associates, Inc. (1985).

Williams and Associates, Inc. recommends that these monitor wells be constructed prior to any future restoration activities or decisions regarding restoration at the Collins Draw Project site. Williams and Associates, Inc. recommends further that the NRC base any decisions on final termination of restoration on the water quality data collected from the new monitor wells.

Williams and Associates, Inc. believes that it is important for the NRC to evaluate the water quality in the suspect areas prior to making a decision on final termination of restoration at the Collins Draw Project site. At a minimum, Williams and Associates, Inc. recommends that the new monitor wells be constructed, and accurate water quality data be collected, as a condition for the final termination of restoration. This requirement will allow the NRC to evaluate the appropriateness of using mathematical models to assess the effectiveness of restoration at in-situ uranium mine sites. It also will provide a basis for future decisions that pertain to the adequacy of aquifer restoration at in-situ uranium mine sites.

APPENDIX A

SOLUTE TRANSPORT SIMULATION OF AQUIFER RESTORATION AT THE COLLINS DRAW MINE SITE

Abstract

In situ mining of uranium was conducted in two research and development (R and D) well fields at the Cleveland Cliffs Iron Company (CCIC) site in the Powder River Basin of Wyoming from March 1980 to July 1981. Aquifer restoration of the well fields was terminated in December 1982.

A complex pumping and injection scheme was used by the mining company during aquifer restoration in an attempt to satisfy the conditions imposed by the mine permit. The complex pumping and injection scheme was necessary because of the absence of adequate disposal facilities.

An analytical "Random Walk" solute transport model was used to simulate aquifer restoration at the mine site. The results of the model simulation show that a plume of particles continued to expand during simulation of aquifer restoration activities. The simulation suggests that the complex pumping and injection scheme utilized by CCIC during restoration tended to push dissolved solids outward away from the well field (monitor wells) rather than remove them. The simulation results suggest also that the post-restoration water quality data collected at the mine site are not an accurate measure of the degree of effectiveness of aquifer restoration at the mine site.

Introduction

Hydrogeology of the Mine Site

The CCIC uranium mine for which the results of a solute transport simulation are presented herein is located about 85 road miles(136 km) northeast of Casper, Wyoming, in the Powder River Basin (Figure 1). The Powder River Basin is a structural and topographic basin bounded on the east by the Black Hills and on the west by the Bighorn Mountains. As much as 18,000 ft (5,500 m) of sedimentary rock are present in the deepest part of the basin (Hodson and others, 1973). The Wasatch Formation of Ecocene age crops out in the area; it is approximately 1,575 ft (480 m) thick in the Pumpkin Buttes area (U.S. Nuclear Regulatory Commission, 1978). The Fort Union Formation of Paleocene age underlies the Wasatch Formation. Tectonic activity in the Powder River Basin has been minor; no major folding or faulting has been reported.

Uranium mineralization at the mine site occurs as roll-front deposits in a sandstone stratum in the Wasatch Formation. The hydrostratigraphy of the Wasatch Formation consists generally of sandstone aquifers confined by siltstone and claystone aquitards. Shallow water table aquifers (unconfined) may be present also; they are of limited areal extent and occur mainly along the more prominent water courses (Williams and others, 1984). Jointed coal beds also produce water in some areas, but they yield much less water than the sandstone aquifers (Williams and others, 1984). Total dissolved solids concentrations range from less than 200 mg/L to more than 8,000 mg/L but most commonly they are between 500 and 1,500 mg/l (U.S. Nuclear

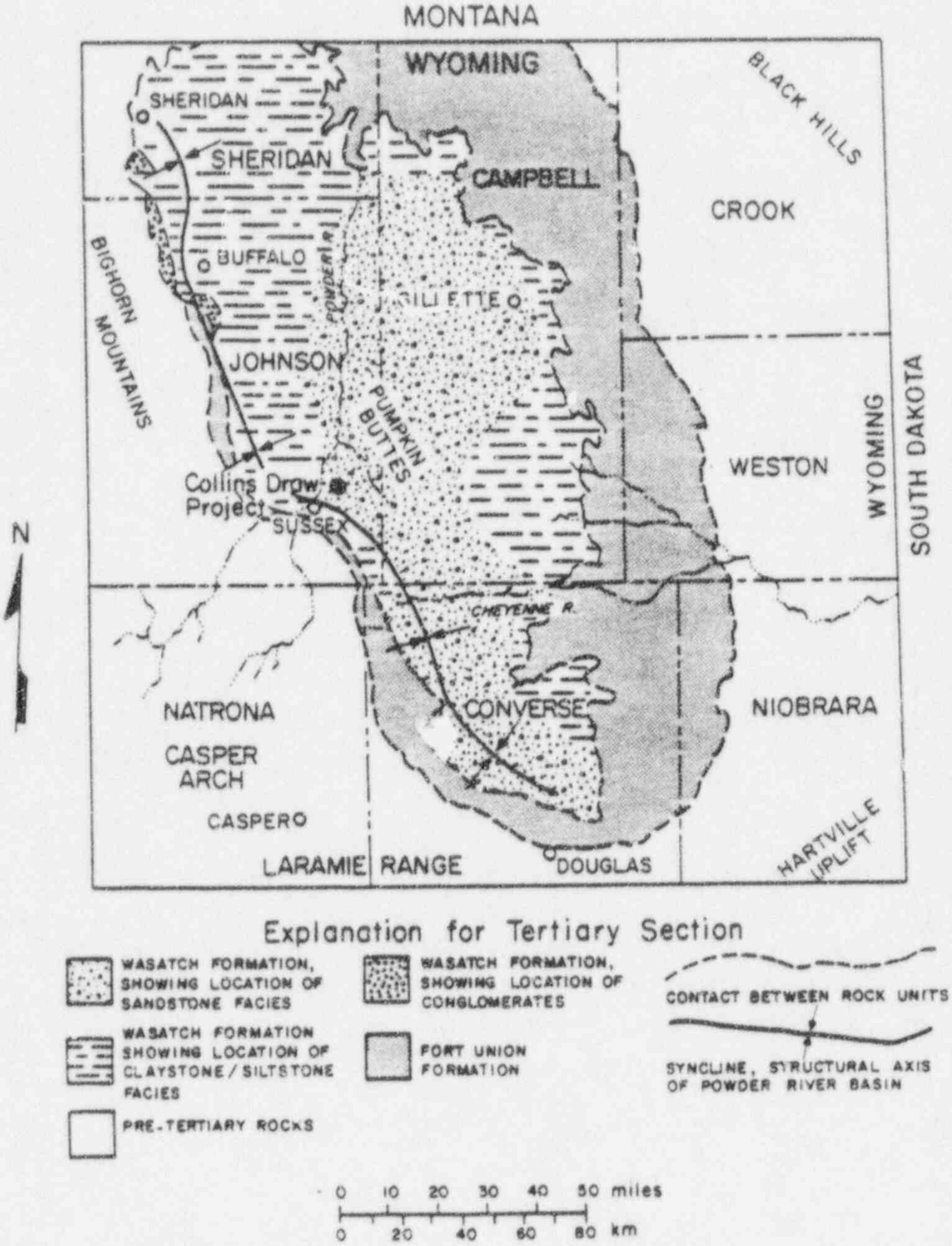


Fig. 1. Regional geology of the Powder River Basin, Wyoming (modified after Sharp and Gibbon, 1954).

Regulatory Commission, 1978). The ground water usually ranges from sodium-bicarbonate to sodium-sulfate type.

Three major water bearing sandstone rock strata (the 1, AB and C sands) are present at the mine site (figure 2). These sandstone rock strata are separated by claystone sediments. The 1-Sand constitutes the ore sandstone at a depth of about 425 ft (130 m). It's thickness averages approximately 50 to 55 ft (15 to 17 m). Interstitial clays of complex mineralogy may comprise as much as 25-30% of the total sandstone volume. Approximately 1% of the sandstone consists of carbonate minerals.

The 1-Sand is a confined aquifer. Data collected by consultants to CCIC indicate that ground water flows in a direction 19° west of north, under a local hydraulic gradient of about .008. Water level fluctuations measured over a 1.5 year period are on the order of a few centimeters.

CICC conducted a baseline water quality sampling program in 1978. Thirteen wells were sampled an average of four times each; 11 of these wells were completed in the ore-bearing sandstone aquifer. One well was completed in the overlying aquifer and one in the underlying aquifer. Table 1 presents the average measured concentrations of total dissolved solids (TDS), chloride, pH and ammonia for each baseline well.

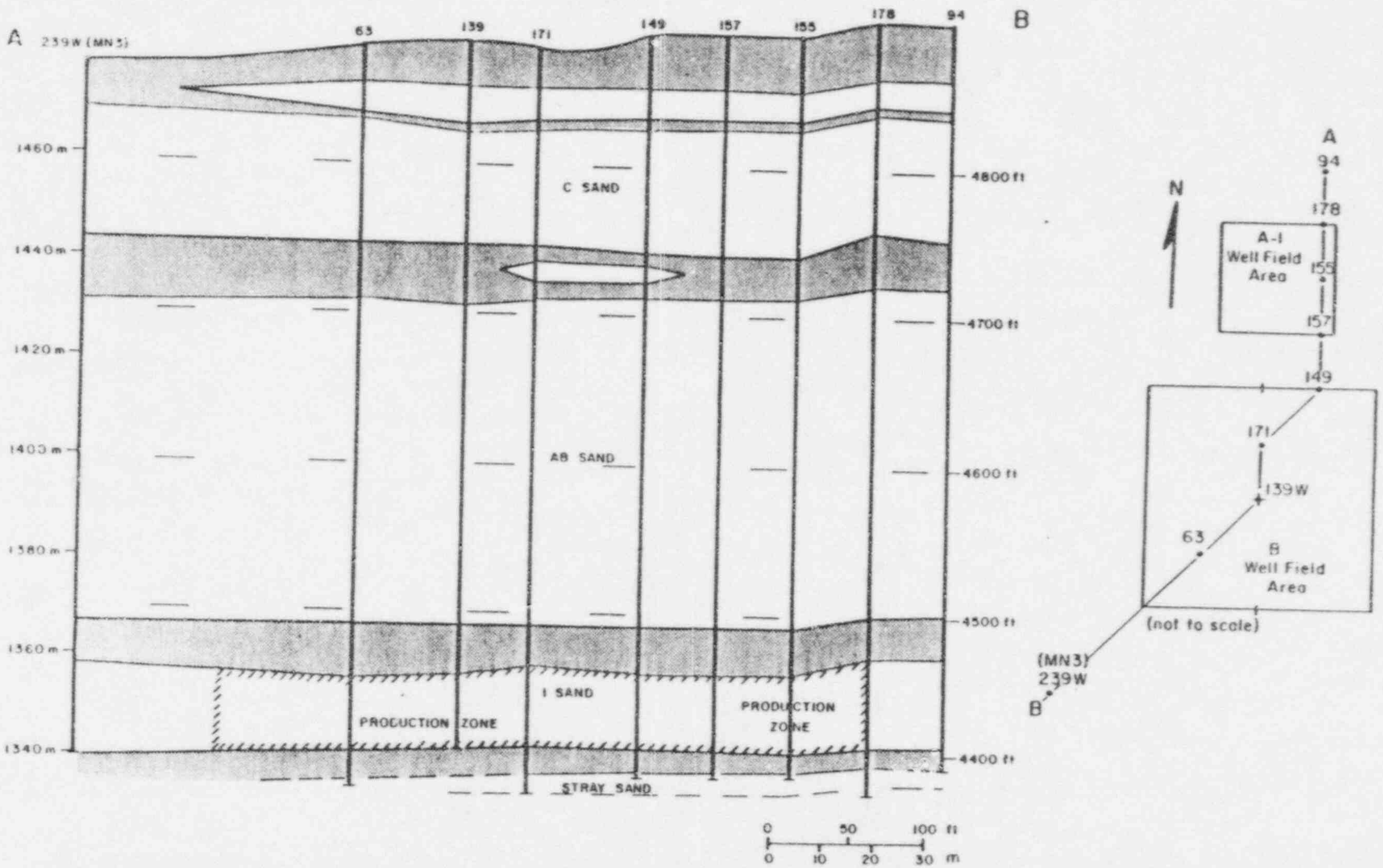


Fig. 2. Cross section through the Collins Draw mine area (after Cleveland Cliffs Iron Company, 1981).

Table 1. Average baseline water quality for each well at the Collins Draw Mine site (after Cleveland Cliffs Iron Company, 1981).

Parameter (mg/L)	Well												
	139W	146W	191W[2]	230W	231W	232W	233W	234W	237W	238W	239W	240W	241W
Total Dissolved Solids (105°C)[1]	363	375	586	543	397	402	401	385	326	360	433	387	374
Chloride[1]	12	13	17	12	13	25	13	12	51	12	45	22	20
pH, unit (field)[1]	7.5	7.8	8.0	7.5	7.2	7.7	7.4	7.5	9.1	8.0	7.1	7.7	7.8
Ammonia (as N)[1]	0.15	0.21	0.50	0.33	0.09	0.07	0.06	0.13	0.21	0.15	0.07	0.08	0.07

[1] Average concentration of baseline samples collected between May, 1978 and January, 1980.

[2] The location of well 191W is unknown.

Operational Procedures Employed at The Mine Site

Production Phase

Research and development testing at the CCIC mine site began in the A-1 well field in March, 1980, and was expanded to the B well field in November, 1980 (Fig. 3). Ammonium carbonate lixiviant (leaching solution) was used in both well fields. No well field activity other than ground water sampling has been conducted since 1983.

The A-1 well field covers approximately 1/4 acre and consists of 12 wells spaced approximately 20 ft (6.1 m) apart in a staggered pattern. Wells 242, 243, 296 and 297 were not used in mining operations; the latter two wells were added to the well field for restoration operations. Approximately 3.4×10^5 gal (1.3×10^6 L) of water that had been treated by reverse osmosis to remove calcium were injected into the production zone before leaching began. This injection was intended to displace formation water containing high calcium concentrations which would react with the ammonium carbonate lixiviant and cause precipitation of calcium carbonate. Injection of the ammonium carbonate lixiviant and an oxidant (hydrogen peroxide and/or oxygen) commenced on April 2, 1980. The lixiviant, which contained from 1 to 5 g/L carbonate and from 1 to 4 g/L ammonium, was injected at rates of 0.1 to 20 gal/min (0.06 to 1.3 L/sec) under well head pressures ranging from 15 to 30 pounds/square inch (psi) (1.1×10^5 to 2.1×10^5 Newtons/square 1.1×10^5 to 2.1×10^5 Newtons/square meter (N/m^2)).

From April 2 to July 3, 1980, the A-1 well field was operated as follows: Wells 248 and 249 were utilized as production wells and wells 244, 246, 247, 252, 253, and 254 were injection wells. In July, wells

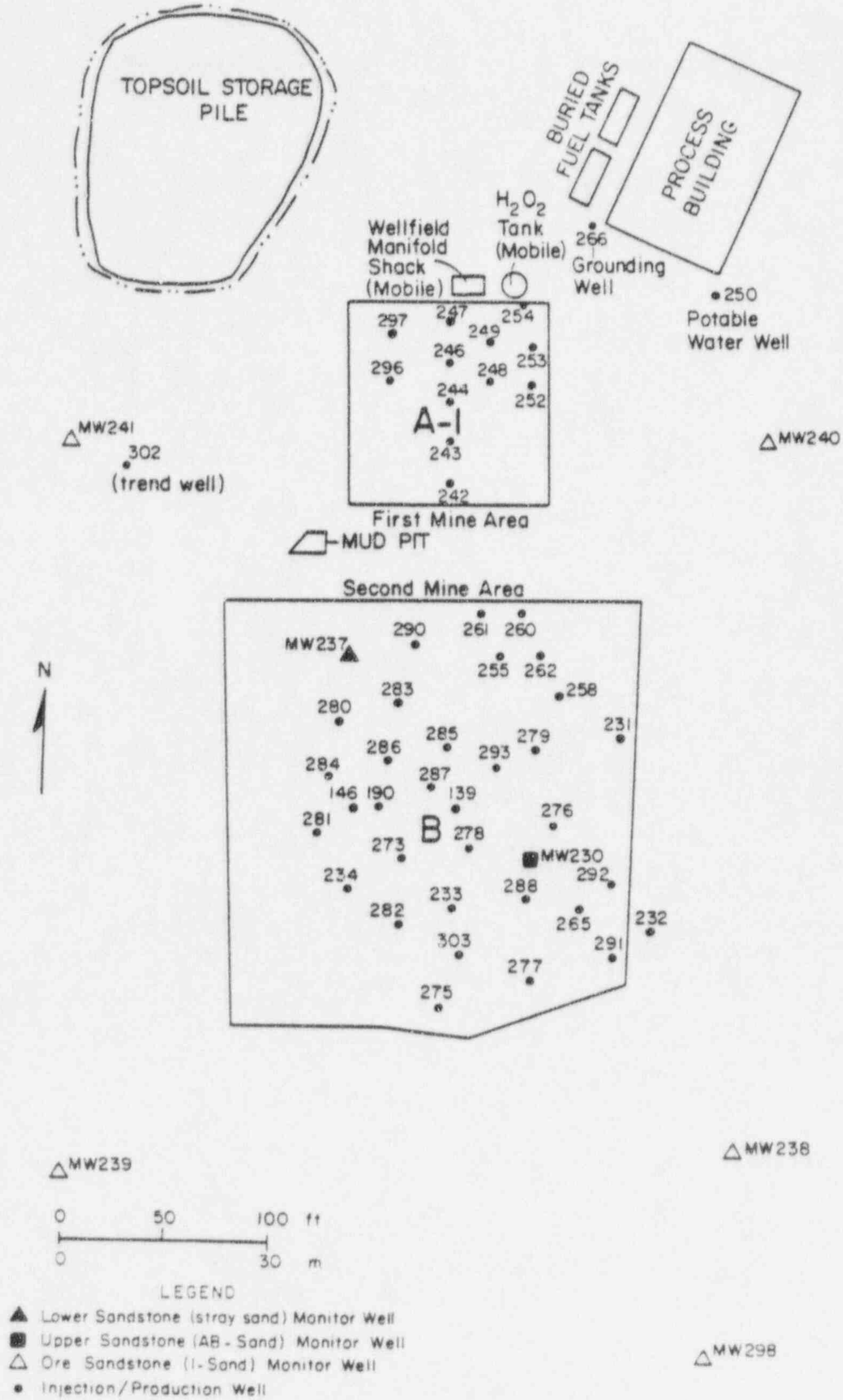


Fig. 3. Location map of the facilities at the Collins Draw mine (after Cleveland Cliffs Iron Company, 1981).

252, 253, and 254 were shut down and the mode of operation (production or injection) of the remaining wells, with the exception of well 249, was changed frequently until the termination of the test (November 3, 1980). Well 249 was operated as a production well exclusively during the mining of well field A-1. Approximately 1.3×10^6 gals (4.9×10^6 L) of lixiviant were used in mining the A-1 well field. Production and injection rates were forced to balance because an evaporation pond was not constructed to contain waste water. CCIC reportedly did not bleed mining solution from the circulation solutions routinely.

Injection of lixiviant at the B well field began on November 4, 1980, with the transfer of approximately 9.2×10^6 gal (3.5×10^6 L) of solution from the A-1 field production zone into the B well field production zone. The B field consists of 33 wells, although mining operations utilized only 20 wells that initially formed four connecting production cells. These cells were irregularly shaped 7-spot patterns with well spacings ranging between 20 and 40 ft (6 and 12 m). The operational mode (production or injection) of any given well was varied during the course of the mining test in an effort to achieve desired operating flow rates. Lixiviant injection and solution recovery were conducted in a manner similar to mining of the A-1 well field. Mining continued in the B well field until July 23, 1981, when restoration was initiated.

Uranium was recovered from the water withdrawn from the pumping wells by passing it through ion exchange resins which captured the ammonium uranyl tricarbonate complex. According to the mining company, a

strong ammonium carbonate solution was used to strip the uranium complex from the ion exchange resins.

Restoration Phase

Several techniques were used in an attempt to restore background or near background water quality in the ore zone aquifer at the mine site. Restoration of the A-1 well field was initiated on November 4, 1980, with the transfer of lixiviant from the A-1 well field to the B well field. A total of about 9.2×10^5 gal (3.5×10^6 L) of solution was pumped from the A-1 well field ore zone through wells 246, 248, and 249. This procedure resulted in a partial ground water sweep of the ore zone stratum and a general improvement in ground water quality. Ammonium (NH_4^+) concentrations were reduced from 720 mg/L to 420 mg/L. A more complete ground water sweep was considered impractical by CCIC because of the absence of a disposal facility.

Recirculation with treatment by ion exchange was employed subsequent to the lixiviant transfer to reduce further the concentrations of NH_4^+ and uranium in the ground water. Three fixed-bed, downflow columns of Ionac C-C resin (trade name) were utilized for ammonium removal and three similar columns of Ionac 641 resin (trade name) were utilized for uranium removal. Each column contained approximately 35 ft^3 (1 m^3) of resin. Ammonium ions from the ground water were replaced unexpectedly by hydrogen ions from the ion exchange resin, thereby reducing the pH. Reinjection of this water into the ore zone aquifer reportedly dissolved calcium from the host sandstone. Calcium ions (Ca^{2+}) displaced NH_4^+ and hydrogen ions from the cation exchange resin and from the production zone aquifer itself; this exchange process increased the NH_4^+ concentration

in the ground water from 420 to 630 mg/L (NRC, 1983). Approximately 7.5×10^5 gal (2.8×10^6 L) of water were treated by ion exchange; the process was terminated due to poor efficiency of the resins for NH_4^+ removal and falling well productivity.

Reverse osmosis (R.O.) was utilized next for restoration of the A-1 well field. The R.O. unit contained three Dupont Permasep Model Number 0840-155 (trade name) permeators (membranes) arranged in a two-stage operation. The unit was designed to operate at 30 gal/min (1.9 L/sec). Solution was produced from the ore zone aquifer and passed through the R.O. unit; the cleansed water then was reinjected into the ore zone. This method was utilized for only 33 days because the mining company considered it ineffective in reducing NH_4^+ concentrations; however, information provided by the mining company shows that NH_4^+ concentrations were reduced in the withdrawn ground water from 630 to 140 mg/L by the R.O. method. About 1.1×10^6 gal (4.2×10^6 L) of ground water were treated by R.O. during this period.

Removal of ammonia (NH_3) by air stripping was the next method of restoration applied to the A-1 well field. Sodium and/or potassium hydroxide was added to ground water produced from the well field to promote the conversion of NH_4^+ to NH_3. The water then was circulated through an air stripping column to volatilize the NH_3. The treated water was reinjected into the ore zone following this procedure. Air stripping was discontinued on July 25, 1981, when NH_4^+ levels apparently had stabilized at 25 mg/L. Approximately 4.4×10^6 gal (1.7×10^7 L) water were circulated through the air stripping column and subsequently were reinjected into the 1-Sand.

The final effort to restore the A-1 well field involved injection of "fresh" ground water into the ore-zone in November-December, 1982, to reduce remaining NH_4^+ and TDS concentrations by dilution. The water was obtained from a potable water source (AB Sand) that contained less than 500 mg/L TDS and very low concentrations of selenium, uranium, and NH_4^+.

Restoration of the B well field began on July 14, 1981, by pumping well 286, treating the produced solution by air stripping for NH_3 removal, and then reinjecting the treated water through wells 280,283, 284, and 285. Potassium hydroxide was added to the water prior to entry into the air stripping column to promote conversion of NH_4^+ to NH_3 and to maintain elevated TDS concentrations in the water injected into the ore zone. CCIC believed that high TDS concentrations in the injected fluid would promote removal of NH_4^+ from clays in the ore zone aquifer by ion exchange. Subsequently, various combinations of pumping and injection wells in the B well field were utilized to supply water to the air stripping unit and to inject the treated water into the ore zone aquifer. Over 2.5×10^7 gal (9.5×10^7 L) of water had been treated in this manner when the process was terminated in January, 1982. In addition, from August 3 to November 19, 1981, water from the AB-Sand was injected into the ore zone aquifer through wells 260 and 261.

A ground water sweep of the B well field ore zone aquifer was initiated following the acquisition of an NPDES surface discharge permit. This permit was necessary to accommodate discharge because of the absence of disposal facilities. From February 2 to March 23, 1982, over 3.3×10^6 (1.2×10^7 L) of ground water were removed from the ore zone aquifer; this

water was discharged to the surface. Overall water quality improved and NH_4^+ levels dropped to 120 mg/L following the ground water sweep.

Air stripping for NH_3 removal was employed again from March 23 to July 13, 1982. From July 13 to November 10, 1982, ground water sweeping was conducted; the produced water was discharged to the surface under the NPDES permit. Water from the AB-Sand was mixed with ground water withdrawn from the ore zone to dilute concentrations of contaminants to meet NPDES standards prior to surface discharge. Finally, from November 11 to December 23, 1982, approximately 5×10^3 gal (1.9×10^4 L) of water from the AB-Sand were injected into each of 14 wells (some of which are in the A-1 well field) selected by the Wyoming Department of Environmental Quality (DEQ) in an attempt to reduce NH_4^+, selenium and arsenic concentrations further by dilution. Ammonium levels averaged 2.54 mg/L at the culmination of B well field restoration efforts.

Post Restoration Ground Water Quality

Following the conclusion of restoration efforts at the A-1 well field, ground water was sampled over a six month period to evaluate the adequacy of restoration and the stability of water quality in the mined aquifer. The U.S. Nuclear Regulatory Commission (NRC) determined that restoration was not successful because the average concentration of TDS, NH_4^+, arsenic, selenium, vanadium, ^{226}Ra and pH exceeded baseline or Wyoming DEQ Class I (domestic) standards (Table 2). In December, 1982, samples were collected from all A-1 and B well field wells to evaluate NH_4^+, selenium and arsenic concentrations. Arsenic concentrations were below the Class I standard in all but two wells (248 and 297); selenium concentrations were above the Class I standard of 0.01 mg/L in 20 wells

Table 2. Comparison of water quality before and after restoration of the A-1 well field at the Collins Draw mine (after Cleveland Cliffs Iron Company, 1982, and U.S. Nuclear Regulatory Commission, 1983).

Parameter mg/L	Baseline Average[a]	Class I Standard	Average after 6 Month Stability Period[b]
TDS	414	500	582
Ammonia	0.18	0.5	35
Arsenic	<0.02	0.05	0.335
Selenium	<0.01	0.01	0.79
Vanadium	<0.05	--	0.33
pH (units)	7.5 to 8.7	6.5 to 8.5	9.1
Radium-226 (pCi/L)	21.6	5	>100

[a]Average of all wells sampled in A-1 and B well fields.

[b]Average of A-1 wells.

and exceeded 0.10 mg/L in 10 of these wells. Ammonium concentrations were significantly below 30 mg/L (a target set by the Wyoming DEQ) in all wells.

Ten wells in the B well field were sampled 10 months after restoration efforts culminated. These data indicate that NH_4^+, TDS, selenium, uranium, sulfate, pH and ^{226}Ra continued to exceed baseline and/or Class I standards (Table 3). The average concentrations of TDS, sulfate, NH_4^+, selenium and uranium showed steady increases over the 10 month period.

Computer Simulation of In Situ Mining and Restoration Operations

The mining and restoration operations conducted in the A-1 well field were simulated to evaluate whether all lixiviant and dissolved ions introduced into the 1-Sand aquifer during mining could have been removed during restoration operations. Modeling was accomplished using a modified version (Peterson, 1984) of the "Random Walk" (microcomputer version) solute transport computer code written by Prickett and Voorhees (date unknown). Modeling was performed on the NRC IBM PC microcomputer located at the NRC Uranium Recovery Field Office in Lakewood, Colorado. The effects of convection, dispersion, and retardation can be simulated by the model. Solutions for ground water flow incorporate an analytical formulation. The model is based on the concept that dispersion in porous media is a random process; the transport portion of the model is based on a particle-velocity technique for solute movement by convection, and a random-walk technique for solute movement by dispersion.

Table 3. Comparison of water quality before and after restoration of the B well field at the Collins Draw mine (after Cleveland Cliffs Iron Company, 1982, and U.S. Nuclear Regulatory Commission, 1983).

Parameter mg/L	Baseline Average[a]	Class I Standard	Average After 10 Month Stability Period[b]
TDS	414	500	594
Sulfate	159	250	252
pH (units)	6.0 to 8.7	6.5 to 8.5	8.7
Ammonia	0.18	0.5	34.3
Selenium	<0.01	0.01	1.02
Uranium	0.05	5.0	5.28
Radium-226 (pCi/L)	21.6	5.0	54.3[c]

[a]Average of all wells sampled in A-1 and B well field.

[b]Average of B field wells.

[c]Value reported is for six months after restoration.

The 1-Sand aquifer at the Collins Draw mine was modeled as a confined, homogeneous, isotropic aquifer of infinite areal extent. The hydrogeologic characteristics of the 1-Sand aquifer were constant for all modeling runs; these values were set as follows:

Porosity (n) = 0.28

Transmissivity (T) = 185 gpd/ft

Hydraulic Conductivity (K) = 3.5577 gpd/ft^2

Storativity (S) = 8.8×10^{-5}

Radius at which particles were injected at injection wells (r) = 2 ft

Longitudinal Dispersivity (D_L) = 3 ft

Transverse Dispersivity (D_T) = 1 ft

Regional hydraulic gradient based on cartesian coordinate system

[1]Component of Regional Ground Water Flow in X (East-West) Direction (V_X) = -0.00562 ft/day

[1]Component of Regional Ground Water Flow in Y (North-South) Direction (V_Y) = 0.0163

Adsorption (retardation) of particles onto aquifer matrix materials was not simulated.

Simulation of production and restoration operations in the A-1 well field was accomplished in conformance with the pumping and injection schedule provided by the mining company. Production and restoration of the A-1 well field was modeled as a single event extending from an initial time of zero (April 2, 1980) at the beginning of production activities to 485 days (July 31, 1981) at the end of restoration. The

simulation was continued for the period from 485 to 1734 days to evaluate post-restoration particle movement. Changes in pumping and injection rates, and any changes in the service capacity (pumping or injection) of individual wells were made at the proper number of days (Date) into the simulation in accordance with the pumping and injection schedule provided by the mining company.

The first phase of the modeling study was to simulate production (mining) operations in the A-1 well field. Production operations at the mine site were conducted between April 2, 1980, and November 3, 1980. Operations during the preconditioning phase were assumed to have a negligible effect on the hydraulic gradients in the aquifer. Based on this assumption, it was decided that the preconditioning phase could be omitted from the simulations because operations during this phase would have a negligible effect on particle movement during production.

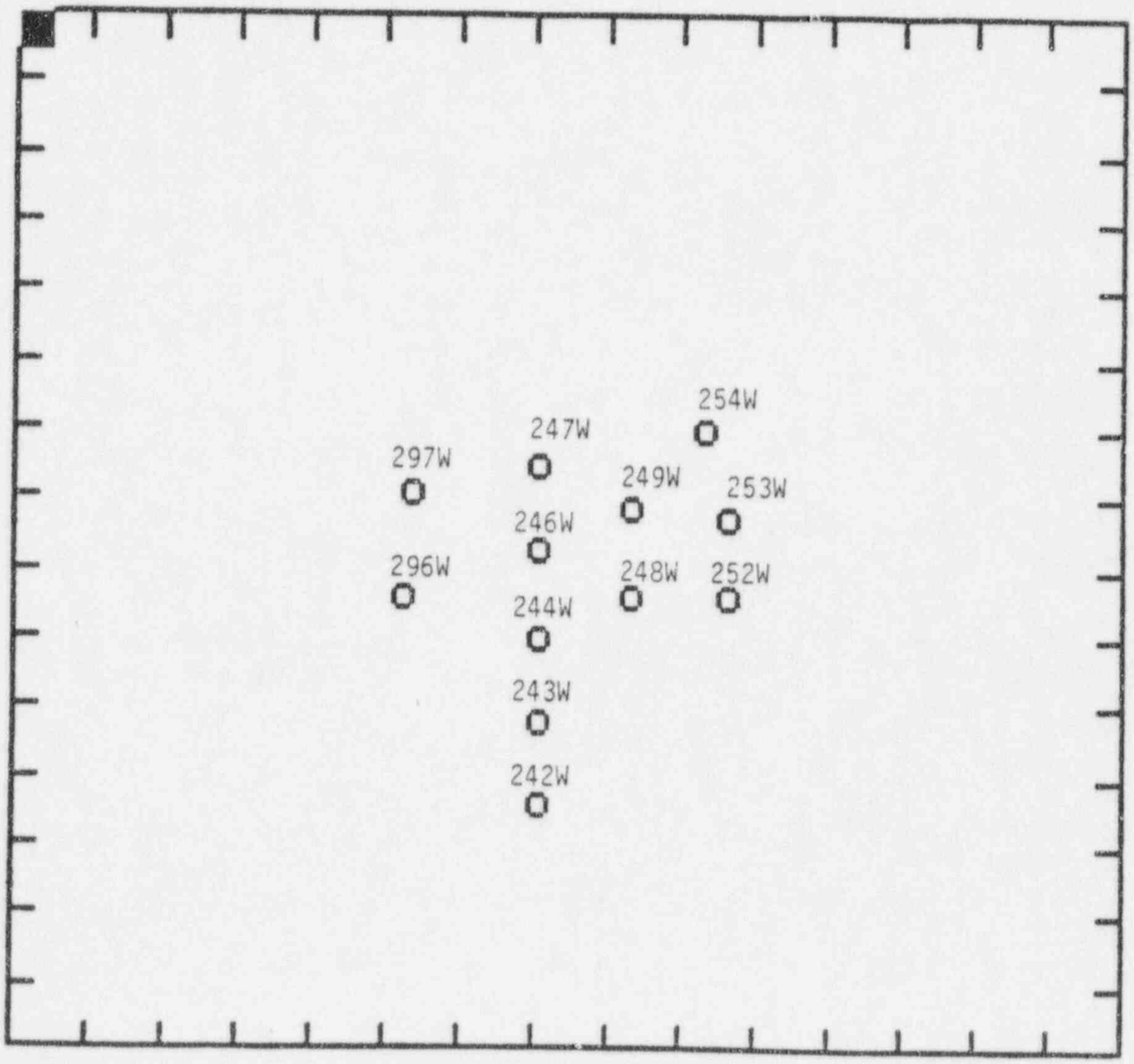
The simulated production period extended from an initial time of zero to 216 days. Production was simulated by injecting particles at injection wells and removing particles at pumping wells in accordance with the information provided by the mining company. At least one particle was injected for each time step. The number of particles injected into the aquifer or remaining in the aquifer after restoration does not represent a specific concentration of total dissolved solids. Particles were used to simulate the migration characteristics of lixiviant during production and restoration. The presence of a specific particle represents the existence of dissolved solids at that point in space only. Although particle density reflects a relative concentration; no specific concentrations are implied by the presence of particles.

Well locations for the simulation of the A-1 well field production and restoration operations are shown on Figure 4.

Figures 5 and 6 present particle maps which suggest that a plume of particles (dissolved solids) expanded continuously at the mine site as time increased during the production period (lixiviant injection) from April 2, 1980, to November 3, 1980.

Restoration of the A-1 well field began with the transfer of solution from the A-1 well field to the B well field during the period of November 3 to November 22, 1980. This procedure was simulated during the model simulation period of 216 to 235 days. Figure 7 shows the effects of the solution transfer on the simulated plume in the A-1 well field. Comparison of Figures 6 and 7 illustrates that pumpage of solution from the A-1 well field to shrink.

Restoration of the A-1 well field was conducted from November 23, 1980, to July 31, 1981. The simulation consisted of restoration for NH_4^+ removal only. Ammonium was considered to be completely mobile in the aquifer and completely removed from the withdrawn ground water by all restoration methods employed (conservative assumption). Treatment by ion exchange, reverse osmosis and air stripping was assumed for the purpose of the simulation to reduce the total number of particles in the withdrawn ground water to zero (conservative assumptions). This approach means that the restoration methods employed were assumed to be 100% effective and that all water injected into the 1-Sand aqufier during the simulation was devoid of particles (NH_4^+). Actual particle density should be greater than predicted because, in reality, the restoration methods did not actually remove all particles. However, no ion exchange



Approximate Horizontal Scale = 40 feet/inch
Approximate Vertical Scale = 43.2 feet/inch

Fig. 4. A-1 well field well locations.

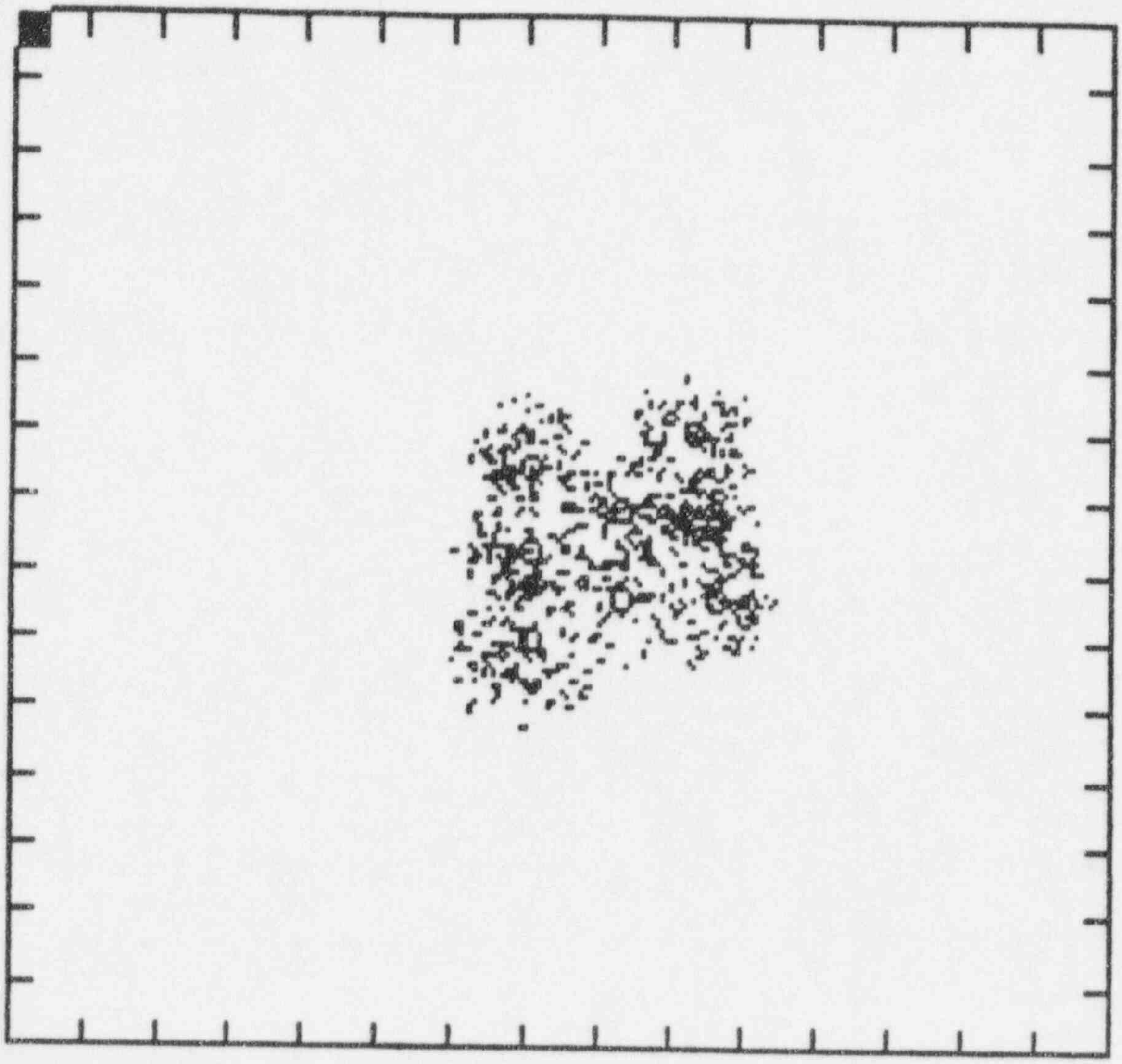


Fig. 5. Graphic display of particles in the A-1 well field at the end of the period April 2-25, 1980.

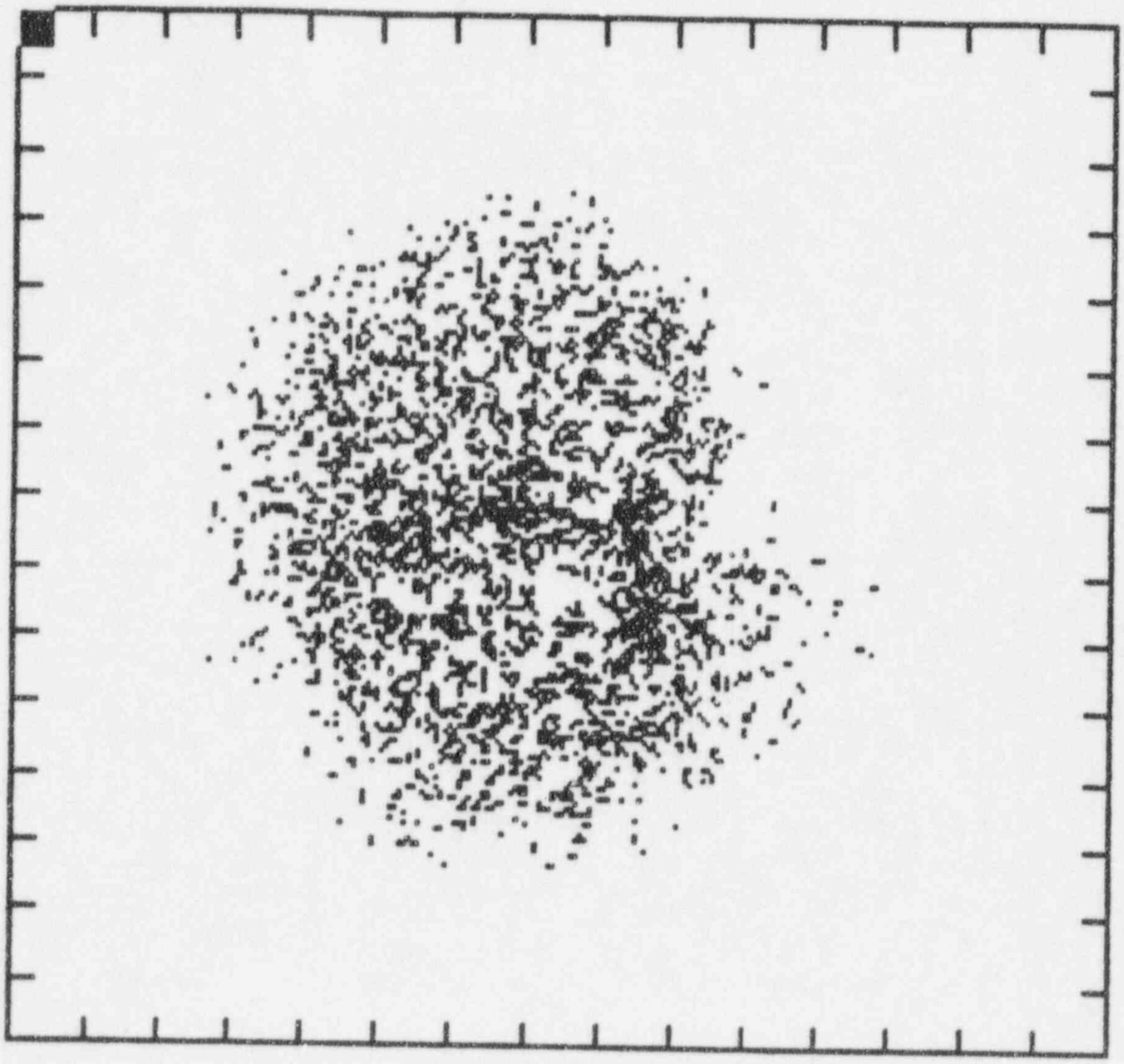


Fig. 6. Graphic display of particles in the A-1 well field at the end of the period September 16-November 3, 1980.

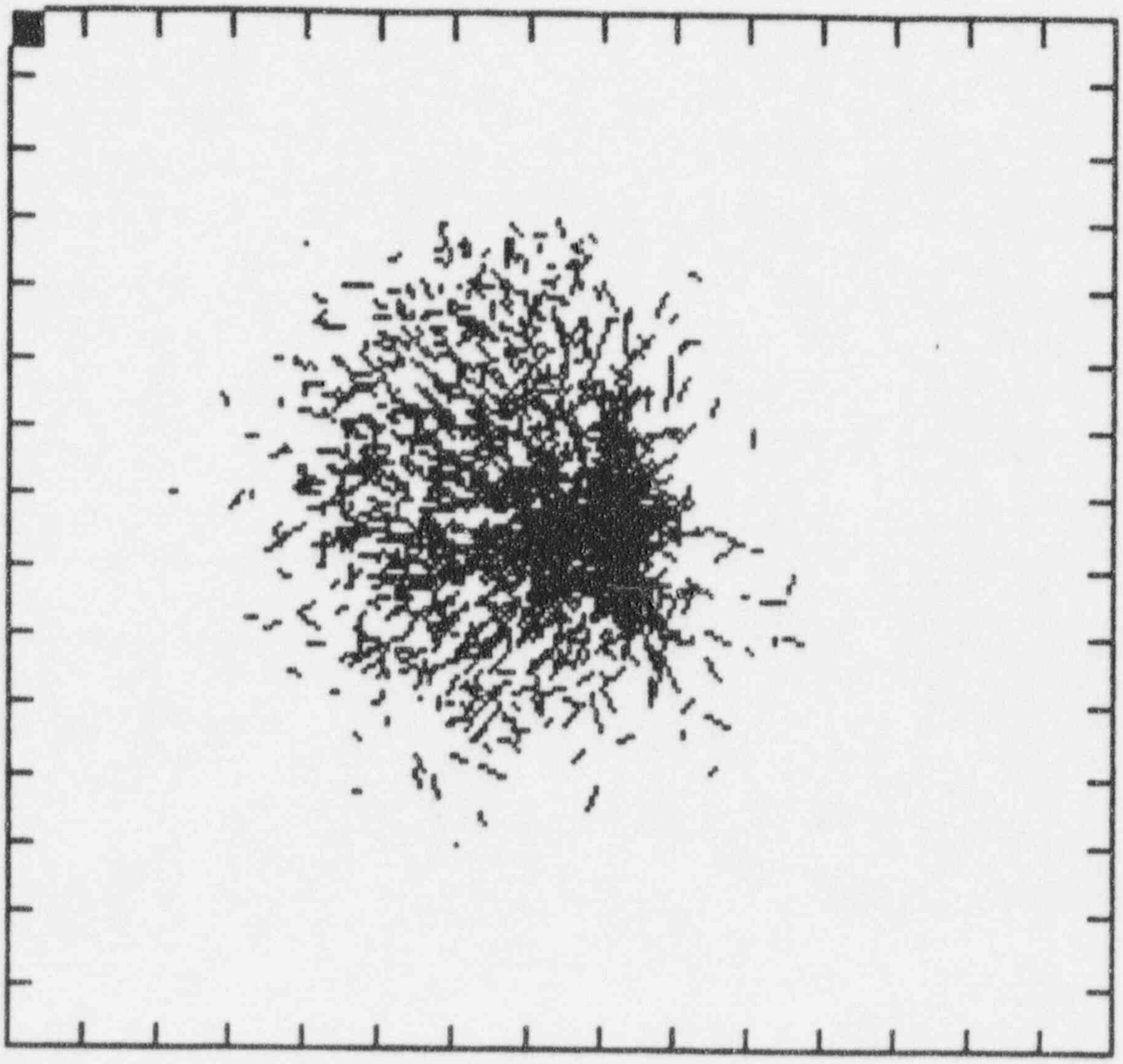


Fig. 7. Graphic display of particles in the A-1 well field at the end of the period November 3-22, 1980.

was assumed in the simulation (non conservative assumption) so that the actual particle front may have migrated less than predicted due to retardation.

In addition to the water treatment methods used during restoration of the A-1 well field, the mining company attempted to reduce the total dissolved solids concentration in the 1-Sand aquifer by diluting the ground water with water from the AB-Sand. This objective was accomplished by injecting the water into the 1-Sand aquifer through various well combinations. For the purpose of the simulation, this water was modeled as having a total particle concentration of zero (conservative assumption). No particles were added during injection of this water. Figure 8 shows the simulated plume at the completion of restoration operations.

Conclusions

The results of the simulation show that the plume continued to expand as restoration progressed from November 23, 1980, to July 31, 1981. The simulation suggests that the complex pumping and injection scheme utilized by CCIC during the restoration period tended to push the particles away from the well field rather than remove them. The simulation suggests also that the pumping-injection scheme displaced the particles (dissolved solids) to the outside of the well field and that some mixing occurred at the particle front due to dispersion. This mixing produced a decrease in the number of particles per unit area within the well field from the beginning to the end of restoration.

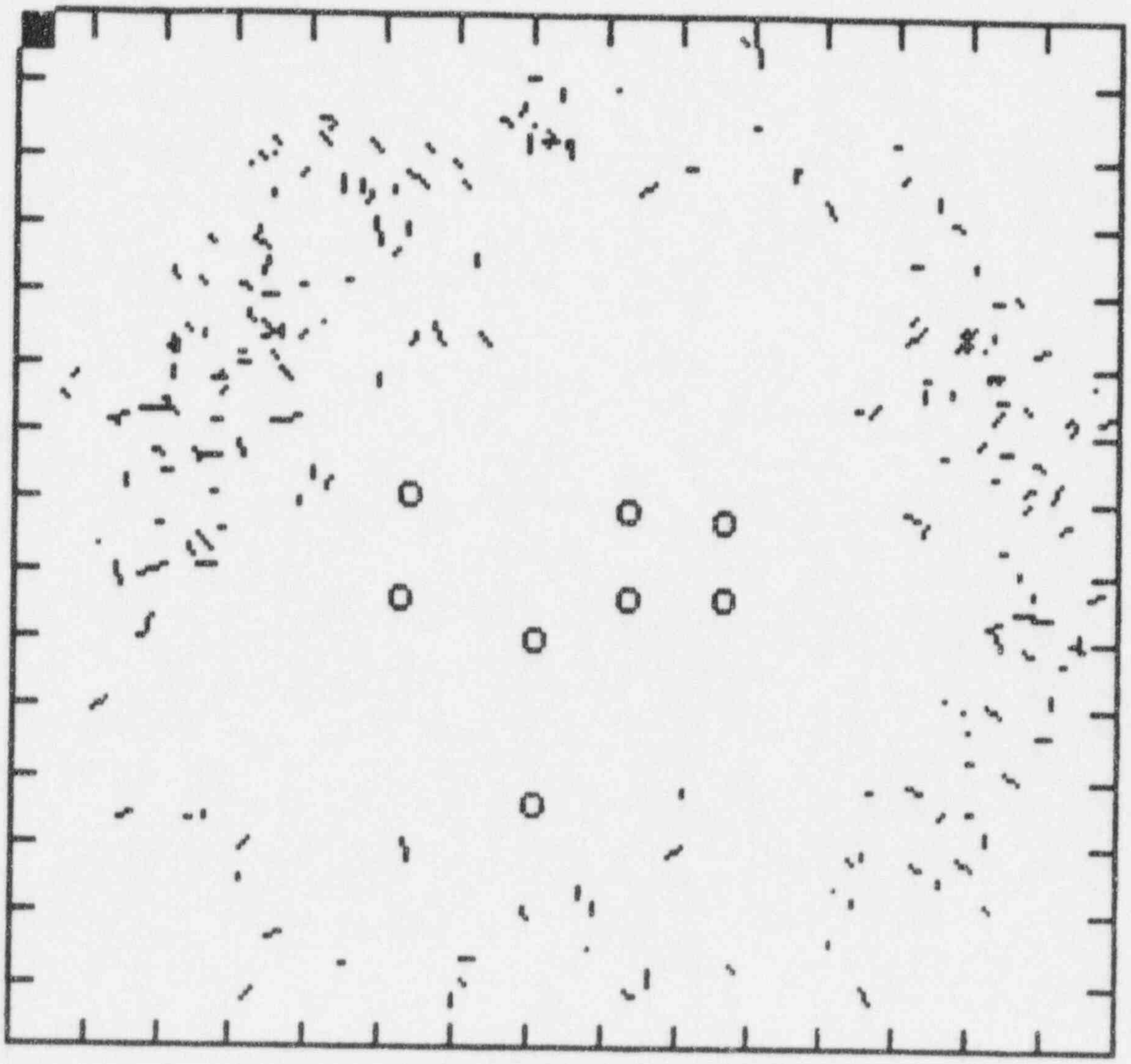


Fig. 8. Graphic display of particles in the A-1 well field at the end of the period July 13-31, 1981.

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