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An analysis of the use of programmable controllers to control an in situ leach mine wellfield

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AN ANALYSIS OF THE USE OF PROGRAMMABLE

CONTROLLERS TO CONTROL AN IN SITU

LEACH MINE WELLFIELD

A Dissertation

Submitted

In Partial Fulfillment

of the Requirements for the Degree of

Doctor of Industrial Technology

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ABSTRACT

In situ mining is a relatively new method that has the potential of recovering a variety of minerals. This process is quickly becoming an alternative to conventional mining techniques that are environmentally unsound. Two problems associated with in situ mining are, the amount of waste water generated by the process (bleed) and the uncontrolled migration of lixiviant outside the production zone (an excursion).

The purpose of this study was to determine if in situ mining processes could be monitored and controlled with a Sequential Control and Data Acquisition (SCADA) system. Using programmable logic controllers, a cost-effective SCADA system was designed and implemented in a uranium mine in northwestern Nebraska. The tests on this system's effectiveness to control the mining process yielded extensive data on flow control, waste water generation and excursion monitoring.

A *t* test was used to analyze the flow rates calculated for each individual production well in the wellfield by both the automated system and by locally mounted flow meters. No significant differences were found between the two sets of data, indicating the automated system accurately monitors flow data.

The daily percentage of bleed from the mining process was calculated for each of three randomly selected months. The result was 0.4% average daily bleed as compared to the upper limit of 0.5% required by the mining license.

To detect excursions, 40 monitor wells were installed around the perimeter of the wellfield and above the ore bearing acquifer. Hundreds of biweekly samples were taken from these wells during the three years the mining unit was in operation. These

samples were analyzed by a laboratory in Casper, Wyoming for the excursion indicators chloride, sodium, sulfate, alkalinity, and conductivity. None of the samples taken had chemical parameters high enough to declare an excursion.

The findings of this study support the use of a Sequential Control and Data Acquisition system to monitor and control in situ mining processes. The SCADA system, as implemented in this investigation, yields accurate data through a cost effective method that can be used to recover uranium while controlling excursions and limiting the waste water generated by the process.

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CHAPTER I

INTRODUCTION TO THE STUDY

Nuclear power has seen, in the last decade, a sudden upsurge of popularity in both civilian and scientific communities. This increase in popularity was demonstrated in April 1990 by Time magazine through a telephone poll taken to find out how the American public currently views nuclear energy. Of The 1000 Americans included in the poll, the results indicated that 40% of those surveyed feel that nuclear fuel will be the most relied upon fuel in the next 10 years, and that only 32% of those surveyed strongly oppose the idea. This acceptance of nuclear power is also supported by the National Academy of Sciences. In their findings following a 15-month study of the world's greenhouse problem, they concluded that nuclear power is seen as a way to fight the greenhouse effect. Likewise, Ratib Karam, Director of the Neeley Nuclear Research Center at North Georgia Tech stated, "Nuclear energy does not produce CO_2, and in terms of our global society, nuclear power plants are essential" (Greenwald, 1991, p. 54). With the depletion of the world's fossil fuel supplies coupled with their hazardous effects on our global environment, nuclear power's rewards are starting to outweigh its risks (Greenwald, 1991).

The U.S. presently produces 21% of its electricity from nuclear power. To gain the popularity it needs to become a major energy source, nuclear power needs to make economic, environmental, and practical sense in all phases of operation. One phase, mining uranium, has experienced many dramatic changes as the recovery process has shifted from the traditional open pit operation to modern in situ leach or solution mines. Solution mining emerged as an idea in the 1950s, and is a chemical method of mining that was first tested in the United States in 1963. Since that time, it is fast becoming an accepted and preferred mining technology, not only for uranium, but also for copper, gold, silver and other minerals (Schmidt, 1980). In addition, solution mining studies initiated in 1983 by Istanbul Technical University and the Turkish Atomic Energy Authority have proven that in situ uranium leaching is one of the most economical processes for recovering this metal, especially from underground formed deposits (Okutan, Oner, Saygili, & Savguc, 1989). Thus, in fragile, highly restrictive environments the in situ leach process (solution mining) for uranium recovery has recently gained popularity as a viable alternative to the costly and environmentally destructive open-pit uranium mine.

In situ mining has been used on a commercial basis since the mid-1970s to produce uranium from porous sandstone deposits in Texas and Wyoming. Typically, a leach solution (lixiviant) is injected through wells into the ore zone aquifer to dissolve the uranium-bearing minerals. The uranium-rich solution (pregnant lixiviant) is pumped from the ore zone by recovery wells, stripped of its uranium by ion exchange, chemically treated to remove the uranium and then reinjected into the ore zone through injection wells (Berglund, 1989).

The major environmental concerns during the operation of an in situ mine are the potential impacts of mining on the surrounding groundwater, radiological concerns, evaporation, storage pond leakage, and the disposal of wastes. Furthermore, if these conditions are not kept under complete control, they can be extremely costly and can even result with the mining operation being suspended until the United States Nuclear Regulatory Commission (USNRC) is assured the process is safe (Staub et al., 1986). Two of the problems addressed by this study, the distribution of fluids throughout the wellfield and, the uncontrolled migration of mining lixiviant and dissolved constituents (uranium) into the surrounding groundwater (an excursion), are accepted by mining companies as the most difficult to control.

This study was conducted at the Crow Butte Project near Crawford, Nebraska. The Crow Butte Project is a uranium mine that uses the in situ leach process to recover uranium from a subteranian aquifer. The overall mining project was divided into four phases. The first three phases were completed prior to the start of this study. Phase one was to identify the instrumentation required to design seven individual monitoring systems capable of controlling and monitoring the flow of mining solution into and out of the individual wells in an in situ uranium mine. In phase two, a software program was developed for two small logic controllers (SLCs) to collect, compile, and transmit flow data from each well to a single large host programmable logic controller (PLC), and to control and monitor the out-flow from producing wells. Phase three was the development of the software necessary to network seven SLCs, one PLC, and two 386 personal computers. This network was used to compile the data collected from the individual wells into graphs and charts that represented the condition of the water tables, flow patterns and mining efficiency within the wellfield. The fourth and final phase of the mining project was the subject of this study. Data were collected from two independent monitoring systems, a local readout recorded manually and an automated system described previously. The two sets of data were compared for differences to establish the accuracy of the automated system for wellfield control. The goal of wellfield control was to limit the waste water generated by the mining process (bleed) and to control for excursions.

Statement of the Problem

One of the major problems associated with the in situ mining process is the uncontrolled migration of mining solutions both horizontally and vertically outside the production zone. These undesirable and costly migrations are known as excursions. Numerous excursions have occurred in the Western United States at in situ uranium mining sites and are recognized by mining companies as events that need to be prevented. This would be possible if there existed an accurate monitoring system for the injection and recovery of water in the wellfield. With valid data, the wellfield could be balanced and water levels within it could be predicted and maintained. Water levels have never been used formally as an excursion indicator by in situ mining companies but they are recognized as the best possible early indicator of an excursion. Also, once an excursion has been declared, water levels should always be observed closely to bring the situation under control (Staub et al., 1986). This monitoring is difficult at best because of the size of in situ wellfields (typically hundreds of acres), the large number of wells involved (typically 300 to 1,000 wells), and the unreliable, time-consuming methods used to monitor the injection and production flow rates of each well (manually reading meters and timing flow rates with a stopwatch).

The problem of this study was to analyze the accuracy and effectiveness of using remotely located small logic controllers fitted with direct communication modules to collect and transmit wellfield flow and control data onto a larger network. The nodes on the network included seven SLCs (used for remote sequential control and data acquisition), a large host logic controller (used for data collection), and two 386 personal computers (used for compiling data from the host). The purpose for the entire network and its individual processors was to control wellfield water levels in an effort to effectively identify the possibility of a horizontal excursion before it could develop, and to limit the damage caused by horizontal excursions to acceptable levels once they occurred.

Purpose of the Study

The purposes of this study were to:

1. Establish the accuracy of small logic controllers equipped with a Direct Communications Module (DCM), to collect well-flow data, and transmit the data collected from remote locations within the in situ uranium mine wellfield.

2. Establish the accuracy of small logic controllers with a DCM to: (a) monitor the volume and distribution of fluids into and out of injection and production wells,

(b) to effectively form, maintain and move a cone of depression, and (c) to effectively access and mine ore from an in situ uranium mine.

3. Establish the accuracy of small logic controllers with a DCM to monitor the fluid flow rate of injection and production wells for the purpose of accurately controlling and predicting variations in the wellfield water levels and flow lines when manipulating individual well-flow rates.

4. Establish the accuracy of small logic controllers with a DCM to monitor the fluid flow rates of injection and production wells for the purpose of preventing in situ leach mining solutions from migrating horizontally into ground water resources adjacent to the mining process thus causing an excursion to develop.

5. Make the results of this study available to the in situ mining industry regarding the accuracy of small logic controllers to: (a) monitor the injection and production fluid flow rates in a wellfield, (b) to limit the number of regulation violations against mining companies, and (c) to immediately identify conditions that will ultimately result in a regulatory violation.

6. Make the results of this study available to the in situ mining industry regarding the accuracy of the data collected and transmitted over long distances by small logic controllers with a DCM to control the water levels in an in situ wellfield in an effort to conserve water, increase production and reduce operating costs.

Need for the Study

The need for this study was based on the following factors:

1. The uranium mining industry has a present and future need for reliably predicting and monitoring the flow of leach solution in an in situ wellfield. Groundwater is inherently affected by the mining process itself, in that it may cause the migration of naturally occurring radium-226 and solubilized uranium. Likewise, some heavy metals commonly associated with uranium mineralization may be mobilized by

the injection mining solutions (Durler, 1982). Therefore, the control of leaching solutions for optimum mining results and environmental safety is critical in the efficient and continued operation of in situ mining sites.

2. According to Beck (1980), nuclear fuel buyers are giving paramount importance to long term security of uranium supplies, and are turning to domestic producers for a portion of or all of their mineral needs. Presently, the domestic industry is facing environmental issues that threaten its survival. While traditional open-pit mines are costly and nonflexible, solution mining is the only hope domestic producers have for volume production necessary to meet the demand for uranium (Pool, 1989).

In situ mining has three distinct advantages over traditional mining methods: (a) the relatively low capital requirements, (b) production facilities can be brought on line and expanded more quickly than conventional mines (Clark, 1989), and (c) the lixiviant used in in situ mining is selective and dissolves only the natural uranium, thus, minimizing the effect the operation has on the surrounding environment. Precise control of water into and out of the wellfield is critical to this process and as of yet is extremely difficult if not impossible to accomplish.

3. There are approximately 23 in situ mining operations in the midwestern and western United States, currently in production, that could be impacted by this study. As the world nuclear power production continues to increase as pressure from environmental concerns increases, and as spot market prices continue to fluctuate, the in situ mining industry will be giving more attention to wellfield monitoring and control systems that are less labor intensive and provide a high degree of accuracy.

Research Questions

The research questions answered in this study were:

1. Do the well-flow rates indicated by the data collected and transmitted by the small logic controllers differ significantly from actual down hole flow rates that are indicated by locally mounted monitoring instrumentation?

2. Can the data collected and transmitted by the small logic controllers be used to minimize the bleed to no more than 0.5% of the fluid used in the mining process?

3. Are the data collected and transmitted by the small logic controllers accurate enough to justify operational changes in the wellfield balance to prevent lixiviants from migrating into the ground water resources near the in situ leach mining operation?

Significance of the Study

Reliability in predicting, monitoring and controlling the flow of leach solution is paramount in planning and operating a solution mine. Accurate knowledge of flow patterns is critical when assessing the mining process, minimizing bleed to conserve water resources, determining the amount of bleed to create and maintain a cone of depression, and controlling the rate and direction of leach solution flow. Through precise and continuous monitoring of each well's flow rate, flow patterns for these wells within the wellfield could be determined. These patterns could then be used to determine the optimum water flows for uranium recovery, to identify the best methods for conserving water and to maintain the safest water levels during the continuous operation of the mine (Reed, 1981).

Presently, most uranium in situ leach mining operations have remotely located wellfields containing equipment that is used to collect well-flow data. The two most popular methods of collecting data from the wellfield are: (a) to manually read flow meters attached to individual wells, the injection trunkline and the production trunkline, and (b) to use a portable recording device to record the totalized flow of each well in the wellfield (Hydril, 1990). Both methods incorporated a water meter attached to the injection and production lines to totalize and indicate the flow and distribution of lixiviant through individual wells. Typically a stop watch is used in conjunction with the water meter to calculate, set and monitor the flow rate of each injection or production well within the mining and restoration area.

Operating the wellfield by either of these methods created the problem of not having data current enough to accurately represent the flow rates of individual wells, individual totalized injection well-flow nor individual totalized production well-flows to predict and monitor the water levels in the wellfield. Either method lacks the ability to rapidly monitor the flow rate of individual wells and alarm plant personnel if a well has exceeded its maximum or fallen below its minimum flow rate. This is a critical variable in mining operations with wellfields that have a high permeability of three to five darcies like the Crow Butte site where a change in the flow rate of a group of wells can affect the wellfield water levels within as little as one hour. If the distribution of water is not precisely controlled the result could be a horizontal excursion endangering the surrounding groundwater and the mining operation being suspended (Collings, Knode, & Miller, 1990).

Tweeton, Cumerlato, Hanson, and Kuhlman (1989) stated that, "Safeguarding the ground water resources near an in situ leach mining operation is a responsibility shared by the mining company and regulatory agencies. Improved methods of predicting and monitoring flow could help mining companies control leaching solutions and assure regulatory agencies that these solutions will not escape from the wellfield" (p. 1). A major factor affecting the control of flow in a wellfield is the speed, accuracy and frequency at which data used to monitor the mining process can be collected and compiled into useful information. If this process was quick and reliable, individual well-flow rates and totalized flow data could be used to accurately control the flow and distribution of fluids within an in situ leach wellfield. This accuracy in control could then be used to produce a cone of depression that would provide for the most efficient mining process. Likewise it would limit the possibility of horizontal excursions from occurring and insure that the groundwater bordering the wellfield would not be affected by leach solutions.

If in situ leach mining is going to survive as a viable method for uranium recovery, these problems of wellfield control must be solved. This solution lies in the application of programmable logic controllers to monitor and control the in situ leach mining process.

Assumptions

The following assumptions were made in pursuit of this study:

1. The wellfield water level monitoring equipment was accurate and the person or persons taking the measurements were trained and knowledgeable in water table measurement.

2. The positive displacement water meters on the injection lines and the turbine water meters on the production lines in the wellfield were within 1% accuracy in ideal conditions; but due to non-homogeneous flow caused by entrained gasses, the meters were only accurate relative to each other.

3. The instruments used for continuous measurement or sample collection were calibrated accurately from the factory.

4. Radiation instruments used by independent laboratories employed in this study were calibrated against standards that are traceable to the National Bureau of Standards.

5. The person or persons evaluating the sample data were trained and knowledgeable in the area of water sampling analysis.

6. The data collection methods, data analysis and final reporting did not conflict with the interests of Ferret Exploration of Nebraska, Inc., Denver, Colorado.

7. The data collection methods, data analysis and final reporting did not jeopardize in any way the licensing agreement between Ferret Exploration of Nebraska, Inc., Denver, Colorado, and the State of Nebraska.

8. Subterranean water levels can be affected by changes in barometric pressures and lunar gravitational forces. It was assumed that the variations in water levels that were a result of these natural phenomena were homogeneous throughout the wellfield.

Delimitations of the Study

This study was conducted in view of the following delimitations:

1. The data collected for this study was delimited to the 2,500 acre surface area and wellfield in the Crow Butte Uranium Mining Project in Crawford, Nebraska, licensed to Ferret Exploration of Nebraska, Inc., Denver, Colorado.

2. Since this research was for a specific industry, the researcher was delimited to the programmable controllers and development software produced by the Allen Bradley Company, Milwaukee, Wisconsin, and to the instrumentation provided by Ferret Exploration of Nebraska.

Limitations of the Study

This study was conducted in view of the following limitations:

1. The methods used to conduct this research project were limited to the parameters described in the licensing agreement between Ferret Exploration of Nebraska, Inc., Denver, Colorado, and the United States Nuclear Regulatory Commission.

2. The methods used to conduct this research project were limited to standards set forth in the Commercial Quality Assurance Program, Radiological Monitoring Groundwater and Surface Water Sampling (Knode, 1993).

Definition of Terms

For the purpose of this study the following definition of terms were used:

<u>Accuracy</u>--The closeness with which an instrument reading approaches the true value of the variable being measured.

Aquiclude--Any geological formation which may contain considerable quantities of water but which does not transmit it at a sufficient rate to supply springs, wells, etc.

Darcy--The mathematical expression most suitable for this study is described by the equation:

$$Q = KA\,\frac{(ha - hb)}{L}$$

Q is the quantity of flow obtained in time; ha and hb are the hydraulic head at the inlet and outlet faces of the porous body of length (L). A is the gross cross section area. The parameter K is referred to as the permeability or hydraulic conductivity (Baver, Gardner, & Gardner, 1972).

Four filtration rates have been classified by the National Cooperative Soil Survey (Miller & Donahue, 1990).

1. Very low: less than 0.25 cm per hour.
2. Low: 0.25-1.25 cm per hour.
3. Medium: 1.25-2.5 cm per hour.
4. High: rates greater than 2.5 cm per hour.

Data Highway--The means of transmitting frames between stations interconnected by a data transmission line. A data highway consists of a data circuit and the physical and data link layers of the stations connected to the data circuit.

Digital--The characteristic of being continuous or discontinuous in nature. A signal that is present or not present that can be counted and represented directly as a numerical value.

Direct Communications Module--A solid state electronic device that provides connectivity between the PLC and SLC families for distributive processing. The DCM acts as a Remote I/O device to a PLC (supervisor) on the link.

Excursion--An uncontrolled migration of lixiviant and its associated dissolution products and by-products away from controlled areas of in situ mining ore zones.

In Situ mining--A method of extracting metal from an ore body "in place" without excavating the ore-bearing rock.

Instrument--A device for determining the value or magnitude of a quantity or variable.

Network--A series of points or devices connected by some type of communication medium.

Peer Communications Link--A hard-wired link to form communications in which messages are exchanged between entities with comparable functionality in different systems.

Programmable Logic Controller--A solid state control device that can be programmed to control process or machine operation. The programmable controller consists of five basic components: processor, memory, input/output, power supply, and programming device (Jones & Bryan, 1983).

CHAPTER II

REVIEW OF LITERATURE

In situ leach (ISL) mining is a relatively new method that has the potential of recovering a variety of mineral commodities such as copper, uranium, gold, silver, manganese and nickel. This mining method can be applied to smaller or lower grade deposits that would otherwise not be mined and also has major advantages when compared with other conventional mining in the areas of health, safety and the environment. Past experience has indicated that lower capitol costs are required for in situ leach mining, and the process yields a quicker return on investments.

Copper and uranium have been the two primary commodities extracted by in situ mining. In situ leaching of copper oxide deposits has been carried out at five locations in the southwest. During 1980 there were 16 commercial scale in situ uranium leaching operations at various stages of production and construction which accounted for about 10% of the domestic uranium production (D'Andrea, 1981).

The Bureau of Mines began conducting research in 1971 to improve in situ leach mining techniques and to minimize risks the mining process has on the environment. Research areas included well construction techniques, computer simulation, borehole mining, economic analysis and environmental concerns, with the initial research directed toward copper oxide deposits. Their emphasis shifted toward uranium in 1975 and presently in situ leach mining research is aimed at the development of in situ mining methods for the recovery of a variety of minerals (D'Andrea, 1981).

Briefly the in situ leach uranium mining process involves, (a) injecting a suitable leaching solution (lixiviant) into the ore zone below the water table, (b) oxidizing, complexing, and mobilizing the uranium, (c) pumping the uranium-rich solution from the ore zone through recovery wells, (d) stripping the solution of its uranium through an ion exchange system, and (e) reinjecting the solution into the ore zone through injection wells. Stratigraphy of most in situ uranium mine sites (including the Crawford, Nebraska site) consists of interbedded layers of sand, silt and clay with sinuous deposits of sand and/or gravel, deposited in fluvial environments (Collings et al., 1990). Facies changes (both laterally and vertically), erosional channels, scour and fill deposits, and zones of high hydraulic conductivity often exist at in situ uranium mining sites. These natural factors and man-made factors, such as unplugged boreholes, poorly sealed wells, and poor control of injection and production rates complicate in situ mining of uranium.

One of the major problems associated with the in situ mining method is the uncontrolled migration of lixiviant outside of the production zone. This migration of lixiviant is undesirable and known as an excursion. Horizontal and vertical excursions have occurred at many of the in situ uranium mine sites in the western United States and are recognized by mining companies as events that are costly and should be prevented.

Vertical and horizontal excursions are the result of both man-made and natural causes. The hydraulic properties of the aquifer and confining layers, the characteristics of faults, the condition of abandoned drill holes prior to mining, and the natural groundwater gradient and external influences on the gradient contribute to the incidence of excursions (Staub et al., 1986). Of the two, horizontal excursions are the most controllable during the mining operation. This can be done with accurate monitoring of the field-wide injection and production rates and maintaining the production rate a few percentages greater than the injection rate (a process called bleeding).

Wyoming and southern Texas were the prominent areas for early field experiments and in subsequent commercial scale production. Most recently Ferret Exploration of Nebraska was permitted to operate an in situ uranium mine near Crawford, Nebraska, the Crow Butte Project. Due to the underground strata this was an optimum site for testing the capability of programmable electronic controllers to control the in situ mining process and monitor for horizontal excursions. The results of two aquifer tests indicate that the ore zone aquifer was essentially isotropic and homogeneous. No faults or other conditions, which may result in vertical excursions, exist which allowed for horizontal excursions to be the isolated variable.

The Crow Butte Project

Ferret Exploration Company of Nebraska, Inc., (FEN) built and operates a commercial scale in situ uranium leach mining facility located in Dawes County, Nebraska. FEN acquired a major interest from Wyoming Fuel Company in June, 1986 and is now the operator of the Crow Butte uranium mining project. The project is located near the town of Crawford in the northwest corner of Nebraska.

The project site layout, process building area, office, lab and R & D facilities, and the pond areas are shown in Figure 1. These facilities are located in Section 19 of Township 31 north, Range 51 west. Figure 2 shows details of the project process facility areas for the Crow Butte Commercial Production facility, and the locations of the areas referred to in this study.

The existing mining operation evolved out of an R & D facility operated from July 1986 to January 1988. Uranium is recovered from the Basal Chadron sandstone by the in situ leaching process at a depth of 400 to 800 feet. The overall width of the mining area varies from 1,000 feet to 5,000 feet. The ore body ranges in grade from less than 0.05% to greater than 0.5% Uranium Oxide, with an average grade estimate at 0.26% equivalent Uranium Oxide (FEN, 1987).

Figure 1. Project site layout.

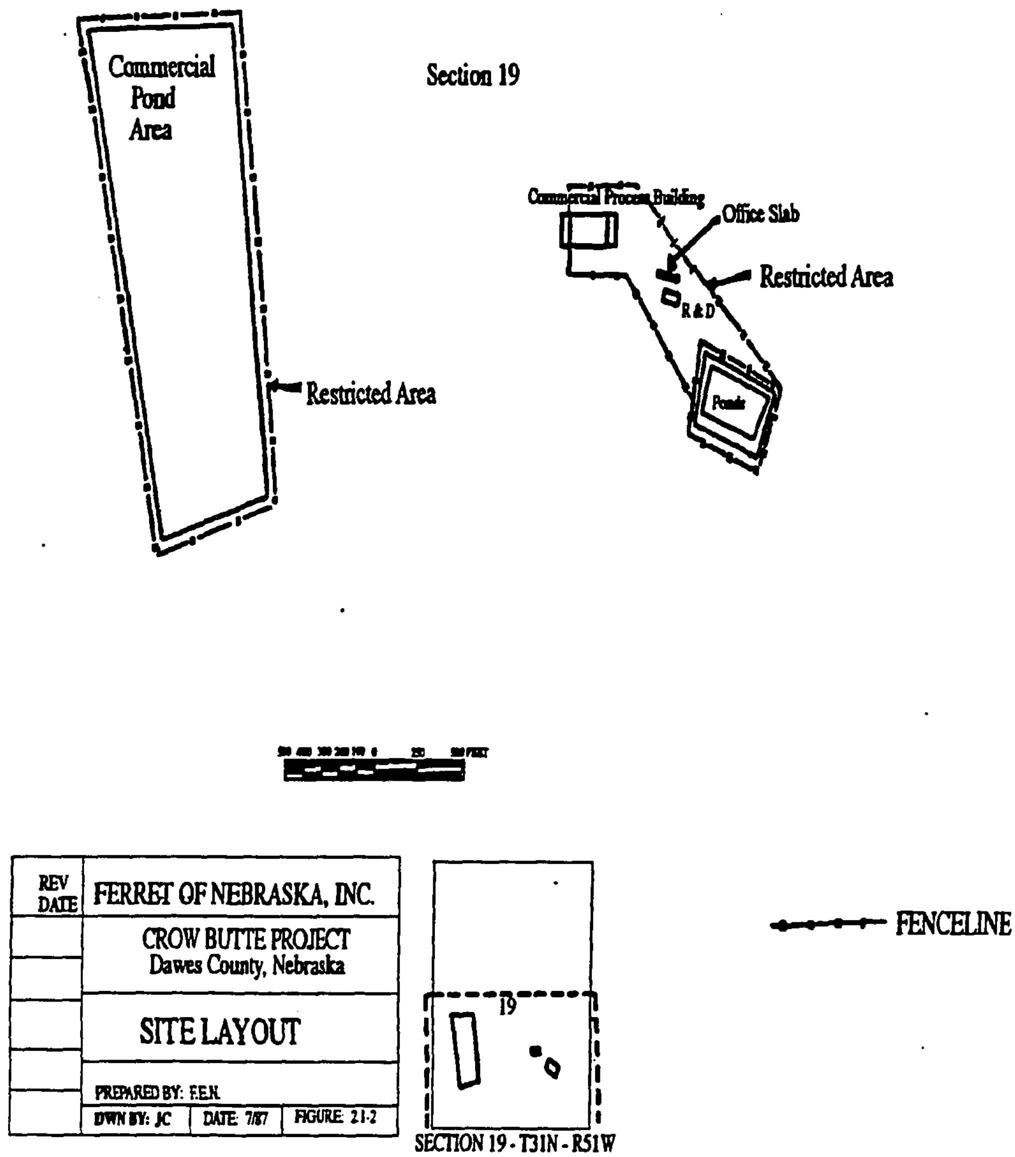


Figure 2. Details of the project process facility.

The uranium in the Crow Butte ore body occurs as a coating around individual grains of sand in the sandstone rock formation. The in situ leaching process used to free up the uranium from the host rock is divided into two steps, oxidation and dissolution. Adding oxygen to the groundwater causes the uranium to change into a liquid state or "go into solution." The uranium bearing solution, resulting from the leaching, is recovered by pumping the groundwater to the surface into the ion exchange column in the plant building where the uranium is extracted. The plant process uses the following steps:

1. Loading of uranium complexes onto an ion exchange resin.
2. Reconstitution of the solution by addition of sodium bicarbonate and oxygen.
3. Elution of the uranium complexes from the resin using a sodium chloride bicarbonate eluant and the precipitation of uranium using H_2O_2 and a base (Collings et al., 1990).

Groundwater containing solubilized uranium is recovered at 2,500 gpm and FEN expects to recover 1,000,000 pounds of uranium oxide per year. Two liquid wastes are the result of operating this facility. These are: (a) process waste water which includes filter backwash, wellfield bleed, eluent bleed and water treatment brine; and (b) restoration waste, primarily brine from the reverse osmosis unit. Solar evaporation ponds store and evaporate the liquid wastes.

Project Area Geology

Subsurface Faults

The present ISL mining operation of the Crow Butte ore body lies in what has been named the Crawford Basin. DeGraw (1969), made detailed studies of the pre-Tertiary subsurface in western Nebraska using primarily deep oil test hole information. He was able to substantiate known structural features. The Crawford Basin was defined by DeGraw as being a triangular asymmetrical basin bounded by the

Toadstool Park Fault on the northwest, the Chadron Arch and Bordeaux Fault to the east and the Cochran Arch and Pine Ridge Fault to the south.

A reproduction of the State Geologic Map of Northwest Nebraska, (see Figure 3), illustrates the recognized faulting in the area. Six northeast trending faults are present in Sioux and Dawes Counties. All of these faults are down thrown to the north. The White River Fault, follows the White River north of Crawford and was discovered during the exploration drilling phase of the Crow Butte project (Collings & Knode, 1984). The only other fault illustrated, the White Clay Fault, terminates the Arikaree Group rocks on the east from White Clay to about six miles east of Gordon (Nebraska Geological Survey, 1981).

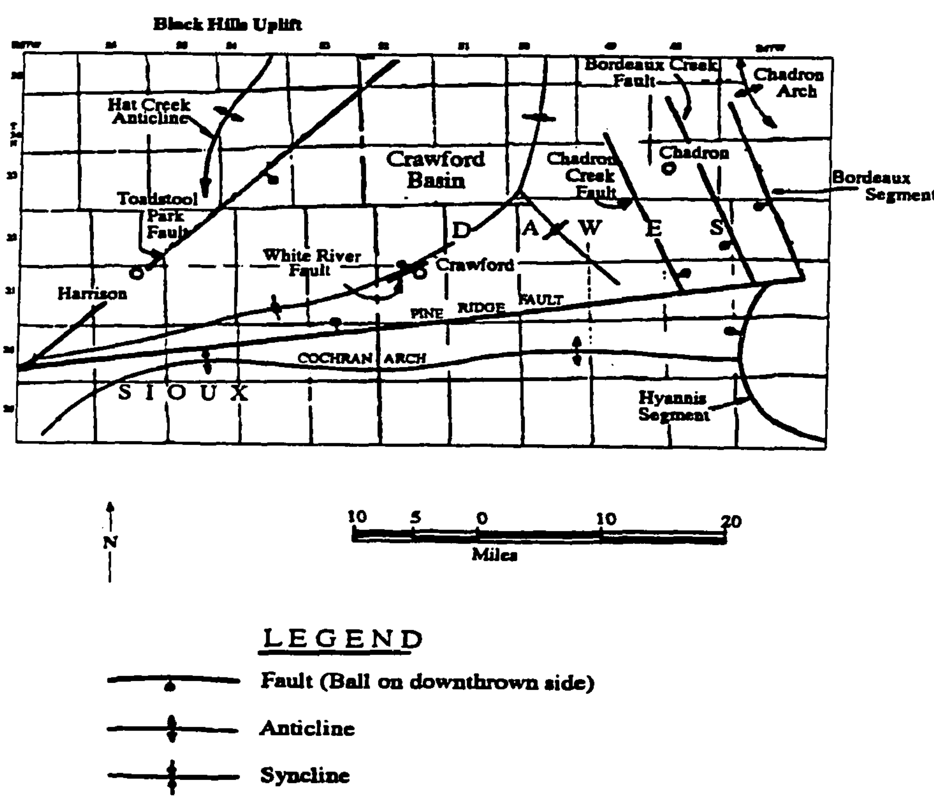


Figure 3. Geologic map of faults.

Present along the northwest margin of the project is the White River Fault. It is dated as post-Oligocen since it cuts both the Chadron and Brule Formations. The fault has a total vertical displacement of 200 to 400 feet with the upthrown side on the south. The White River Fault is about one and one-half miles northwest of the proposed northern extent of the wellfield area.

Drill data throughout the project area indicate that no significant faulting exists in the wellfield area. Although small faults have been identified in and near the project area, they have offsets of a few feet. These small faults have no effect on the confinement of the Chadron Sandstone based on hydrologic testing in the area (FEN, 1987).

<u>Strata</u>

Sedimentary strata ranging from the late Cretaceous through Tertiary age are exposed throughout northwest Nebraska. Pleistocene alluvial and colluvial material are abundant south of the main portion of the ore body along the north slope of the Pine Ridge. Figure 4 is a generalized stratigraphic chart for the region (Collings & Knode, 1984). The stratigraphic nomenclature of Swinehart, Souders, DeGraw, and Diffendal (1985) and FEN (1987) are shown on the same column.

Seven east-west cross sections have been constructed through the wellfield area to demonstrate the geology of the Basal Chadron Sandstone and its relationship to the confining horizons (see Appendices A-H). One northwest-southeast cross section is included to show the continuity of the geology (see Appendix I). Reduced electric geophysical logs from FEN exploration holes were used in the cross sections. These logs consist of two curves, single point resistance on the right and either neutron-neutron or spontaneous potential on the left. The Pierre Shale, Chadron Formation, Brule Formation, and Arikaree Group, if present, are subdivided on these cross sections based on log characteristics which are the most important consideration

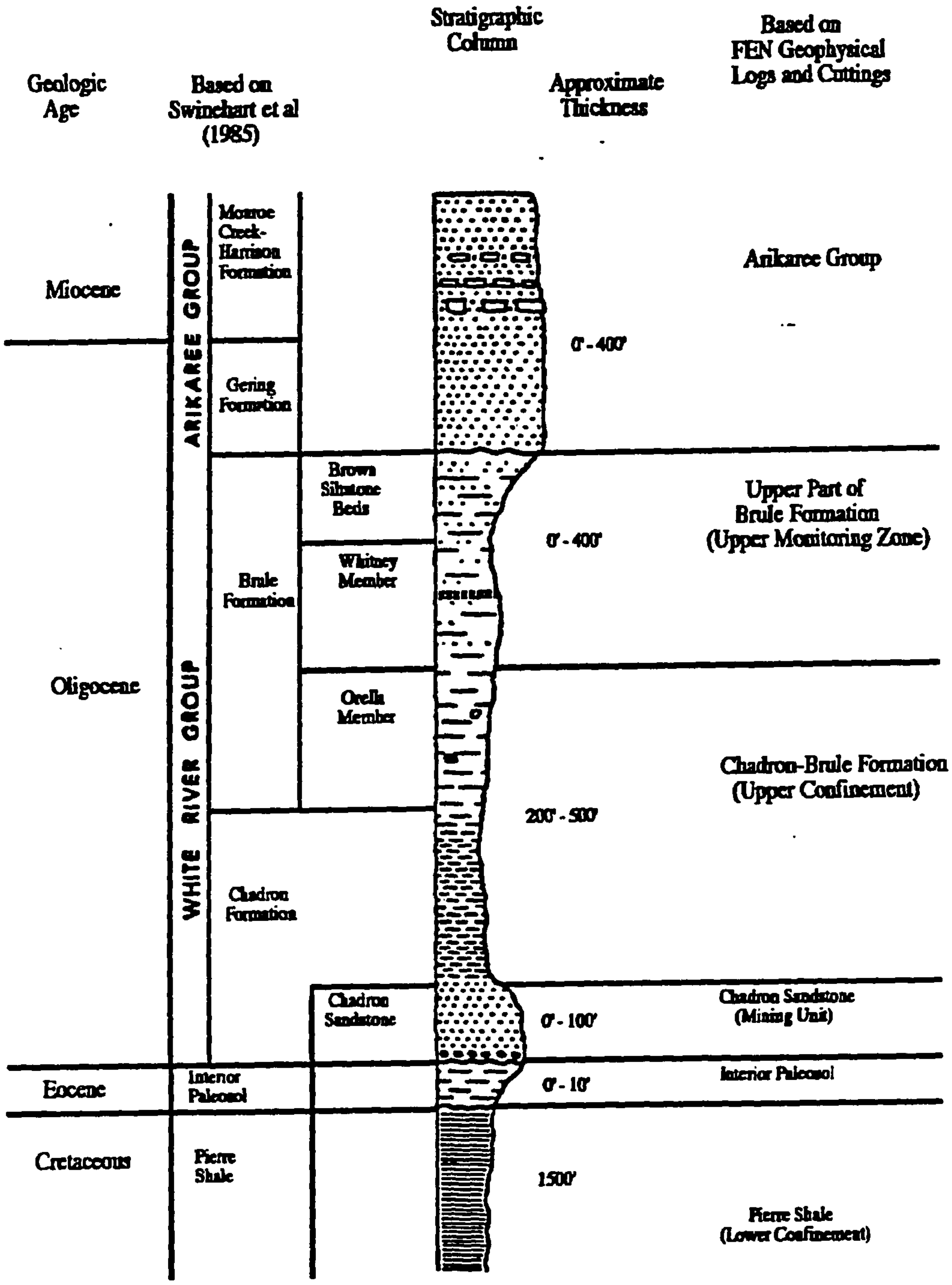


Figure 4. Stratigraphic chart for project area.

in a solution mining project. These sections demonstrate the continuity of the Chadron Sandstone and the excellent confinement provided by the overlying Chadron and Brule Formations and the underlying Pierre Shale (FEN, 1987).

Pierre Shale--Lower Confinement

The Pierre Shale of the Cretaceous age, is a black marine shale and is the oldest formation encountered in FEN test holes within the Crow Butte project area. Since it is the lower confining formation for the uranium mineralization all company test holes are terminated as soon as the Pierre Shale is intersected. The Pierre is a widespread dark gray to black marine shale, with relatively uniform composition throughout, and is essentially impermeable (Spalding, 1982). Although the Pierre Shale is up to 5,000 feet thick regionally, in Dawes County deep oil tests have indicated its thicknesses to be 1,200 to 1,500 feet (Collings & Knode, 1984). The Pierre Shale is the confining bed below the Chadron Sandstone which is the host for uranium mineralization.

Chadron Sandstone--Mining Unit

The Chadron is the oldest Tertiary Formation in northwest Nebraska. The Chadron Formation lies on top of the Pierre Shale. The Chadron Formation has sandstone at the base with overlying siltstone, mudstone, and claystone, that is typically green hued (Singler & Picard, 1980). Regionally, the vertical thickness of the Chadron Formation varies greatly with the maximum thickness of the Chadron Formation as being estimated at 300 feet (Swinehart et al., 1985).

The upper part of the Chadron represents a distinct change from the underlying sandstone. This area exhibits a light green-gray bentonitic claystone at the top grading downward to green and frequently red claystone often containing gray-white bentonitic clay interbeds (FEN, 1987).

At the bottom of the Chadron Formation is the Chadron Sandstone; it is a coarse grained sandstone interbedded frequently with thin clay beds. The Chadron

Sandstone is the host member and mining unit of the Crow Butte ore deposit, the only area where uranium mineralization is present. The vertical thickness of the Chadron Sandstone within the mining area averages about 60 feet thick. An isopach of the Chadron Sandstone indicates a range in thickness of 0 feet on the northeast to nearly 100 feet on the west (see Figure 5) (FEN, 1987).

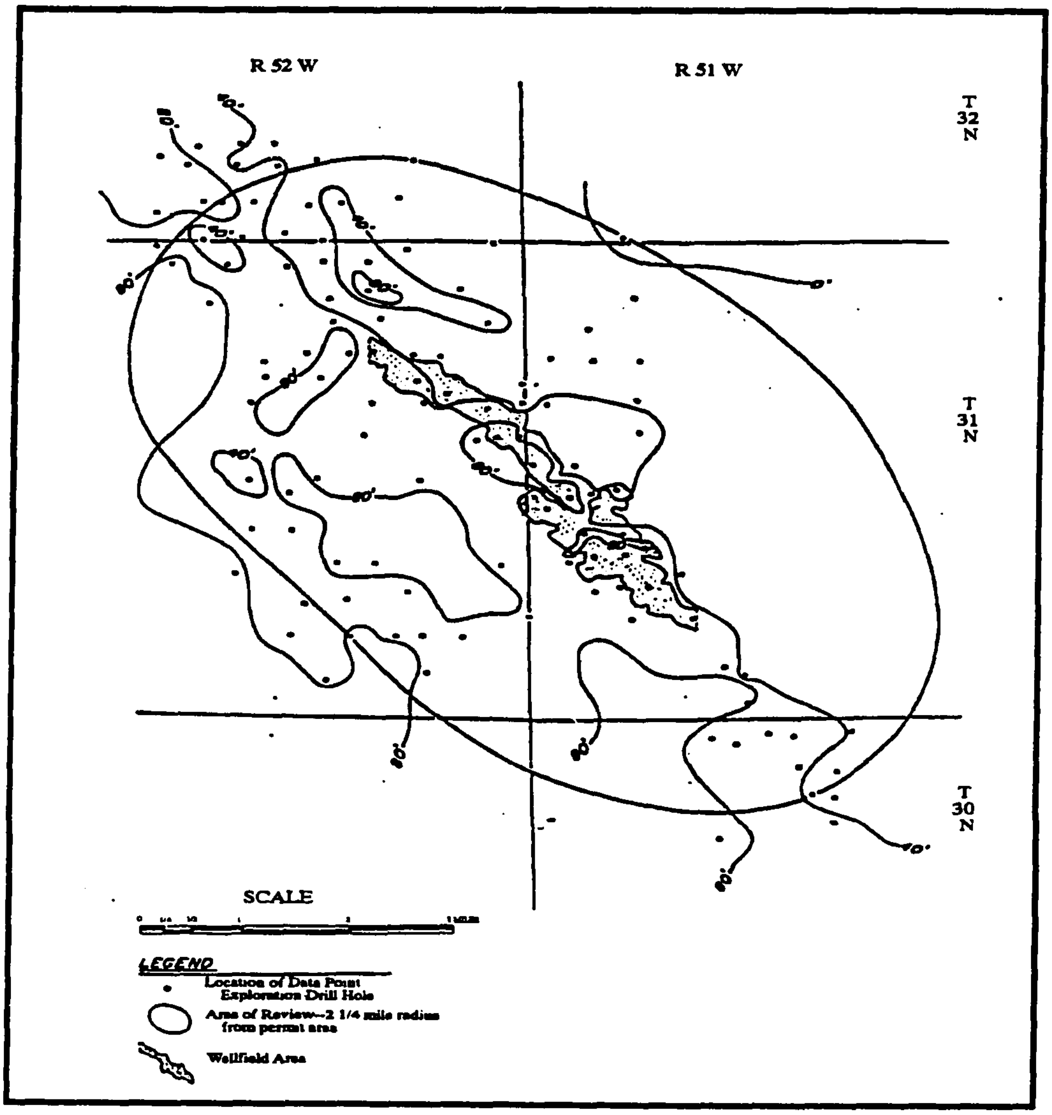


Figure 5. Isopach of the Chadron Sandstone.

The Chadron Sandstone is composed of 50% monocrystalline quartz, 30% to 40% undifferentiated feldspar, plagioclase feldspar and microcline feldspar. The remainder includes polycrystalline quartz, chert, chalcedonic quartz, various heavy minerals and pyrite (Collings & Knode, 1984).

Chadron-Brule Formations, Upper Confinement

In addition to the upper part of the Chadron Formation, the Brule Formation forms the upper confinement overlying the Chadron Sandstone. This is observable by the epigenetic occurrence of the uranium mineralization, which is strictly confined to the Chadron Sandstone. The upper part of the Chadron represents a distinct and rapid facies change from the underlying sandstone unit (see Table 1). The upper part of the Chadron Formation is a light green-gray bentonitic clay grading downward to green and frequently red clay. This portion of the Chadron often contains gray-white bentonitic clay interbeds. The light green-gray "sticky" clay of the Chadron has been observed in virtually all drill holes within the mine site. The measured vertical hydraulic conductivity of the upper confinement is less than 1.0 x 10 - 10 cm/sec (FEN, 1987).

Table 1

Composition of the Chadron and Pierre Shale Formation

	Estimated Weight Percentage as Determined by X-ray Diffraction		
Phase	Upper Part Chadron Formation (2) (Upper Confinement)	Chadron Sandstone (4) (Mining Unit)	Pierre Shale (2) (Lower Confinement)
Quartz	22.5	75.5	26
K Feldspar	2	13	4
Plagioclase	1	9.5	1
Kaolinite-Chlorite	--	<1	9
Montmorillonite	44	<1	32
Mica-Illite	1	<1	15
Calcite	22	--	1.5
Fluorite	0.5	--	--
Amorphous	7	1	10.5
Unidentified	--	<1	1
	100	100	100

Note. Number in parentheses is number of core samples.

Brule Formation

Directly above and lying conformably on top of the Chadron Formation is the Brule Formation. It consists of interbedded siltstone, mudstone, and claystone with occasional sandstone, with the lower portion consisting primarily of siltstones and claystones. Infrequent fine-to-medium grained sandstone channels have been observed in the lower part of the Brule Formation but these sandstone channels have very limited lateral extent. The maximum thickness of the Brule Formation has been described as 1,150 feet. (Swinehart et al., 1985).

Upper Part of the Brule Formation--Upper Monitoring Unit

The upper part of the Brule Formation is primarily buff to brown siltstones which have a larger grain size than the lower part of the Brule Formation. Occasional sandstone units are encountered in the upper part of the Brule Formation, but these small sand units have limited lateral continuity and, although water bearing, do not always produce usable amounts of water. These sandstones have been included in the upper part of the Brule Formation and are illustrated on the series of cross sections as overlying the upper confinement (see Appendices A-I). The lowest of these water bearing sandstones are monitored by shallow monitor wells during mining (FEN, 1987).

Seismology

The Crow Butte Project Area in northwest Nebraska is within the Stable Interior of the United States. The project area along with most of Nebraska is in seismic risk Zone 1 on the Seismic Risk Map for the United States compiled by Algermissen (1969). Most of the central United States is within seismic risk Zone 1 and only minor damage is expected from earthquakes which occur within this area. The nearest area to the project area of higher seismic risk is in the southeastern part of Nebraska within the eastern part of the central Nebraska Basin (Burchett, 1979) about 300 miles from the project area.

Although the project area is within an area of low seismic risk, occasional earthquakes have been reported. Over 1,100 earthquakes have been catalogued within the Stable Interior of the U.S. since 1699 by Docekal (1970). This study, considered complete to 1966, noted several earthquake epicenters within northwest Nebraska. All but two of these earthquakes were classified within the lowest category, Intensity I-IV, the Modified Mercalli Intensity Scale of 1931.

Aquifer Testing

To evaluate the hydraulic properties of the uranium bearing sand and the confining strata within the permit area, an aquifer testing program was conducted consisting of two aquifer tests. This study was primarily concerned with the control of horizontal excursions. Therefore the results of the tests were important to establish the integrity of confinement of the mine aquifer and the unlikely occurrence of a vertical excursion.

The first multiple-well aquifer test was conducted in the R & D wellfield in November, 1982. The pumping period of this test was 50.75 hours and the recovery period was 27.6 hours. During this test, water levels in four production zone observation wells and two shallow Brule monitor wells were measured.

After analysis of the data from the first aquifer test it was determined that the Basal Chadron Sandstone, the ore-bearing aquifer at the Crow Butte site, is a non-leaky, confined, isotropic aquifer. Furthermore, evidence from the test shows that the Basal Chadron Sandstone is not hydraulically connected to the overlying aquifer in the Brule Formation (FEN, 1987).

The second test, a multiple-well aquifer test, was performed in the area where the commercial plant is operating. The purpose of this test was to accurately characterize the hydrogometric regime of the commercial mining area. The specific objectives of the second test, a multiple-well aquifer test, were to:

1. Confirm the confinement of the ore-bearing aquifer.

2. Determine the transmissivity, hydraulic conductivity, and storativity of the ore-bearing aquifer.

3. Determine the azimuth and magnitude of the major and minor axes of transmissivity in the ore-bearing aquifer.

4. Use the Neuman-Witherspoon Method to determine the vertical hydraulic conductivity under in situ conditions, of the confining layers which overlie and underlie the ore-bearing aquifer.

5. Design the groundwater monitoring system.

6. Obtain predictive analysis of the mining and restoration efficiency.

The length of the second test was 72 hours. The overlying aquifer showed no response to the pumping. Results of the test indicate that the Basal Chadron Sandstone, the ore-bearing aquifer is a non-leaky, confined, slightly-anisotropic aquifer (FEN, 1987).

The aquicludes which overlie and underlie the Basal Chadron Sandstone probably yielded some small amount of water as recharge (or leakage) to the aquifer during the aquifer-test pumping. However, the amount of this recharge or leakage was extremely small. The lack of substantial leakage is the result of the extremely low vertical hydraulic conductivity of the confining layers. The vertical hydraulic conductivity of the overlying confining layer, as determined from the laboratory tests of core samples, is about 7.8 x 10-7 ft/day, and that of the underlying confining layer is about 9.6 x 10 - 8 ft/day (FEN, 1987). Confining layers with vertical hydraulic conductivities this low are, by definition, called aquicludes.

The integrity of confinement of the ore-zone aquifer (Basal Chadron Sandstone) may be characterized most graphically by the hydraulic resistance factor. The time needed for a water molecule to travel through the entire thicknesses of the aquicludes are about 12,000 years for the overlying aquiclude and about 7,500,000 years for the underlying aquicludes (FEN, 1987).

Discussion of the Project Area

The Crow Butte ore body represented an excellent area for in-situ mining of uranium and conducting this study. The lower confining bed, the Pierre Shale, is over 1,000 feet thick. The Pierre Shale is homogenous black shale with very low permeability and is one of the most laterally extensive formations of northwest Nebraska.

The upper confinement is composed of the Chadron Formation above the Chadron Sandstone and that portion of the Brule Formation underlying the intermittent Brule Sandstones (see Appendices A-I). This part of the Chadron Formation is an impermeable clay grading upward into several hundred feet siltstones and claystones of the Brule Formation. These units separate the zone of extent and have been observed in all holes within the project area.

Small faults and fractures may occur in the sediments overlying the Chadron Sandstone unit and there may be areas of secondary permeability within isolated areas of the Brule Formation. However, two pump tests conducted in the area of review indicate no faulting or fracturing which affects the confinement of the Chadron Sandstone. The tests further indicate that no faulting or fracturing would affect in-situ mining of the uranium nor would allow the possibility of a vertical excursion.

ISL Mining Process, Instrumentation, Monitoring and Control

The Crow Butte ISL facility was designed to process 2,500 gallons of water per minute. The facility consists of a plant building that uses state-of-the-art unit operations to recover uranium and seven remote well houses located throughout the area being mined. These remote buildings are used to house motor control centers, the individual well head meters and the small logic controllers. The control instrumentation in the processing plant and wellfield is microprocessor based, and manufactured largely by the Allen-Bradley Company. The purpose for this equipment is wellfield data collection, monitoring individual well flow rates and controlling production flow in the wellfield. The plant building control center is hard-wire interfaced to the individual processors located in the outlying wellfield buildings. Wellfield instrumentation is used to count, record, monitor and control producing well flows and to count, record and monitor injection well flows. This information is transmitted sequentially to the plant building via a Data Highway Plus link and the hard-wire connection.

Wellfield

The ore body mined with the in situ process lies in the Basal Chadron Sandstone ranging from 400 to 800 feet deep. The overall dimensions of the area mined is approximately 1,000 to 5,000 feet wide and 40 feet thick.

Two well construction methods were used for the well construction and installation of production and injection wells. Both of these methods were used for completion of injection wells, producing wells, and monitor wells.

Method No. 1, (see Figure 6) involves the setting of an integral casing/screen string. The method consists of drilling a hole, geophysically logging the hole to define the desired screen interval, and reaming the hole to the desired depth and diameter. Next, a string of casing with the desired length of screen attached to the lower end is placed in the hole. A cement basket is attached to the blank casing just above the screen to prevent blinding of the screen interval during cementing. Cement is then pumped down the inside of the casing to a plug set just below the cement basket. The cement passes out through weep holes in the casing and is directed by the cement basket back to the surface through the annulus between the casing and the drill hole. After the cement has cured sufficiently, the residual cement and plug are drilled out, and the well is developed by air lifting or pumping (FEN, 1987).

WELL COMPLETION METHOD NO. 1

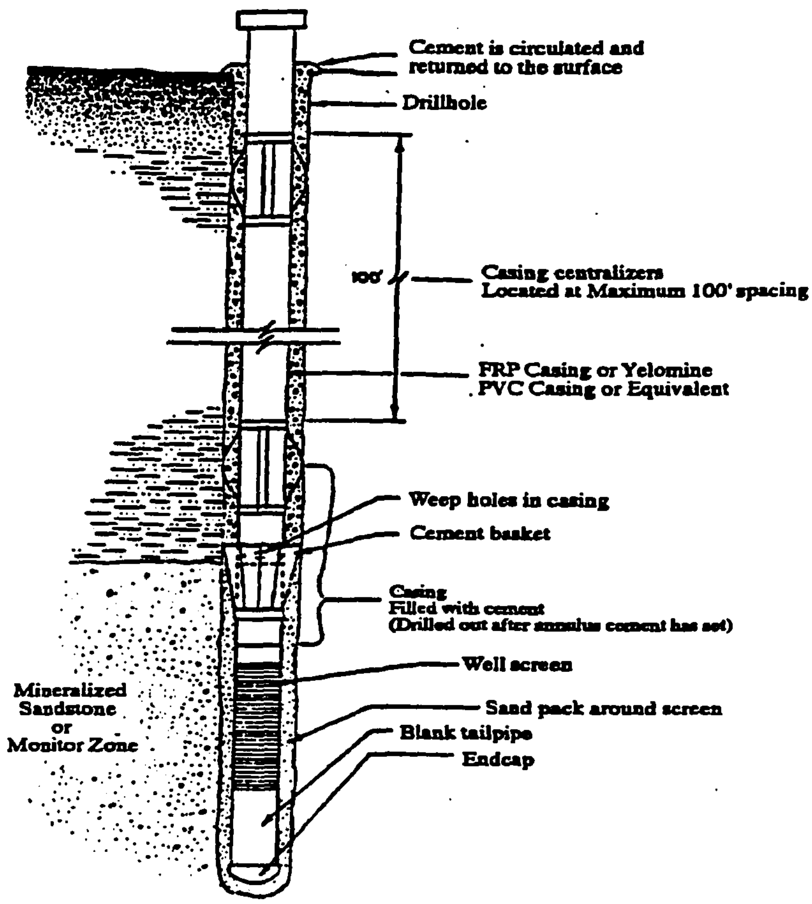


Figure 6. Well completion method number one.

Method No. 2, shown in Figure 7 uses a screen telescoped down inside the cemented casing. A hole is drilled and geophysically logged to locate the desired screen interval; it is then reamed if necessary but only to the top of the desired screen interval. Next a string of casing with a plug at the lower end and weep holes just above the plug is set in the hole. Cement is pumped down the casing and out the weep holes; it then returns back to the surface through the area between the casing and the earth. After the cement has cured, the residual cement in the casing and the plug are drilled out and the drilling continues through the desired zone. The screen with a packer and/or shale traps is then telescoped through the casing and set in the desired interval. The packer and/or shale traps serve to hold the screen in the desired position while acting as a fluid seal (FEN, 1987).

WELL COMPLETION METHOD NO. 2

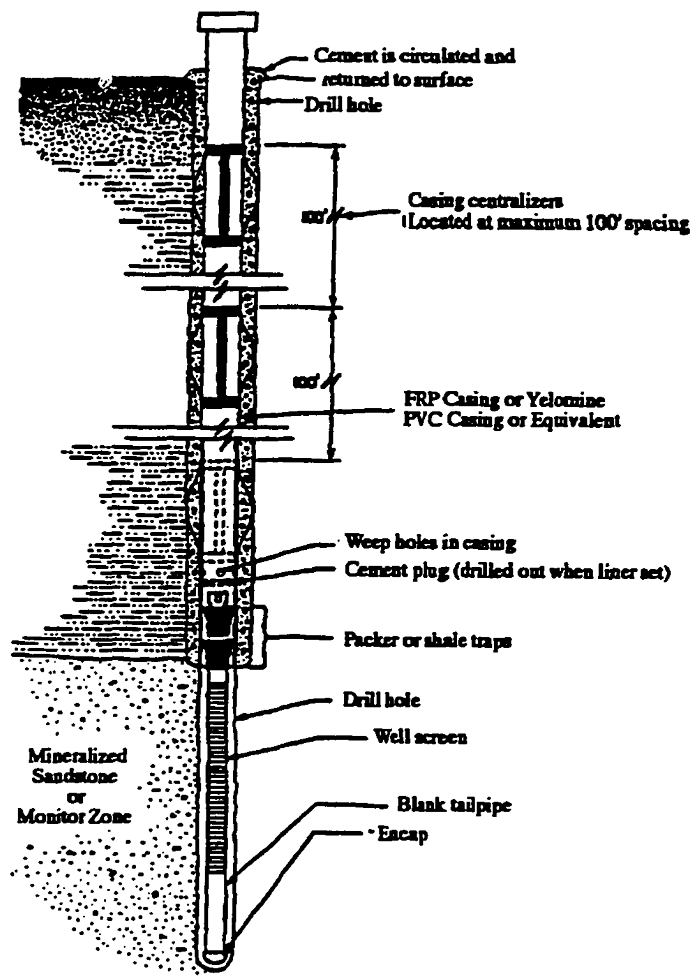


Figure 7. Well completion method number two.

Before each well could be used for leach solution injection, field testing was performed to demonstrate the mechanical integrity of the well casing. The testing was performed using pressure-packer tests. The mechanical integrity tests used the following procedure:

1. The well was tested after the cement plug at the bottom of the casing had been drilled out. The test consisted of placement of one or two packers within the casing. The bottom packer was set just above the well screen and the upper packer, if used, was set at the wellhead. Alternatively a well cap could be used at the wellhead. The bottom packer was inflated and the casing was pressurized to a value which simulates the maximum anticipated operating pressure plus an engineering safety factor.

2. The well was then "closed in" and the pressure observed for a minimum of 20 minutes.

3. If more than 10% of the pressure was lost during this period, the well was deemed unacceptable for use as an injection well (FEN, 1987).

If possible, attempts were made to repair faulty wells and the integrity tests were repeated. If the well casing leakage could not be repaired or corrected, the well was plugged and reclaimed.

The wellfield is a repeated 5 spot design, or a repeated 7 spot hexagon design or a combination (see Figure 8). The spacing between injection wells ranges from 40 to 100 feet. Piping from the plant building to the wellfield building and from the wellfield building to the individual wells was buried below the frost line and PVC pipe was used for the underground service. At the wells, pitless adapters were used to eliminate any above ground piping. All underground piping was leak tested prior to use. Figure 9 shows details of the piping connections and meter placement between the wells and the main manifolds.

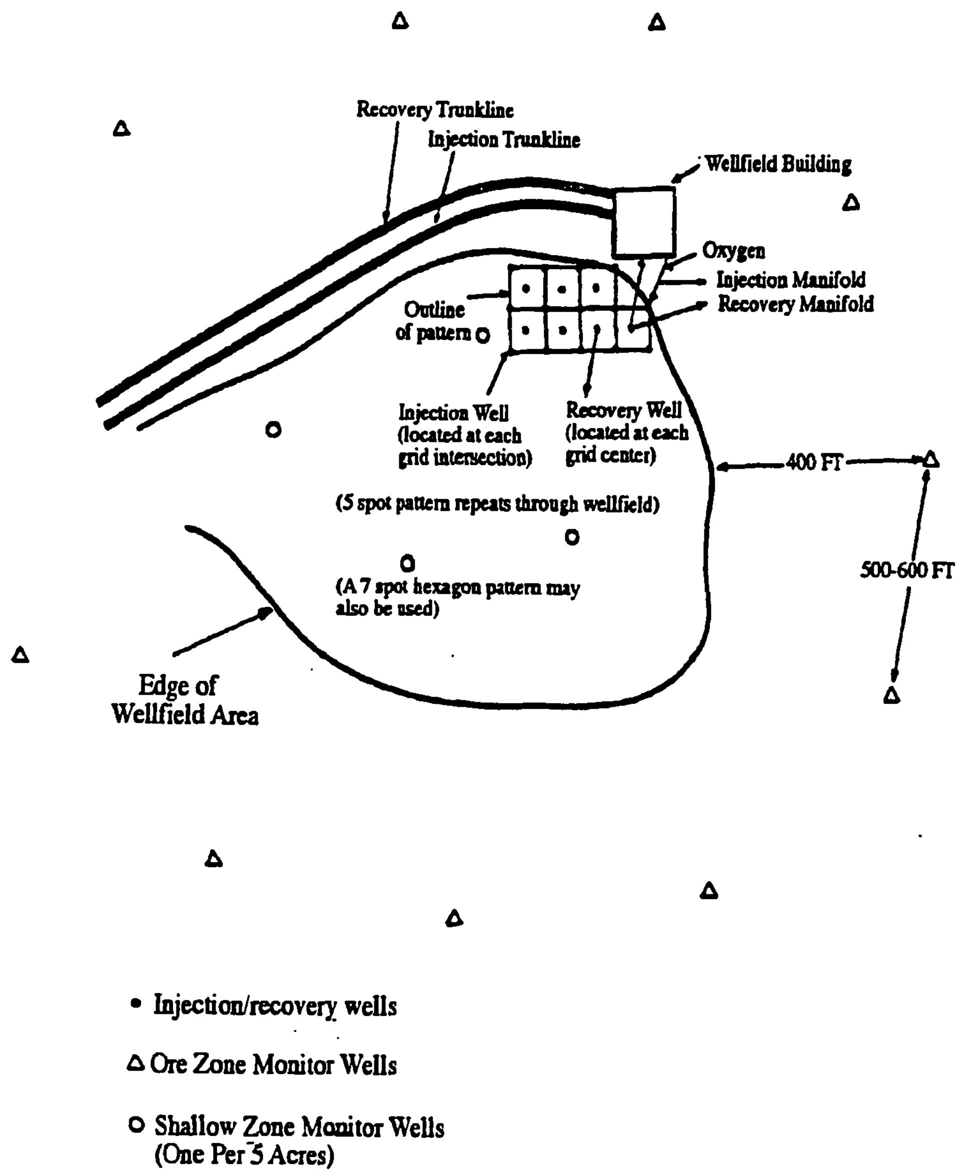


Figure 8. Project well pattern.

Monitor wells were placed in the Chadron Sandstone and in the first significant water bearing Brule Sandstone above the Chadron Sandstone. All monitor wells were completed and developed prior to any leach solution injection.

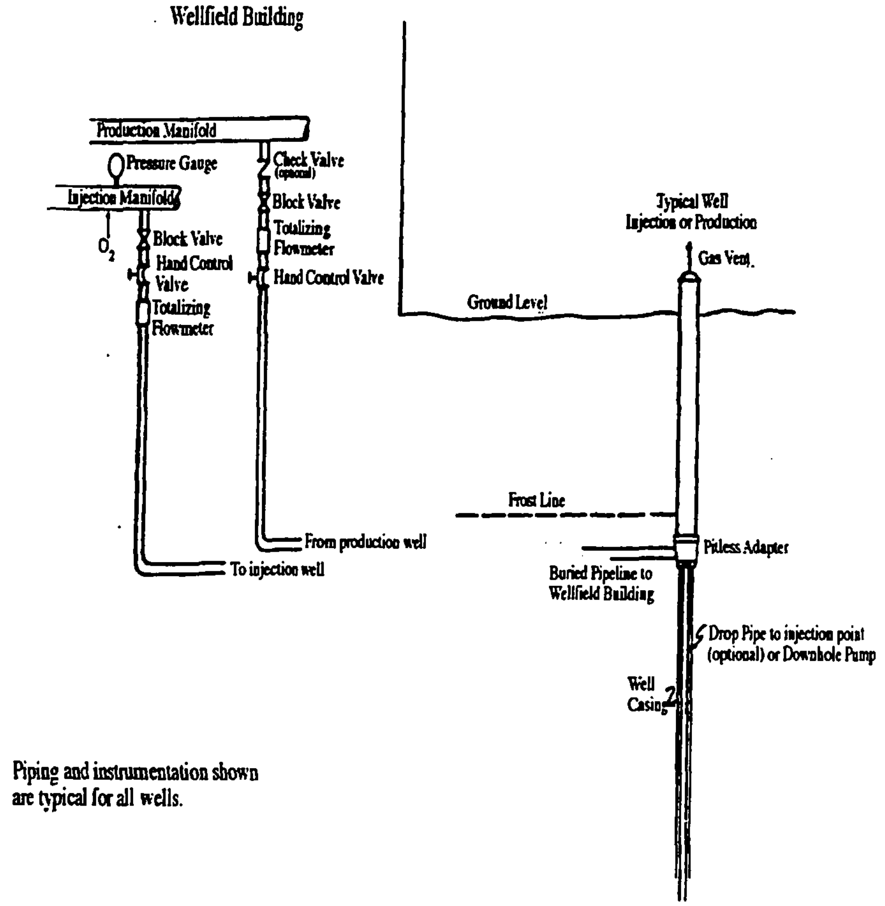


Figure 9. Detail of wellfield piping.

Instrumentation

Instrumentation included two types of water meters used to measure the total production and injection flow. A positive displacement water meter with a local readout was installed on each injection well head. It was manufactured by Kent Manufacturing Company, with no alterations made to these meters. The sand and particulate produced in the producing wells required that a turbine meter be used to meter the production flow.

A Haliburton turbine meter with an inductive pickup and panel mounted Liquid Crystal Display (LCD) was installed on each production well head. The same turbine meter assembly was installed on the injection and production trunklines entering the individual well-houses.

The Haliburton turbine flow meter was fitted with a solid state electronic HPO-RTU Pulse Output transmission head. The unit provided an output pulse in the form of a dry contact from a relay and a pulse from a solid state emitter/collector opto-isolated output at the rate of one pulse per gallon of water. The instrument was housed in a Class I, Group D, Division I conduit enclosure which mounts directly on top of the flow meter. The instrument used in this research project provided a pulsed 24vdc signal with a time on duration of 260ms. This time duration was achieved by increasing the value of the resistance in the instruments relay holding circuit from 681 kilo-ohms to 3.3 Mega-ohms (see Appendix J). This change in pulse duration insured that the contact closure within the meter exceeded the SLC scan time. This was done to keep the SLC from missing a contact closure and providing erroneous data. This change was approved by Mr. Duane Bryan, an Electrical Engineer for Haliburton Services.

Programmable Electronic Controllers

Small Logic Controllers/501

An Allen Bradley small logic controller/501 (SLC) was used in this research as a remote data collection, storage and transmission device. In addition it monitored and controlled the status of the production well pumps. Its 13 slot backplane was designed to house a central processing unit, a power supply, five 24vdc 16 point single ended input modules, two 120vac 16 point single ended input modules, three dry contact 8 point relay output modules and one direct communications module (DCM). All dry contact pulsed outputs from the Haliburton and Kent meters were connected to the five 24vdc input modules. The auxiliary contact from each production well motor starter was connected to the 120vac input modules. The relay output modules were used to start and stop each individual production well pump.

The SLC responded to each pulsed input and stored the information in its random access memory (RAM) that is backed-up with a lithium battery to guard against loss of data during a power failure. If a power failure occurred and the program in the SLC was corrupted it automatically reloaded a new copy of the program from an electrically erasable programmable read only memory chip (EEPROM) located on the mother board of the SLC. The DCM was connected to the PLC5/25 (PLC) Data Highway with approximately 3,000 feet of three conductor transmission line and was used to transmit the data collected by the SLC to the supervisory PLC.

Programmable Logic Controller 5/25

An Allen Bradley Programmable Logic Controller PLC5/25 was used in this research as a supervisory processor controlling and sequencing the data being transmitted from the two remote SLC/501 processors. The PLC5/25 was designed to house in a 4 slot backplane, a power supply, a central processing unit, and two 120vac 16 point single ended input modules. The PLC5/25 was connected to the DCM in each individual SLC/501 through a remote I/O link. In turn it received and transmitted data from the individual SLC's via the Data Highway. In addition the two 120vac input modules were connected to the control panel located in the main plant building to allow manual control of each production well.

The PLC5/25 was operator interfaced through a 1784-KT communications module and an interrupt-driven RS-232-C serial port (COM1) in two 386 personal computers (Allen Bradley, 1990). The personal computers provided the graphic interface and database necessary to monitor and control the mining operation.

Summary

Numerous geologic and hydrologic studies have been conducted for ISL mine sites by mining companies and their consultants. From these studies many reports have been generated about the in situ mining process but very little has been reported on wellfield monitoring and excursion control (Staub et al., 1986). With the development of Programmable Electronic Controllers and more specifically the Direct Communications Module by the Allen Bradley Company, it is now possible to connect the small logic controller, via Data Highway Plus, to personal computers and families of larger programmable electronic controllers (Allen Bradley, 1990).

Programmable controllers are used as replacements for hard wired, fixed automation employing relays, motor starters, timers, and counters. Since their introduction by the auto industry in 1969, they have steadily seen new applications (Kale, 1989). Problems seen in the ISL mining industry with excursion control indicates that better, more efficient well-flow monitoring systems need to be developed. The communications hardware recently developed by Allen Bradley, along with Haliburton's introduction of the HPO-RTU Pulse Output transmission head, enabled ISL wellfield monitoring and control using Programmable Electronic Controllers to become feasible at a reasonable cost. Like the success experienced in the automobile industry, the programmable controller can be used as a viable monitoring and control system for the in situ leach mining industry. With Programmable Electronic Controllers, efficiently controlling wellfield mining operations with minimal threat of a horizontal excursion is possible.

CHAPTER III

METHODOLOGY

This research project was experimental in nature. A new system for monitoring and controlling the flow and distribution of water used in the in situ mining process was developed. Its effectiveness was evaluated through field tests and actual use. Before the study could be executed, various preliminary procedures had to be completed. These included the development of new electronic monitoring instrumentation and the creation of numerous computer programs.

System Design

The system designed for this study consisted of experimental electronic hardware, computer programs written in ladder logic, and the development of three databases for Controlview. Controlview is an interactive video monitoring system produced by Allen Bradley Corporation. In addition, the data collected by the system was converted into ASCII files in order to import them into the software programs, ISL-50 Flow Modeling, Excel and Lotus 1-2-3. The system networked together two Allen Bradley small logic controllers (SLC/501) fitted with a Direct Communications Module (DCM), an Allen Bradley programmable logic controller (PLC 5/25), two 386 personal computers and an Automation Electronics control center (see Figure 10). The two Data Store 386 personal computers housed the Allen Bradley network development package, Controlview. The personal computers and programmable controllers were linked together onto a local area network to accomplish the Sequential Control and Data Acquisition (SCADA) process.

Each remote well-house contained one SLC/501 with a DCM to collect well-flow totalized data. The SLC alarmed the host controller of any changes in well-flow rates, and also controlled the status of the production well pumps. The host controller, a

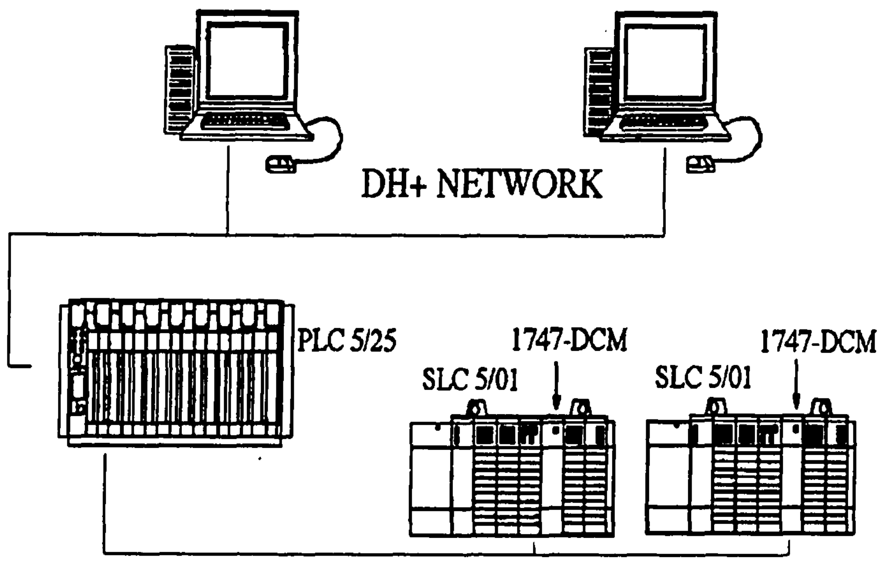


Figure 10. Remote I/O network.

PLC 5/25, scanned and collected the data and pump control information from the individual well house processors. It was in turn connected by a peer communications link to the two personal computers which were used to: (a) display the totalized flow data from each well, (b) display the status of each individual production well, (c) set an alarm if a well, either an injection or production well, fell out of its preset operating range, (d) allow the upper and lower flow limits to be changed for each well from the keyboard, and (e) set an alarm if a production well lost power and backflowed due to a faulty check valve.

Because of its length, the wellfield program developed for this study limited the scan time of the SLC/501 to approximately 90 milliseconds, and the host program limited the PLC 5/25 scan time to approximately 15 milliseconds. To insure the accuracy of the data collected, the duration of the contact closures in the wellfield flow meters were specifically designed to exceed 260 milliseconds, approximately three times the longest scan time of any processor. The flow rates in gallons per minute were calculated every 90 seconds in the individual SLC's for each well in the wellfield. This information was sent to the host PLC 5/25 along with each well's totalized flow every scan time or every 90 milliseconds. Via the same local area network, each production well could be started or shutdown from the control room in the plant. Backflow conditions that occurred in production wells were calculated in the host PLC 5/25 at two minute intervals and alarms were set if this condition existed. All data collected by the host PLC 5/25 were transmitted to the two personal computers at one second intervals.

Hardware

The hardware used for this study included:

1. Three Allen Bradley programmable logic controllers (two SLC/501s and one PLC 5/25), two Allen Bradley Direct Communications Modules (DCM), and two 386 personal computers.

2. Turbine water meters fitted with Halliburton HPO-RTU pulsed output transmitters. These were connected to the 39 production wells and also the injection and production trunklines in mining unit one. Each provided a 24 volt DC output pulse for each gallon of water that passed through it.

3. Positive displacement Kent water meters that were connected to all 120 injection wells in mining unit one. Each was fitted with a dry contact that closes once for each one gallon of water that passed through it.

The HPO-RTU pulsed output transmitters used in this research were manufactured by Halliburton Services, Duncan, Ohio. Due to its length, the scan time for the SLC program could be as long as 120 milliseconds. The factory transmitter required that the duration of the contact closure on the pulsed output be lengthened to exceed the 120 millisecond scan time. This researcher supplied to Halliburton Services, the specifications for the necessary changes needed to alter the electronic components located on the sensing module within the turbine meters to increase the duration of the pulsed output to an acceptable time of approximately 260 milliseconds.

Software Design

The software programs were specifically developed by the researcher and installed into the programmable logic controllers and personal computers.

Small Logic Controller/501

The software for the small logic controller was developed to interface the wellfield instrumentation, via the local area network, to the other PLC's and personal computers. Each gallon of production water through the turbine meter generated one 260 millisecond pulse output from the HPO-RTU Halliburton transmitter, and in turn was recorded and stored in two consecutive words (each word is 16 bits) located in the SLC integer file. Each word was capable of holding 32,767 counts, one for each pulse received from either the Kent or Halliburton HPO-RTU unit. The first word was used as a low count and overflowed into the second, the high count, giving the capability of storing 1,073,676,288 bits of information, again, with each bit representing one gallon of water.

The Direct Communications Module was limited to transmitting eight words of information onto the Data Highway at a time with the first word being used by the DCM as a program status word. This left seven words available for wellfield data transmission. Each processor stored the flow data for 64 wells. Therefore, the information sent to the PLC 5/25 by the DCM was broken into 36 groups of three wells each. Imbedded in word one was the group identification and underflow/overflow alarm bits. Words two through seven contained the totalized flow data for three wells (see Figure 11). Of the 36 groups of data sent to the PLC 5/25, 22 were used for flow totalizing, 13 were used for calculating the gpm for each well, and one was used for production well control (see Appendices K-L).

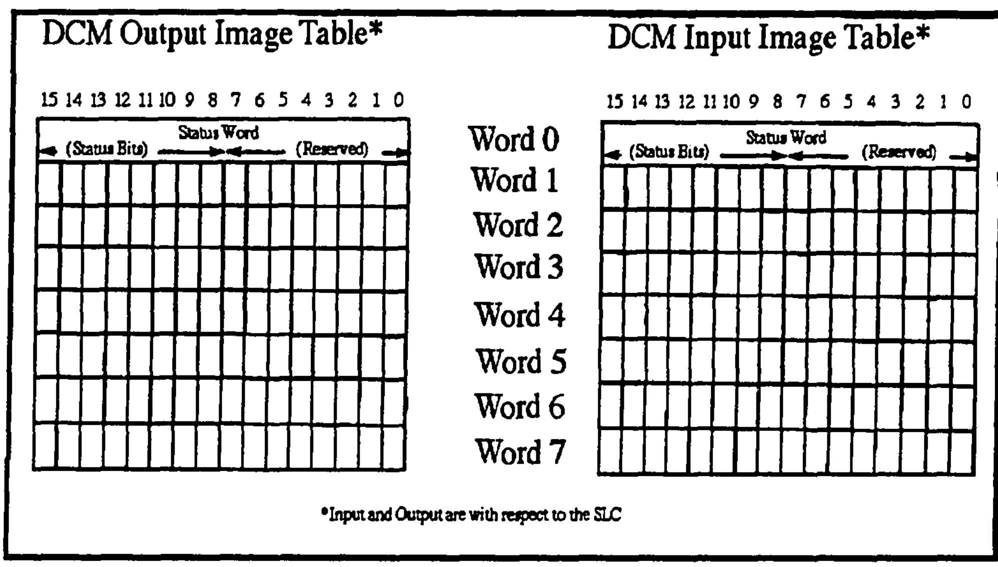


Figure 11. Input and output image tables.

The SLC program sequentially loaded the DCM with the contents of the integer files where it was transmitted to host PLC 5/25 as it became available. In addition, flow limits and production well control were sent to the wellhouse processors via the same route. This information was written into the SLC's binary and interger files.

Programmable Logic Controller 5/25

The program developed for the PLC 5/25 made this processor the supervisor of up to seven SLCs located throughout the wellfield. Each SLC is seen as a remote I/O link, and information from them was brought up into the PLC's I/O image tables. This was done sequentially, with each SLC sending its respective well data onto the Data Highway as the host requested it. To ensure the accuracy of the transmission process, each word transmitted from a small logic controller was loop checked for errors before it was stored in one of the host's 30 integer files.

Production well control was accomplished by connecting normally open push button switches to the PLC 5/25's two digital input cards. This information was coded exactly like the well-flow data but was sent to the respective SLC in the wellfield from the PLC. This enabled each production well in the mining operation to be controlled from the plant control room.

Controlview

With the enormous amount of information coming from the individual SLCs, an additional software package was developed to organize and display the conditions in the wellfield. This was done with Allen Bradley Corporation's software development package, Controlview. This software was housed in the two 386 personal computers, and replaced the conventional enunciator panel seen in most industrial control rooms. Well-flow data, totalized gallons, production well status, reverse flow conditions, and underflow/overflow alarms were displayed on the computer screen for each well in the wellfield. The flow data for the 39 wells included in this research project were converted into a standard ASCII file. Data in this format were downloaded from the memory of the 386 personal computer to disk and imported into a Lotus, Excel or an ISL-50 Flow Modeling file for analysis.

Collection of Data

Procedure for Research Question One

Research question one was: Do the well-flow rates indicated by the data collected and transmitted by the small logic controllers differ significantly from actual down hole flow rates that are indicated by locally mounted monitoring instrumentation? Manually reading well totalizers and downloading computer data at exact intervals was virtually impossible. Two problems that inherently restrict this process were: (a) the time interval between the two methods differed extremely and the data that were collected, although accurate, could not be easily compared, and (b) the meters were not zeroed when they were installed on the wellheads, and likewise, the totalized gallons kept in the computer were not zeroed when a new meter was installed. Therefore the only comparison data that were common to both monitoring systems was the flow rate of fluid through each wellhead. This flow was calculated using totalized gallons from both the manual and computer monitoring systems. It was based on the number of gallons of fluid that passed through each wellhead in one minute. Preliminary sample tests indicated this was accurate comparison data that could be readily collected. Thus, this portion of the study was designed around the comparison of flow rates for each well. It was conducted with the following procedure.

Ferret Exploration of Nebraska, Inc., installed totalizing meters with local readouts on all of the 39 production wells and trunklines in the wellfield for this study. They consented to provide this researcher with one plant engineer and one miner to read each wellfield meter on a regular basis for a period of 40 working days. In 40 days, approximately 15 million gallons of water passed through the production meters. It was the opinion of the plant engineer at the Crow Butte site that this quantity of water was sufficient to establish an accurate gpm rating for each well.

Using the data collected manually, the actual gallons per minute between each meter reading cycle were then calculated. The same information collected by the automated system was downloaded from the computer data files within a similar time frame. Again the gpm for the production wells and trunklines was calculated for each recording cycle. Both sets of data were loaded into a Lotus 1-2-3 database and were compared using a t test to determine if any significant differences existed.

Procedure for Research Question Two

Research question two was: Can the data collected and transmitted by the small logic controllers be used to minimize the bleed to no more than 0.5% of the fluid used in the mining process? For the purpose of the research project, Ferret Exploration of Nebraska installed a Kent water meter on the potable water line, a magnetic flowmeter on the waste line leaving the plant and a RTO-HPU Halliburton turbine meter on both the injection and production trunklines. Each meter was recorded daily for the life of mining unit one. The mass balance and bleed for the plant was calculated based on this data collected.

Procedure for Research Question Three

Research question three was: Are the data collected and transmitted by the small logic controllers accurate enough to justify operational changes in the wellfield balance to prevent lixiviants from migrating into the ground water resources near the in situ leach mining operation? The groundwater excursion monitoring system was designed to detect excursions of lixiviants into the ore zone aquifer outside of the wellfield area being leached and into the overlying water-bearing strata. The Pierre Shale below the ore zone is over 1,200 feet thick and contained no water-bearing strata. Therefore, it was not necessary to monitor any water bearing strata below the ore zone.

Results of two aquifer tests indicated that the ore zone aquifer was essentially isotropic and homogeneous. No faults or other conditions which required special monitoring locations were noted in the preliminary hydrologic data analysis.

Ore zone monitoring wells were located approximately 400 feet from the perimeter of the wellfield, and these wells were 500 to 600 feet apart. These locations were consistent with the United States Nuclear Regulatory Commission Staff Technical Position found in WM-8102 Groundwater Monitoring at Uranium In Situ Solution Mines. Also, there were monitoring wells in the overlying aquifer at a density of one monitoring well per five acres of wellfield.

Upon installation of the monitor wells, baseline samples were taken from each well (see Appendix D), and the water level in each well was measured. Three samples at two-week intervals were taken from each monitor well and were analyzed for baseline water quality indicators (see Table 2).

From these data the United States Nuclear Regulatory Commission (USNRC) determined that the excursion indicators for the monitor wells were chloride, conductance, alkaline, and sodium. The USNRC set the upper control limit (UCL) for the excursion indicators at 20% above the maximum baseline concentration of the excursion indicators (see Tables 3, 4, and 5).

According to USNRC requirements a water sample was taken from each monitor well at a frequency of once per two weeks following their installation and continuing through the life of mining unit one. As required by the USNRC, the water level elevations in these wells were measured and the barometric pressure was recorded prior to the sampling. This information was used to determine the volume of water in the well casing.

Table 2

Baseline Water-Quality Indicators

Baseline Water-Quality Indicators to be Determined During Premining Data Collection		
	Physical Indicators	
Specific Conductivity[1] Temperature[2] pH[1]	Alkalinity	Total Dissolved Solids[3]
	Common Constituents	
Ammonia Bicarbonate Calcium Nitrate Carbonate	Chloride Magnesium Sulfate Nitrite	Mercury Sodium Potassium
	Trace and Minor Elements	
Arsenic Copper Boron Barium Cadmium Chromium	Mercury Fluoride Iron LeadSelenium Manganese	 Molybdenum Nickel Vanadium Zinc
	Radionuclides	
Radium-226	Uranium	

Note. [1] Field and laboratory determination.
[2] Field only.
[3] Laboratory only.

Table 3

Proposed Upper Control Limits--Mine Unit One

Proposed Upper Control Limits
Monitor Wells
Mine Unit Number One

WELL NO.		SODIUM	SULFATE	CHLORIDE	CONDUCTIVITY	ALKALINITY
SM1-2	Multiple	180	72	50	887	288
	Single	216	86	59	1064	346
SM1-3	Multiple	178	52	99	940	274
	Single	213	62	119	1128	328
CM1-1	Multiple	516	450	281	2528	359
	Single	619	540	337	3034	431
CM1-2	Multiple	492	415	232	2395	358
	Single	590	498	278	2874	429
CM1-3	Multiple	480	437	232	2395	361
	Single	576	524	278	2874	433
CM1-4	Multiple	504	432	264	2476	361
	Single	605	518	317	2971	433
CM1-5	Multiple	600	449	433	3064	368
	Single	720	539	520	3676	442
CM1-6	Multiple	468	426	232	2357	371
	Single	562	511	278	2828	445
CM1-7	Multiple	480	428	232	2359	364
	Single	576	514	278	2831	436
CM1-8	Multiple	480	433	235	2308	355
	Single	576	520	282	2769	426
CM1-9	Multiple	480	438	227	2428	366
	Single	576	526	272	2913	439
CM1-10	Multiple	576	430	389	2810	365
	Single	691	516	467	3372	438
CM1-11	Multiple	492	456	227	2418	350
	Single	590	547	272	2902	420
SM1-1*	Multiple	133	53	15	600	234
(PM-6)	Single	160	64	18	720	281

Note. *Well SM1-1 (formerly PM-6) is a shallow monitor well used during pilot plant operations. The proposed UCL's are the same ones used previously.

Table 4

Proposed Upper Control Limits--Mine Unit Number Two

Proposed Upper Control Limits Monitor Wells Mine Unit Number Two						
WELL NO.		SODIUM	SULFATE	CHLORIDE	CONDUCTIVITY	ALKALINITY
CM2-1	Multiple	500	418	304	2808	356
	Single	600	501	364	3370	428
CM2-2	Multiple	484	402	259	2560	353
	Single	580	482	311	3072	423
CM2-3	Multiple	487	406	239	2542	368
	Single	585	487	287	3050	442
CM2-4	Multiple	492	415	265	2566	367
	Single	590	498	318	3079	441
CM2-5	Multiple	535	421	320	2828	408
	Single	642	505	384	3394	490
CM2-6	Multiple	484	425	246	2621	360
	Single	580	510	295	3145	432
CM2-7	Multiple	486	442	239	2549	364
	Single	583	530	287	3059	436
CM2-8	Multiple	516	442	299	2774	358
	Single	619	530	359	3329	429
CM2-9	Multiple	500	425	266	2666	368
	Single	600	510	320	3200	442
CM2-10	Multiple	500	446	251	2620	365
	Single	600	536	301	3144	438
SM2-1	Multiple	163	64	47	721	254
(PM-11)	Single	196	77	56	865	305
SM2-2	Multiple	148	53	53	1008	262
	Single	177	63	63	1210	314
SM2-3	Multiple	154	64	31	808	287
	Single	184	76	37	969	344

Note. SM2-1 (formerly PM-11) is a shallow monitor well used during pilot plant operations. The proposed UCL's are the same ones used previously.

Table 5

Proposed Upper Control Limits--Mine Unit Three

Proposed Upper Control Limits
Monitor Wells
Mine Unit Number Two

WELL NO.		SODIUM	SULFATE	CHLORIDE	CONDUCTIVITY	ALKALINITY
SM3-1	Multiple	227	114	71	935	312
	Single	272	137	85	1122	374
SM3-2	Multiple	156	50	34	671	254
	Single	187	60	40	805	305
SM3-3	Multiple	143	54	25	607	247
	Single	171	65	30	729	297
CM3-1	Multiple	540	510	270	2328	372
	Single	648	612	324	2794	446
CM3-2	Multiple	533	497	241	2310	367
	Single	639	596	289	2772	441
CM3-3	Multiple	512	503	239	2285	349
	Single	615	603	287	2742	419
CM3-4A	Multiple	520	502	234	2321	350
	Single	624	602	281	2785	420
CM3-5	Multiple	539	487	265	2345	361
	Single	647	585	318	2814	433
CM3-6	Multiple	522	479	250	2333	367
	Single	626	575	300	2799	441
CM3-7	Multiple	535	472	233	2312	371
	Single	642	566	279	2775	445
CM3-8	Multiple	564	490	290	2530	352
	Single	677	588	348	3036	422
CM3-9	Multiple	542	467	241	2302	352
	Single	651	560	289	2762	422
CM3-10	Multiple	529	478	232	2249	355
	Single	635	573	278	2699	426

Each monitor well was pumped prior to sampling to determine the sample pumps flow rate. The sampler then measured the initial ph, temperature and specific conductivity of the water. Measurements of these parameters were made as each one quarter casing of water volume was pumped. A sample was not taken until at least one casing volume had been removed and the temperature, ph and conductivity values were stabilized to reflect normal formation averages.

When the water values stabilized a sample was collected. The sample bottle was rinsed at least once with a portion of the water being sampled. Then 1,000 ml was collected; and the bottle labeled accordingly with the following data:

1. Sample Identification Number
2. Sample Location
3. Date Sampled
4. Analysis
5. Sample Treatment
6. Preservation

When the sampling process was complete the bottle was stored in an ice chest and kept at 40° C to preserve the integrity of the samples. The ice chests containing the samples were delivered to an independent laboratory, Energy Labs Incorporated in Casper, Wyoming, for chemical analysis of the excursion indicators. This occurred within 24 hours of the sampling time. A Chain of Custody form was presented to the laboratory representative indicating that all of the samples were delivered and the description of the analysis desired. Part of the Chain of Custody Form was completed in the field by the sampler with the remainder being completed by Energy Laboratory personnel upon receipt of the samples. The Chain of Custody Form assured that no tampering with the samples had occurred between the time of collection and their arrival at the laboratory.

One or more duplicate samples were collected and sent to the laboratory as blank samples to assure internal laboratory quality control. All duplicate sampling sites were randomly selected by the sampler. If the duplicate samples did not agree, an audit was performed to determine whether the problem was with the sampling or the analysis. The independent lab was instructed to check all their calculations and quality control checks. If no discrepancies were found a new analysis was requested on the sample, provided that the maximum holding time had not been exceeded. If the maximum holding time had been exceeded a new sample was ordered.

To further insure the integrity of the process each quarter, samples from the wellfield monitor wells were analyzed by the site laboratory at the Crow Butte Project for the excursion parameters. Identical samples were sent to Energy Laboratories Incorporated for a complete environmental analysis including the excursion monitors. The site lab results were then compared with the Casper Lab and if the results of both labs were not within 10% for all parameters an investigation was performed and appropriate action was taken to identify the problem.

If there were no problems with the analysis of the water samples the results were analyzed to determine if an excursion would have been pending or existed within the well field. If an excursion would have been indicated by the sampling process, corrective action to mitigate the situation would have been initiated immediately and conducted until the excursion had concluded.

Corrective actions could have included:

* Over-recovery of leach solutions,
* Under-injection of leach solutions,
* Modification of the injection-recovery well patterns.

None of these actions would have altered the results of this research and the research project would have been continued.

If an excursion were confirmed, the USNRC would have been notified by telephone within 24 hours and within five days in writing from the time the confirmation sample was taken. In addition to corrective actions, the sampling frequency and analysis of excursion status wells would have been increased and performed once every seven days for the excursion indicators. An excursion would be considered concluded when the concentrations of excursion indicators were below the concentration levels defining an excursion for three consecutive one-week samples.

Analysis of Data

The objective for the data analysis of research question one was to determine if the individual well-flowrate indicated by the data collected and transmitted by the small logic controllers differed significantly from actual down hole flowrate of each well as indicated by the individual local totalizers attached to each well-head.

The well-flowrate data collected to analyze question one were drawn from two independent samples. The data were analyzed to determine if a significant difference existed between the actual flowrate of water through each of the 39 production wells and the individual well-flowrates indicated by the computerized system for the same wells. The assumption was that the two samples taken would have the same variance. Therefore, a t test was used to analyze the data.

The format for the data downloaded from the 386 personal computer was easily imported into a Lotus 1-2-3 spreadsheet. Therefore, this program was used to conduct the necessary statistics.

The objective for the data analysis of research question two was to determine if the percentage of bleed created by the mining operation could be limited to less than 0.5% when the operation was being controlled with the automated system.

The data collected to analyze question two were drawn from the total recovered and injected gallons from the wellfield mining unit one as recorded by the SLCs and the totalizers installed on the potable water and waste lines. The data collected were used to calculate the mass balance of the plant and the percentage of bleed created daily by the mining operation. The mass balance of the mining operation is described by the equation:

Recovered gallons + Potable water used = Injected gallons + Waste water leaving the plant.

Bleed and percentage of bleed is then calculated with the following method:

Bleed = Waste water - Potable water

Percentage of Bleed = (Waste - Potable)/Recovered gallons

Recovered gallons = the total recovered gallons from the mining operation indicated by the data collected by the SLCs.

Potable water = the water used by the plant building for housekeeping and personal hygiene as indicated by the Kent meter.

Waste water = the water leaving the plant building to the waste storage ponds as indicated by the magnetic flow meter.

The daily percentages were averaged to determine a monthly mean for the percentage of bleed. This monthly average would indicate the effectiveness of the use of the automated system to control the mining process and limit the bleed to below 0.5% during normal operations.

The objective for the data analysis of research question three was to determine if the data collected and transmitted by the small logic controllers could be used to effectively control ground water levels within the mining units and prevent horizontal excursions from occurring during the mining operation. To answer research question three, water samples were taken every two weeks from monitor wells within the mining units and analyzed to determine if the excursion indicators would detect the possibility or occurrence of an excursion. This required a comparison of the chemical analysis of samples taken from monitor wells in the mining units during the mining period to baseline samples taken prior to the mining operation. Every excursion indicator parameter for each well was compared to its single and double upper control limit (UCL) that was set by the USNRC. If two UCL values would have been exceeded in a well, or if one UCL value would have been exceeded by 20%, another water sample would be taken within 24 hours of the first analysis and again analyzed for the same excursion indicators. If the second sample did not indicate excedance of the UCLs, a third sample would be taken within 48 hours from the first sample. If neither the second nor third sample indicated excedance of the UCLs, the first sample would be considered in error. If the second or third sample indicated an excedance of the UCLs, the well in question would have been placed on excursion status. An excursion would have been confirmed if two or more UCL values were exceeded, or if one UCL value was exceeded by 20% or more. This process was conducted throughout the life of mining unit one.

CHAPTER IV

FINDINGS

Chapter IV presents the data compiled from the flow meter readings, the bleed calculations and the excursion monitor sampling. The analysis of data in this chapter will follow the pattern of the research questions in Chapter I. Therefore, this chapter will be divided into three separate parts: Comparison of Flow Calculations, Bleed Monitoring and Excursion Control.

The study was limited to the three-year life span of mining unit one starting March 7, 1991 and continuing through December 24, 1993. To record the flow of water used in the mining process, flow meters were attached to all of the 39 production wells in mining unit one. In turn, these meters were connected to a locally mounted small logic controller and a separate gallons totalizer. Production well 2, was never used in the mining process during the recording period. All but one of the flow meters used functioned properly; the malfunctioning meter was attached to production well 24. The data collected from the flow meters attached to production well 2 and production well 24 were not usable and, therefore, were deleted from this study. The remaining 37 flow meters developed only minor problems, typically a faulty relay contact, that were corrected soon enough to not significantly affect this study. The data collected from these flow meters attached to the production wells in the wellfield were complete and usable. To monitor the waste water generated by the mining process, a gallons flow meter and totalizer were also installed on the potable water and waste water lines located at the processing plant. Both of these meters functioned properly with no apparent problems. Again the data from these meters were complete and usable.

To detect any horizontal or vertical migration of mining fluid from the leach field the entire mining unit was surrounded by 40 monitor wells. The monitor wells were positioned both around the perimeter of the wellfield in the Chadron Sandstone and in the overlying strata above the mining area. Monitor wells drilled in the parameter surrounding the wellfield were designated as commercial monitor wells and were, for recording purposes, identified by CM numbers. Monitor wells drilled above the ore zone were designated as shallow monitor wells and, for recording purposes, were identified by SM numbers. As the mining area grew, new wells were added to the grid and the monitor wells that were consumed by the growth were taken off. The Pierre Shale formation below the ore zone is approximately 1,200 feet thick and was determined to be impermeable (Spalding, 1982); therefore, no monitor wells were drilled into this lower strata.

Samples were taken from the water in each monitor well before the mining process was started and baseline water chemistry was established. The baseline chemistry was used in comparison with chemical analyses of water samples taken biweekly during the operation of mining unit one. An elevation in chemical makeup of the samples taken during the mining process would indicate that the groundwater surrounding the wellfield was coming under the influence of the mining solutions and that an excursion was possible.

On March 26, 1992 the meter reading for flow calculations was completed, and the excursion monitoring was concluded December 24, 1993. The final chemical analysis of the groundwater for the excursion monitoring parameters was received from Energy Laboratories in Casper, Wyoming on September 12, 1994. This information was sufficient for analysis to determine the effectiveness of the automated monitoring system to control the in situ mining process.

Comparison of Flow Calculations

To answer the first research question, and initial phase of this study, flow meters were attached to all of the 39 production wells in mining unit one (production wells are identified with the letters, PR in the figures and tables in this paper). In turn, these meters were connected to a locally mounted small logic controller and a separate gallons totalizer. As mentioned earlier, production well 2 was never used in the mining process and the data recorded for this well were deleted from this study. All but one of the flow meters used functioned properly; the malfunctioning meter was attached to production well 24. The data from production well 24 were deleted from this study. Some of the remaining 37 flow meters did develop minor problems, typically a faulty relay contact, and these problems were repaired quickly to avoid inaccurate flow totals. It was impossible to adjust for these problems, therefore, the data from these wells were not deleted and were included in this study.

The totalized flow for each of the 39 production wells was recorded using two separate methods. One set was manually recorded by a mine operator and automatic recordings were taken by the small logic controllers attached to the flow meters. The recording started on February 17, 1992 and continued through March 26th of the same year. During this time, 26 separate readings were recorded manually from the locally mounted totalizers connected to the flow meters at each production well head. In the same period, 26 flow totals were downloaded from the small logic controllers monitoring the same flow meters into a text file and imported into a Lotus 1-2-3 computer spreadsheet. The time that each reading was taken was recorded and used in conjunction with the totals to calculate the gallons per minute of flow for each well. There were 26 different recording intervals during the 38-day time period for each recording method. During that time 34,138,250 gallons of water were recovered from the 38 individual production wells in mining unit one. This amount of water and time span yielded enough data to compare the two recording methods.

Research question one was: Do the well-flow rates indicated by the data collected and transmitted by the small logic controllers differ significantly from actual down hole flow rates that are indicated by locally mounted monitoring instrumentation?

In order to answer this question, the computer program Lotus 1-2-3 was used to compare the 26 computed flow rates calculated from each recording method for the 39 production wells in mining unit one. It was assumed that the two sets of flow rate data would have the same variance with no significant difference between either method of recording. Therefore, the flow rates calculated from each method, were compared with the Lotus 1-2-3 t test function to find if any significant difference existed between the two sets of data.

The level of significance for the t test was set at the 0.01 level. A two-tailed test was used to analyze the 26 samples giving 25 degrees of freedom and a critical value of t equal to 2.78 (Best, 1981). None of the computed t values for any of the wells included in the study exceeded the critical value.

The results of the analysis indicate that the variances of the samples compared do not differ by an amount that is statistically significant. It appears that the automated system and manual system of recording yield similar data at the 0.01 level of significance. Table 6 graphically presents the results of this analysis by well number in ascending order. The data from production wells 2 and 24 have been deleted. As indicated earlier, both wells had mechanical difficulty and the data collected from their flow meters were not used in this study. Column one contains the production well numbers identified with the letters PR. Column two of the table contains the arithmetic average of the flow rates calculated for the 26 different recording intervals from the data read manually. Column three of the table contains the arithmetic average of the flow rates calculated for the 26 different recording intervals from the data collected by the computerized monitoring system. Visual comparison of these two sets of data, columns 2 and 3, further shows the similarities between the two methods of recording. The difference between the flow rates calculated from the manually recorded data and the flow rates calculated from data collected by the computerized system is presented in column four. This comparison was done to determine whether the two sets of data were similar. Again, the results of this analysis indicate that the two methods of recording yield similar results. The computed t is presented in column seven with the significance of this score given in column eight. If the computed value of t was not significant at the 0.01 level, NS was entered into this column; if it was significant an S would have been entered indicating a significant level. As indicated earlier none of the computed t values were significant at the 0.01 level.

Bleed Monitoring

To monitor the waste water generated by the mining process and answer research question two, it was necessary to calculate the mass balance of the mining process. The mass balance of the mining process is described by the equation:

Recovered gallons + Potable water used = Injected gallons + Waste water leaving the plant.

To collect data to calculate the mass balance, flow meters with gallons totalizers were installed on the waste line, potable water line, and production trunkline in the plant building. These meters were used to record the total gallons of fluid passing through each line with recovered gallons being recorded by the flow meter attached to the production trunkline. The totals for each meter were recorded daily during the life of mining unit one starting March 7, 1991 and continuing through December 24, 1993.

Bleed and percentage of bleed was then calculated for each day of operation with the following method:

Bleed = Waste water - Potable water

Percentage of Bleed = (Waste - Potable)/Recovered gallons

The monthly bleed rates were then compared to the 0.5 % level as described in section 4.2.2 Liquid Waste Volume Estimate found in the Commercial Source Materials License submitted to the United States Nuclear Regulatory Commission by Ferret

Table 6

Well Data

Production Well Number	Average Flow Rate in GPM for the Manual Record Method	Average Flow Rate in GPM for the Computer Record Method	The Difference between the Manual & Computer Flow Rate	Manual Method Sd	Computer Method Sd	Computer t	Significance
PR 1	39.485	39.116	0.369	4.177	3.984	0.148	NS
PR 2	--------	--------	--------	--------	--------	--------	--------
PR 3	30.629	30.449	0.180	3.426	3.272	0.429	NS
PR 4	20.513	20.382	0.131	2.248	2.081	0.398	NS
PR 5	36.086	35.869	0.217	3.858	3.713	0.421	NS
PR 6	23.46	23.440	0.018	2.430	2.387	0.874	NS
PR 7	32.088	31.898	0.190	3.378	3.201	0.426	NS
PR 8	30.422	30.242	0.180	3.249	3.085	0.428	NS
PR 9	23.335	23.198	0.138	2.551	2.429	0.428	NS
PR 10	40.889	40.647	0.243	4.314	4.087	0.424	NS
PR 11	25.335	25.162	0.173	2.724	2.546	0.325	NS
PR 12	37.834	37.589	0.245	4.070	3.855	0.348	NS
PR 13	40.960	40.718	0.242	4.324	4.111	0.425	NS
PR 14	36.504	36.289	0.215	3.901	3.716	0.427	NS
PR 15	27.663	27.320	0.343	2.853	2.563	0.148	NS
PR 16	38.900	38.670	0.230	4.130	3.915	0.424	NS
PR 17	18.130	17.920	0.211	2.092	1.990	0.159	NS
PR 18	27.328	27.011	0.317	5.104	5.131	0.164	NS
PR 19	34.726	34.308	0.418	3.876	3.639	0.148	NS
PR 20	16.083	15.923	0.160	4.830	4.852	0.224	NS
PR 21	22.447	22.158	0.288	2.471	2.267	0.200	NS
PR 22	38.751	38.065	0.686	5.469	5.309	0.096	NS
PR 23	32.974	32.577	0.397	4.093	3.807	0.152	NS
PR 24	--------	--------	--------	--------	--------	--------	--------
PR 25	35.974	35.546	0.428	4.263	4.048	0.153	NS
PR 26	37.377	36.928	0.449	4.184	3.929	0.149	NS
PR 27	23.428	23.149	0.279	2.575	2.429	0.151	NS
PR 28	21.222	20.969	0.253	2.383	2.245	0.151	NS
PR 29	37.259	36.822	0.437	5.501	5.211	0.169	NS
PR 30	41.993	41.492	0.501	4.542	4.270	0.151	NS
PR 31	32.039	31.657	0.381	3.413	3.199	0.151	NS
PR 32	44.219	43.696	0.523	4.695	4.427	0.156	NS
PR 33	25.927	25.620	0.307	2.845	2.695	0.155	NS
PR 34	29.401	29.193	0.207	3.107	2.940	0.349	NS
PR 35	28.098	27.920	0.178	3.106	2.971	0.399	NS
PR 36	38.426	38.199	0.228	4.101	3.903	0.425	NS
PR 37	8.867	8.831	0.037	2.444	2.378	0.637	NS
PR 38	32.051	31.861	0.190	3.316	3.124	0.427	NS
PR 39	33.945	33.714	0.231	15.107	14.942	0.463	NS

Note. N = 26
df = 25
Level of Significance = 0.01
Significant Value of t = 2.79

Exploration of Nebraska (FEN, 1987). This comparison is used to assess the value of the computer data recorded by the small logic controllers to control wellfield balance and minimize the liquid waste generated by the operation of the wellfield and process plant. This bleed rate must be minimized in order to conserve storage space for waste water in the mine's evaporation ponds. Generating bleed rates greater than 0.5 % could cause a suspension of the mining process until more storage ponds are constructed to hold the waste water. High bleed rates limit an in situ mine's ability to produce Uranium at a low cost.

Research question two was: Can the data collected and transmitted by the small logic controllers be used to minimize the bleed to no more than 0.5% of the fluid used in the mining process?

In order to answer this question, three months were randomly selected from the 33-month life span of mining unit one starting March 7, 1991 and continuing through December 24, 1993. They were October 1991, January 1992, and August 1993. The data collected in these three months yielded 92 separate samples that were used to calculate the daily bleed and then, the daily percentage of bleed generated by the mining process. The daily bleed percentages for all three month's operation were averaged to establish a value that represented the total percentage of bleed for the data collected. This analysis provided an accurate representation of the efficiency of the mining process and the waste water it was generating.

It was necessary to look at long-term bleed rates in order to get an accurate representation of the bleed created by the mining process. Daily bleed rates were influenced by the number of backwash dumps that came from the process injection filters. This increased waste water was the result of new wells that were brought on line as the wellfield expanded. Invariably new wells pump sand and this causes more waste water to come from the backwash filters. This activity causes the daily bleed rates to be very erratic and they must be averaged over a long period of time to get a true representation of the condition of the mining process. To demonstrate this a scatter plot of the daily bleed rates for each month sampled was constructed, Figures 12, 13, and 14. The bleed rate for each day of operation is represented and a horizontal line across each plot indicates the average percentage of bleed for the month.

Analysis of the scatter plots shows that the monthly rates are more stable than the daily bleed rates. The monthly rates also present a more accurate description of the waste water being generated by the mining process. However, if the three months used in this study are analyzed separately, the bleed rate for October 1991 would be high (see Figure 12). October's bleed was calculated to be 0.54%, 0.04% above the maximum acceptable 0.5% described in the license agreement. The continuous, excessive bleed was caused by sediment coming from new wells that were started in the first part of the month, October 2nd through October 7th. This sediment caused the injection filters to generate large amounts of waste water during this time, thus raising the monthly bleed rate. There were some high rates recorded on October 22, 23, 26, 29, and 30. Although high, these rates were immediately followed by low rates. This erratic behavior is the result of the normal mining process. As the mining process continues, sediment is periodically brought to the surface that can cause the bleed rate to go high for a short period of time. However, after the sediment is removed from the system the bleed from the mining process returns to a lower level. This erratic behavior represents the normal operation of the mine and the normal amount of waste water generated by the mining process. The bleed rate calculated for January 1992 at 0.32% and August 1993 at 0.35% , were well below the maximum acceptable 0.5% level (see Figures 13 and 14). No new wells were brought on line during these two months and, as mentioned previously, the amount of bleed generated in these months was more representative of the normal mining process.

When the monthly bleed rates for the three months sampled are averaged, the bleed rate for the mining process is better represented. The average for the three-months sampled is 0.4%. This average is well below the maximum acceptable 0.5% described in the license agreement with the United States Nuclear Regulatory Commission. This three-month bleed rate is close to that of the 1993 yearly bleed rate of 0.32% shown in Figure 15. The analysis of the data presented in Figures 12 through 14 indicates that the monthly bleed generated by the mining process is controlled to near or below the maximum acceptable 0.5% described in the license agreement. Furthermore, the data presented in Figure 15 indicates that the bleed rate is controlled well below the maximum acceptable 0.5% level on a yearly basis.

Figure 12, The October 1991 bleed percentage for the Crow Butte project, presents the daily and monthly bleed percentages for October 1991. From the 31 points calculated, the greatest bleed percentage, 1.8%, occurred on October 5, 1991 with the lowest, -0.7%, occurring on October 21, 1991. The monthly average is represented by the horizontal line drawn at the 0.54% level. This average was 0.04% over the maximum acceptable 0.5% limit. The excess bleed at the beginning of the month through October 7th, was attributed to the excessive number of dumps of fluid to the waste line from the backwash filters. This is the result of new production wells being added to the mining operation. New wells invariably pump sediment when they are initially started that is cleaned from the system by the backwash filters. When the wells clean out, the bleed rate decreases and the mine operates normally. The remaining daily rates following October 7th, indicate the normal operation of the mining process.

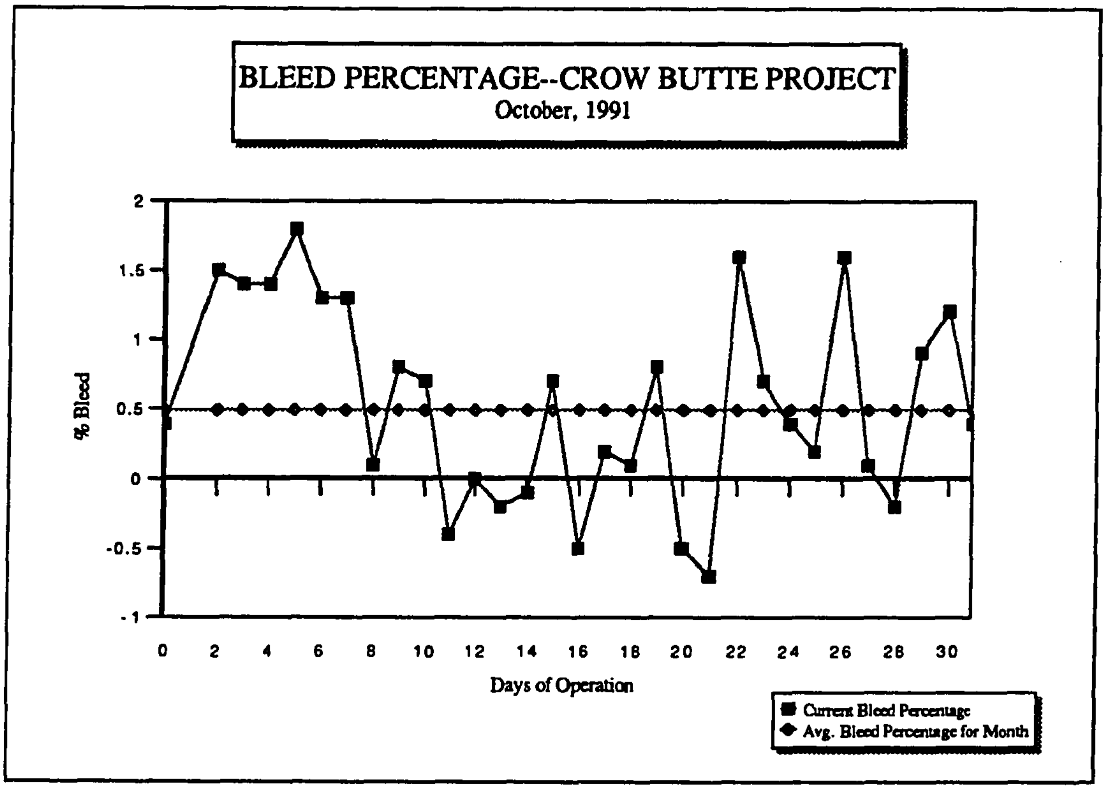


Figure 12. The October 1991 bleed percentage for the Crow Butte project.

Figure 13 The January 1992 bleed percentage for the Crow Butte project, presents the daily and monthly bleed percentages for January 1992. From the 31 points calculated, the greatest bleed percentage, 2.1%, occurred on January 15, 1992 with the lowest, -0.9%, occurring on January 21, 1992. The monthly average is represented by the horizontal line drawn at the 0.32% level. The average was 0.18% below the maximum acceptable 0.5% limit. There were no new wells added to the mining process this month. This bleed percentage is typical of the normal operation of the mining process.

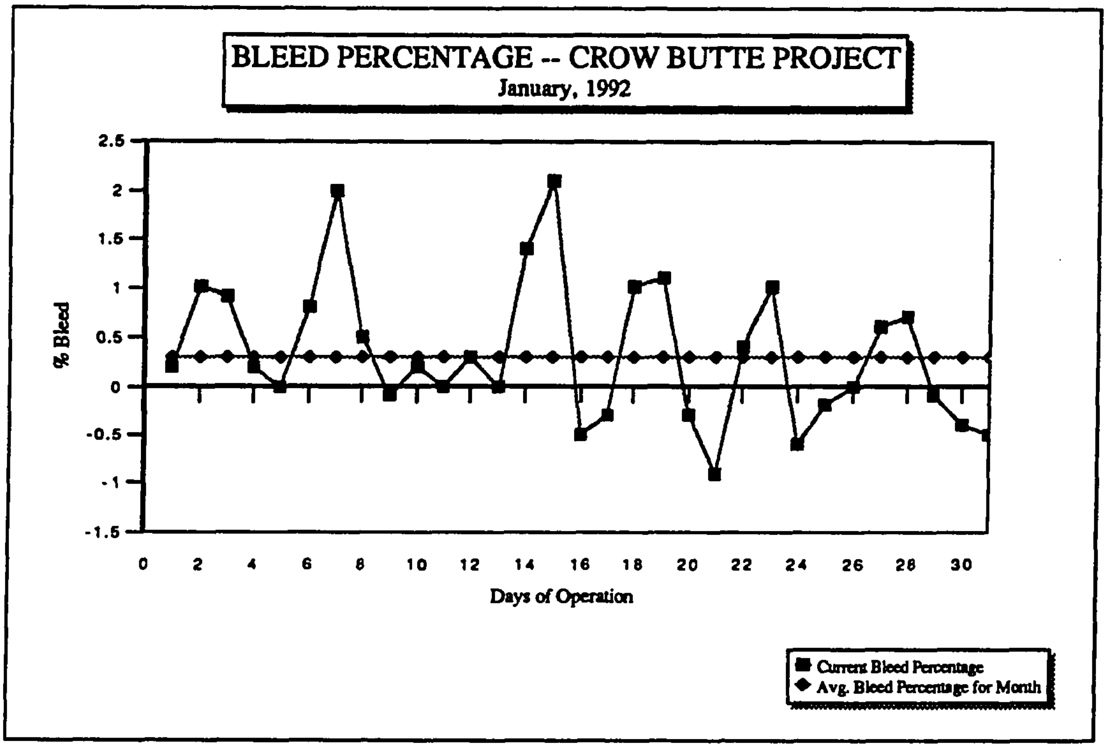


Figure 13. The January 1992 bleed percentage for the Crow Butte project.

Figure 14, The August 1993 bleed percentage for the Crow Butte project, presents the daily and monthly bleed percentages for August 1993. From the 31 points calculated, the greatest bleed percentage, 1.6%, occurred on August 12, 1993 with the lowest, -0.3%, occurring on both August 10th and 27th, 1993. The monthly average is represented by the horizontal line drawn at the 0.35% level. The average was 0.15% below the maximum acceptable 0.5% limit. There were no new wells added to the mining process this month. This bleed percentage is typical of the normal operation of the mining process.

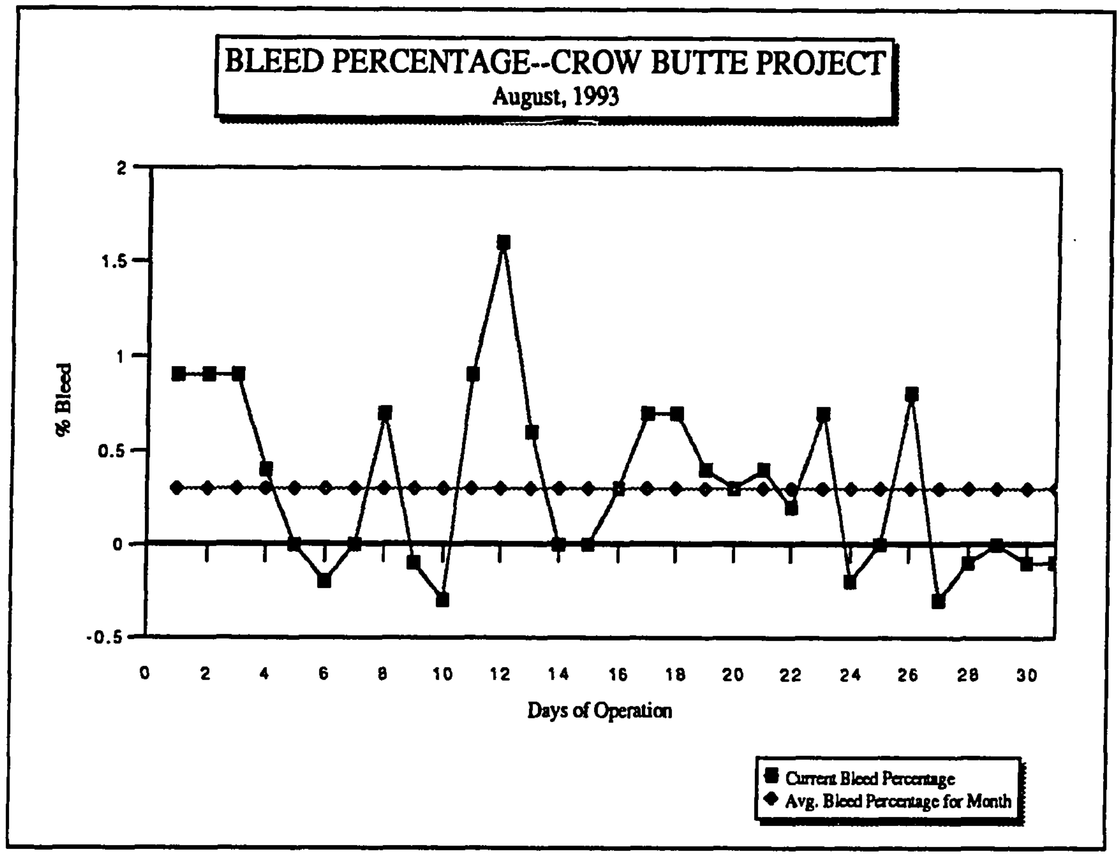


Figure 14. The August 1993 bleed percentage for the Crow Butte project.

Figure 15, The 1993 yearly bleed percentage for the Crow Butte project, presents the monthly percentages for 1993. From the 12 points calculated, the greatest bleed percentage, 0.8%, occurred in January with the lowest, 0.03%, occurring in April. The years average, 0.32% is displayed at the bottom of the figure. The average was 0.18% below the maximum acceptable 0.5% limit. This bleed percentage is typical of the normal operation of the mining process.

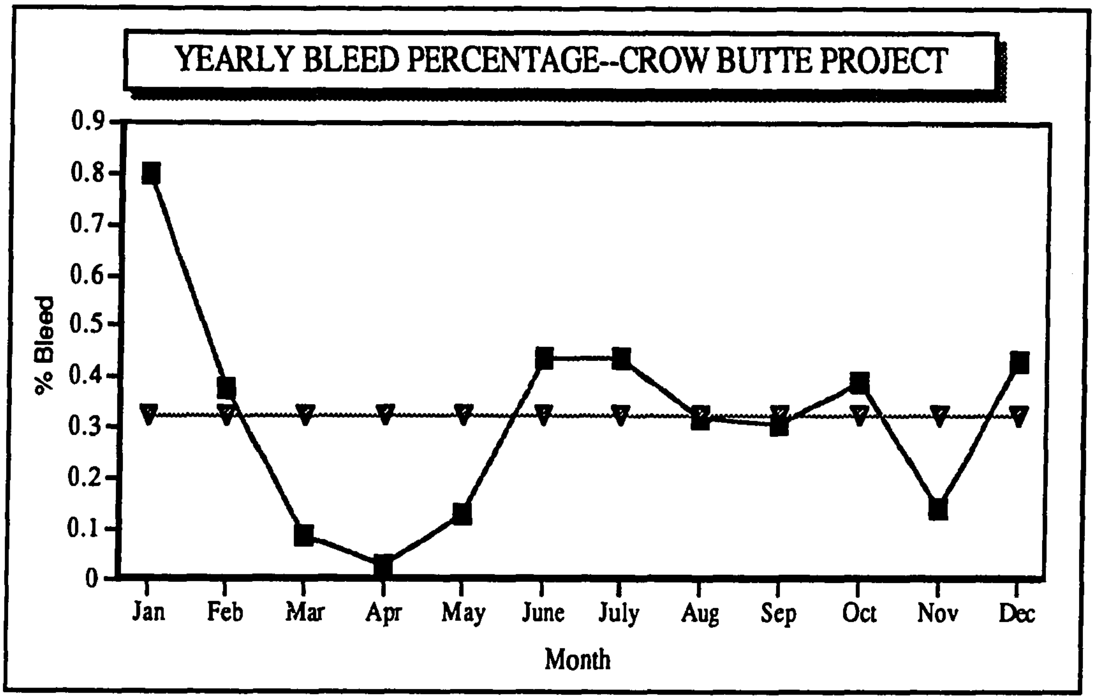


Figure 15. The 1993 monthly bleed percentages for the Crow Butte project.

Excursion Control

This part of the study was directed at the most important component of the in situ leach mining process, excursion control. The direction of fluid flow is vital both inside and outside the mine area. Inside the wellfield the pattern area and the direction of flow determines the efficiency of the ore recovery process. Outside the wellfield the direction of flow is influenced by both natural conditions and the degree to which the production and injection volumes are balanced. These flow directions and velocities are critical to preventing the leachate from migrating into the surrounding groundwater and causing an excursion.

To detect excursions of lixiviants into the ore zone aquifer outside the wellfield area being leached, 40 monitor wells were drilled approximately 400 feet from the perimeter of the wellfield and into the overlying water-bearing strata (see Appendix M). Prior to any mining, baseline samples were taken from every monitor well upon installation and the water level in each well was measured. The water samples were sent to Casper, Wyoming and Energy Laboratories, Inc., to be analyzed. This was done to establish a baseline value for the excursion indicators sodium, sulfate, chloride, conductivity and alkalinity. From this data, upper control limits (UCL) were established following the procedure outlined by the United States Nuclear Regulatory Commission (USNRC). The USNRC set the multiple upper control limit for the excursion indicators at 20% above the maximum baseline concentration for the excedance of any two parameters in the same sampling period from a single well. The USNRC set the single upper control limit at 20% above the multiple UCL for the excedance of any single excursion indicator in any well. The limits for each monitor well are presented in Tables 3, 4, and 5 on pages 48 to 50 in Chapter III. An excursion would be declared if the maximum value of any two excursion indicators were to exceed their multiple UCL or if the maximum value of any single excursion indicator were to exceed its single UCL. This would result in a suspension of the mining operation until the lixiviant was drawn back into the wellfield aquifer.

To answer research question three, biweekly water samples were taken from the monitor wells surrounding mining unit one starting March 7, 1991 and continuing through December 24, 1993. These samples were sent to Casper, Wyoming and analyzed by Energy Laboratories, Inc., to determine the level for each excursion indicator. The sample data collected from each monitor well were compiled in a spread sheet and the greatest value for each excursion indicator during the 33-month life of mining unit one was identified. This high level was compared to the single and multiple upper control limits (UCL) set by the USNRC before the start of the mining operation. From this comparison the excedance of any single or multiple UCL by an excursion indicator's maximum value was identified.

Research question three was: Are the data collected and transmitted by the small logic controllers accurate enough to justify operational changes in the wellfield balance to prevent lixiviants from migrating into the ground water resources near the in situ leach mining operation?

In order to answer this question, every biweekly sample for all of the monitor wells associated with mining unit one throughout its life were analyzed by Energy Laboratories, Inc. The maximum level occurring for each parameter of excursion indicator was then identified. This maximum level was compared to that well's multiple and single upper control limit (UCL) for that parameter as determined by the USNRC regulations. An excursion would be indicated if the maximum value of one parameter exceeded a well's single upper control limit or if two or more parameters in one sample for a well exceeded that well's multiple upper control limit.

It was found from the analysis that the chloride parameter in CM 1-4 (see Table 7) and in CM 1-9 (see Table 8) exceeded the multiple upper control limit set for each well in the sample taken on March 7, 1991. The chloride level in CM 1-4 was 279 mg/l and its multiple UCL was set at 264 mg/l. The chloride level in CM 1-9 was 235 mg/l and its multiple UCL was set at 227 mg/l. No other parameter's value exceeded the multiple upper control limit in CM 1-4 or CM 1-9 in the water sample taken on March 7th. Nor did the chloride level exceed the single UCL for either well. Therefore, an excursion was not declared. From further analysis of injection and production flows on March 7, 1991, it was determined that CM 1-4 and CM 1-9 were in a part of the mining unit where no injection or pumping was underway at the time the samples were taken.

When the mining process started near the two wells the next set of biweekly samples taken on March 3, 1991 showed that the chloride level in both wells had been reduced.

In this second sample the chloride level in CM 1-4 was 244 mg/l and the chloride level was 184 mg/l in CM 1-9. The water chemistry in both wells was within the USNRC set limits. The geologist at the Crow Butte operation indicated that the excessive chloride level was probably caused by insufficient cleaning of the well following the drilling procedure and not from the mining process. It was concluded that an excursion was not indicated.

Table 7

Excursion Monitoring Data for CM 1-4

Excursion monitoring data obtained for CM 1-4 during the sampling period; March 7, 1991 through March 19, 1992.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	420	386	459	504	605
Sulfate	352	335	372	432	518
Chloride	220	176	* 279	* 264	317
Conductivity	2063	1900	2130	2476	2971
Alkalinity	360	240	306	361	433

Note. Number of biweekly samples = 28. Chemical values are in Mg/L, Conductivity is in umhos. The Chloride parameter in this well exceeded the multiple UCL on March 7, 1991.

Table 8

Excursion Monitoring Data for CM 1-9

Excursion monitoring data obtained for CM 1-9 during the sampling period; March 7, 1991 through December 24, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	400	376	448	480	576
Sulfate	365	329	392	438	526
Chloride	189	174	* 235	* 227	272
Conductivity	2023	1900	2050	2428	2913
Alkalinity	305	270	310	366	439

Note. Number of biweekly samples = 74. Chemical values are in Mg/L, Conductivity is in umhos. The Chloride Parameter in this well exceeded the multiple UCL on March 7, 1991.

In contrast an excursion was indicated on April 23, 1992 (see Table 9). The analysis of the water samples taken that day indicated that the groundwater near the monitor well CM 2-9 was being affected by the mining process. It was apparent that an excursion was developing and that a change in wellfield balance needed to take place.

Table 9

Excursion Monitoring Data for CM 2-9

Excursion monitoring data obtained for CM 2-9 during the sampling period; April 9, 1992 through December 30, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	416	405	489	500	600
Sulfate	354	340	383	425	510
Chloride	221	182	* 280	* 266	320
Conductivity	2221	1910	2220	2666	3200
Alkalinity	306	283	311	368	442

Note. Number of biweekly samples = 44. Chemical values are in Mg/L, Conductivity is in umhos. The Chloride Parameter in this well exceeded the multiple UCL on April 23, 1992.

Note. Number of biweekly samples = 44. Chemical values are in Mg/L, Conductivity is in umhos. The Chloride Parameter in this well exceeded the multiple UCL on April 23, 1992.

The chloride parameter in CM 2-9 had exceeded the multiple upper control limit on April 23, 1992 and had reached 280 mg/l, which was 14 mg/l above the 266 mg/l multiple upper control limit. No other parameter exceeded the multiple UCL in the sample taken on April 23; therefore, an excursion was not declared. However, it was clear that a problem was developing and that a change in flow rates in that area of the wellfield was needed. Using the data collected by the computer monitoring system the flows of individual wells in the section of the wellfield near CM 2-9 were changed. Following this change the mining process was continued and in the next sample taken May 7th of the same year the chloride parameter in CM 2-9 was 251 mg/l . The chloride level had been reduced to well below the multiple upper control limit due to this change in flow rates. This indicated that the computer system yielded accurate data that was reliable enough to make an operational change in wellfield balance and control an excursion.

No other wells exhibited high concentrations of excursion indicators during the three year life of mining unit one. Tables 10 and 11 are typical of the results of the excursion monitoring activity for the life of mining unit one. The excursion indicators are listed in the first column with the baseline value for each excursion indicator shown in column two. The minimum and maximum occurring value for each parameter is given in column three and four. Column five and six of each chart display the multiple upper control limits and single upper control limits set by the United States Nuclear Regulatory Commission for each parameter. Because the life of each monitor well was different the number of samples taken for each parameter during the life of mining unit one are given at the bottom of every table. The remainder of the results of the excursion monitoring activity is displayed in Tables 12 through 45 in Appendix N.

Table 10

Excursion Monitoring Data for CM 1-8

Excursion monitoring data obtained for CM 1-8 during the sampling period; March 7, 1991 through December 24, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	400	375	425	480	576
Sulfate	360	316	395	433	520
Chloride	195	172	190	235	282
Conductivity	1923	1850	1910	2308	2769
Alkalinity	295	228	310	355	426

Note. Number of biweekly samples = 74. Chemical values are in Mg/L, Conductivity is in umhos.

In areas of high permeability, like those found at the Crow Butte Project, the mining process must be precisely controlled. Only minimal variations in water chemistry in the monitor wells can be allowed, and the excursion indicators must be maintained within safe limits. The narrow range that the automated system had to maintain is evident when a comparison is made between the excursion indicator's baseline water level shown in column two of Tables 12 through 45 (see Appendix N) and the value of its multiple UCL in column five.

Further comparisons should be made between the maximum occurring value for each excursion indicator shown in column four of the Tables 12 through 45 (see Appendix N) to the multiple and single upper control limits shown in columns five and six. Close analysis of these tables indicates that during the life of mining unit one, there were no other instances where the value of any excursion indicator exceeded either upper control limit.

Table 11

Excursion Monitoring Data for CM 3-1

Excursion monitoring data obtained for CM 3-1 during the sampling period; January 21, 1993 through December 23, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	450	402	432	540	648
Sulfate	425	355	382	510	612
Chloride	225	183	198	270	324
Conductivity	1940	1900	1960	2328	2794
Alkalinity	310	300	311	372	446

Note. Number of biweekly samples = 24. Chemical values are in Mg/L, Conductivity is in umhos.

Summary

Basic to an in situ leach mining operation is the flow of fluids through porous rock from place to place. The degree to which these movements of fluids can be monitored and controlled determines to a large degree the efficiency of the ore recovery operation. The objective of this study was to examine the effectiveness of small logic controllers to control and monitor the processes associated with the in situ leach mining process. To accomplish this, the study was broken into three separate parts. The first was to established that the data collected by the computerized system could be used to accurately calculate the flow rates of each individual well used in the mining process. It was found that no significant difference existed between the flow rates generated by the computerized system and the actual down hole flow rates of each well, and that the flows indicated by both methods were nearly identical.

The second part addressed the control of waste water from the mining process. Data were collected to calculate the percentage of bleed generated by the mining operation. It was determined that the bleed could be regulated to 0.4% of the total fluid used to recover ore from the in situ leach wellfield. This level was below the maximum acceptable 0.5% described in the license application submitted to the United States Nuclear Regulatory Commission by Ferret Exploration of Nebraska.

The final part of the study was directed at one of the most important parts of the in situ leach mining process, excursion control. The direction of fluid flow is vital both inside and outside the mine area. Inside the wellfield the pattern area and the direction of flow determine the efficiency of the ore recovery process. Outside the wellfield the direction of flow is influenced by both natural conditions and the degree to which the production and injection volumes are balanced. Flow directions and velocities are critical to understanding the leachate excursions and their control. The results of this study indicate that operational changes in wellfield balance can be carried out accurately based on the flow rates recorded by the small logic controllers. The entire wellfield balance during the three-year life of mining unit one was based on the data collected by the small logic controllers. During this time, there were no losses of mining fluid into the surrounding groundwater and no excursions were declared. Conclusions and recommendations based on these results are presented in Chapter V.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

In situ leach mining is a relatively new method that has the potential of becoming a viable alternative to conventional mining technology for recovering a variety of minerals. Basic to the in situ mining process is the control of fluids from place to place within the mining area and limiting the impact they have on the surrounding groundwater resources. Controlling and predicting the flow of the mining solutions used in the in situ leach mining operation is a responsibility of the mining company and is mandated by federal regulatory agencies. This study addressed a major problem associated with the in situ mining process, the uncontrolled migration of mining solutions outside the mining area. These undesirable migrations are known as excursions. Excursions are costly and are recognized by mining companies as events that need to be prevented. This would be possible if an accurate system existed for predicting and monitoring fluid flows within the in situ leach wellfield. With accurate flow data, water levels in the wellfield could be controlled and excursions prevented.

Predicting, monitoring, and controlling the flow of leach solutions are paramount in operating a solution mine. Accurate knowledge of flow patterns is not only critical for excursion control but also important for assessing the mining process itself and minimizing the waste water it generates. Most in situ leach mining operations have remotely located equipment that is used to collect well flow data. The equipment is either read manually for individual wells or the data for a group of wells are collected via a portable recording device. Neither method yields data fast enough to accurately control flows in a large in situ mining operation. One solution to this problem is to develop a Sequential Control and Data Acquisition (SCADA) system that can network all the flow monitoring instruments for each well within the in situ mining operation to one central location. This system would allow the mine operators to constantly monitor the mining process and make changes that affect the balance of liquid flows in the wellfield quickly enough to prevent excursions. Mining companies could then control leaching solutions and assure regulatory agencies that these lixiviants would not escape from the wellfield. Recent developments in programmable controller technology have made a SCADA system like this both possible and cost effective.

The use of programmable logic controllers (PLCs) to control an in situ leach wellfield has been successfully implemented in a uranium ore body in northwestern Nebraska. Two separate systems, one manual and one automated with PLCs, were installed to monitor the flow of fluids within the in situ leach wellfield. Both systems were used to control the mining process for one month during commercial operation, and both yielded similar data. The automated system was then used to control the commercial process for the remainder of the three years that the mining unit was in operation. The waste water generated by the process was monitored during the same time. Through the use of the automated system, waste water was controlled to less than 0.5% of the total fluid used to recover the ore. Excursions were monitored by sampling the water in monitor wells surrounding the mining area. These samples were analyzed for any chemical imbalances that could have been caused by the mining process. This sampling and analysis was conducted biweekly for the same three-year life of the mining unit.

The tests on the system's effectiveness to control the mining process yielded extensive quantities of data on fluid flow and excursion indicators. The flow rates of individual wells that were indicated by the PLC network were not significantly different than the actual down hole flow rates at each well head. One well (PR 24) behaved independently due to a mechanical failure and was deleted from the study. Production well 2 was never connected to the system and also was deleted from the study. The remainder of the wells performed adequately and from results of the study it was evident the well flow data collected by the automated system were accurate.

The chemical analysis of the biweekly samples taken from the monitor wells further supported the success of the automated system to control water levels within the wellfield. There were only three wells that exhibited any problems with elevated levels for excursion indicators. Of these three, the high chloride level that two monitor wells exhibited at the start of the mining process was attributed to an incomplete clean-out process of drilling solutions prior to the sampling. The remaining well, CM 2-9 did have an elevated level of chloride as a result of the mining process. This indicated that an excursion was highly possible. To correct this situation, the information from the PLC network was used to make a change in the flows in the wells in that area of the well field. This change in flows halted the migration of mining fluid into the surrounding groundwater and the excursion was avoided. The remainder of the mining process has been well within the parameters set in the license agreement with the United States Nuclear Regulatory Commission (USNRC) and no violations occurred as a result of faulty data being recorded by the PLC network. This further demonstrated the success of using the PLC network to control the well field and protect the surrounding groundwater resources.

Like conventional mining, the goal of in situ leach mining is to produce the optimum quality of the mineral resource economically and to achieve this production in an environmentally sound and acceptable manner. The automated system was used to monitor and control the mining process for mining unit one. The waste water generated by the mining operation was controlled to less than 0.5% of the water used to recover the ore. The low level of waste water generated during the study period indicated the effectiveness of the automated system to control and monitor the in situ process. This system was used to control and monitor the commercial in situ mining process at the Crow Butte Project to acceptable environmental standards without lowering the quality of the mining process.

Conclusions

The objectives of the Crow Butte project field testing were to demonstrate that an automated Sequential Control and Data Acquisition System (SCADA) using small logic controllers could be designed to control the flow of water within the in situ leach wellfield. The system was used to accomplish environmentally sound mining, to keep groundwater to regulatory standards and to develop the technical and operational basis for a commercial in situ leach mining project. Wellfield control in terms of recovery, excursion control and generation of waste water provided a firm base for developing the long-term, large-scale mining plan which is under way at the Crow Butte site at the time of this writing.

This automated system for monitoring the in situ leach mining process was shown to be equally as accurate as the manual method but much faster, thus increasing its value to be used to control excursions. The owners of the Crow Butte project felt that the results of this part of the study were successful enough to use the automated system to monitor and control the well field during the commercial operation of the Crow Butte project. This supports the conclusion that the SCADA system can be used to monitor and control the fluids within the in situ wellfield.

The percentage of waste water generated from the commercial mining process was calculated daily for the three-year life of mining unit one. The results of this analysis indicated that the percentage of waste water generated during this time was maintained to below 0.5% of the water used to recover the ore. This part of the study supported the conclusion that the automated system can be used to control the mining process and limit the amount of waste water it generates.

The entire wellfield balance for the commercial operation during the three-year life of mining unit one was based on the data collected by the automated system. There was only one occurrence, in the second year of operation, that indicted a problem with an excursion. The water chemistry in one monitor well had elevated indicating an excursion was developing. Using the information from the automated system, the wellfield balance in the affected area was changed. This change drew the lixiviant back into the mining unit and no excursion was declared. No other problems developed with the control of mining solutions. The lack of high levels in the remaining monitor well's water chemistry during the life of the mining unit demonstrates the type of control the computerized system can provide. This control of the flow of fluids through the wellfield has supported the ability of the computerized system to yield data that are accurate enough to control for and prevent excursions from occurring as a result of the mining process.

Perhaps the most important feature of any newly developed technology is the opportunity to assess critical design concepts and to then seek means to improve these concepts. While the performance of the flow meters used in this study was excellent, newer flow monitoring instruments have been implemented since this project was started and their adaptation to the SCADA system has proven to be equally successful. This development has been invaluable to the continuing search for the optimum wellfield design. The system developed for this study has provided a wealth of information which has enhanced commercial planning and expansion of the in situ mine. This information has greatly reduced the risks inherent with this mining process.

Recommendations

The following recommendations are made in light of this study:

1. The decline of the price of uranium oxide in the world market has driven mining operations to decrease their overhead operating costs. This automated system allows for more efficient wellfield monitoring with fewer mine operators. The Crow Butte project is controlled by two people, a mine operator and one assistant, and in 1993 they produced 600,000 pounds of yellow cake. During this time no violations of the licensing agreement have occurred. This process seems to be both cost effective and the results of this study

support its accuracy to monitor and control the in situ mining process. This technology should be used to control wellfield flow in the in situ leach mining processes.

2. Storage of waste water produced from in situ mining processes is costly and bleed from the mining process must be minimized. The results of this study support that the automated system used to monitor and control the mining process at the Crow Butte project can minimize the amount of waste water produced by in situ mining. This technology should be used to effectively control waste water production by in situ mines.

3. Mine owners and operators are acutely aware of the ramifications of an excursion happening as a result of their mining operation. Identifying and terminating an excursion before it happens is the best method of excursion control. The results of this study have supported the effectiveness of this technology for excursion control. The system should be used to monitor in situ mining processes and control the migration of lixiviants to surrounding groundwater.

Recommendations for further study

Given the findings and outcomes of this study along with the practical application of the automated system to the in situ mining process, the following recommendations for further study are offered:

1. The computerized system yields data so quickly and accurately that it can easily be used to control groundwater levels. A study should be conducted to determine how well a cone of depression could be controlled.

2. A study should be conducted to determine the relationship of well flows and their effect on head grade.

3. The flow data collected by the automated system should be used in a flow charting program like ISL-50 to map underground flow channels to determine the effectiveness of the mining operation.

4. This monitoring system should be applied to in situ mining in other geological formations to determine its effectiveness.

References

Algermissen, S. T. (1969). Seismic risk studies in the United States: Proceedings of the fourth world conference on earthquakes, engineering. Santiago, Chile: National Oceanic and Atmospheric Administration Reprint, 1:4-27.

Allen-Bradley Company. (1990). Controlview core users manual. Milwaukee, WI: Industrial Control Group.

Baver, L. D., Gardner, W. H., & Gardner, W. R. (1972). Soil physics. New York: John Wiley and Sons, Inc.

Beck, M. (1980). Development of the Christensen Ranch. Sixth Annual Uranium Seminar (pp. 123-128). Hoboken, NJ: Guinn Printing, Inc.

Best, J. W. (1981). Research in education. Englewood Cliffs, NJ: Prentice-Hall.

Berglund, A. (1989). In Situ Development at the Christensen Ranch Uranium Project. In Situ All Mineral Symposium, Casper, WY: Society of Mining Engineers, Inc.

Burchett, R. R. (1979). Earthquakes in Nebraska, Educational Circular No. 4 (pp. 20). Lincoln: University of Nebraska-Lincoln.

Clark, D. (1989). In situ mining in the 1990's uranium market. Presented at the In-Situ All-Minerals Symposium, Casper, WY and Danbury, CN: Society of Mining Engineers, Inc.

Collings, S. P., & Knode, R. H. (1984). Geology and discovery of the Crow Butte uranium deposit, Dawes County, Nebraska, Annual Symposium on Uranium and Precious Metals. Lakewood, CO: Wyoming Fuel Company.

Collings, S. P., Knode, R. H., & Miller, C. M. (1990, March). In situ uranium mining extractive metallurgy at the Crow Butte uranium project. Denver, CO: Extractive Metallurgy Chapter of Denver.

D'Andrea, D. V. (1981). In situ mining research proceedings: Bureau of mines technology transfer seminar. Denver, CO: Bureau of Mines. United States Department of the Interior Report of Investigation No. 8479.

DeGraw, H. M. (1969). Subsurface relations of the cretaceous and tertiary in western Nebraska. Unpublished master's thesis, University of Nebraska-Lincoln.

Docekal, J. (1970). Earthquakes of the stable interior with emphasis on the mid-continent. Unpublished doctoral dissertation, University of Nebraska-Lincoln, Lincoln.

Durler, D. L. (1982) Impact of new regulations on In Situ uranium operations. Paper presented at the sixth Annual Uranium Seminar (pp. 123-128). Hoboken, NJ: Guinn Printing, Inc.

Ferret Exploration of Nebraska, Inc. (FEN) (1987). Crow Butte uranium project Dawes County, Nebraska, Denver, CO: Ferret Exploration of Nebraska, Inc..

Greenwald, J. (1991, April 29). Time to choose. Time, pp. 54-61.

Hydril Company. (1990). Remote terminal unit, model MP-531-A (Bulletin No. 6010). Houston, TX: Hydril Company.

Jones, C. T., & Bryan, L. A. (1983). Programmable controllers concepts and applications. Atlanta, GA: International Programmable Controls, Inc.

Kale, C. O. (1989). Industrial circuits and automated manufacturing. New York: Holt, Rinehart, and Winston, Inc.

Knode, Ralph. (1993). Ferret-Nebraska commercial quality assurance program radiological monitoring groundwater and surface water sampling. Denver, CO: Ferret Exploration of Nebraska, Inc.

Nebraska Geologic Survey. (1981). Inventory of mining operations in Nebraska, Lincoln: State of Nebraska, Nebraska Mineral Operations Review.

Okutan, H., Oner, G., Saygili, G., & Savguc, A. B. (1989). Solution mining of trona and uranium in the country of Turkey. Presented at the In Situ All Mineral Symposium, Society of Mining Engineers, Inc., Casper, WY and Danbury, CN.

Pool, T. (1989). Solution mining--The flexible approach. Presented at the In-Situ All Minerals Symposium. Society of Mining Engineers, Inc., Casper, WY and Danbury, CN.

Reed, E. L. (1981). The application of ground water hydrology to in situ leach mining (RI No. 8479). Denver, CO: Bureau of Mines Report of Investigations. United States Department of the Interior.

Schmidt, R. D. (1980). Computer modeling of fluid flow during production and environmental restoration phases of in situ uranium leaching (RI No. 8479). Denver, CO: Bureau of Mines Report of Investigations. United States Department of the Interior.

Singler, C. R., & Picard, M. D. (1980). Stratigraphic review of oligocene beds. Northern Great Plains Earth Science Bulletin WGA, V13, 1, 1-18.

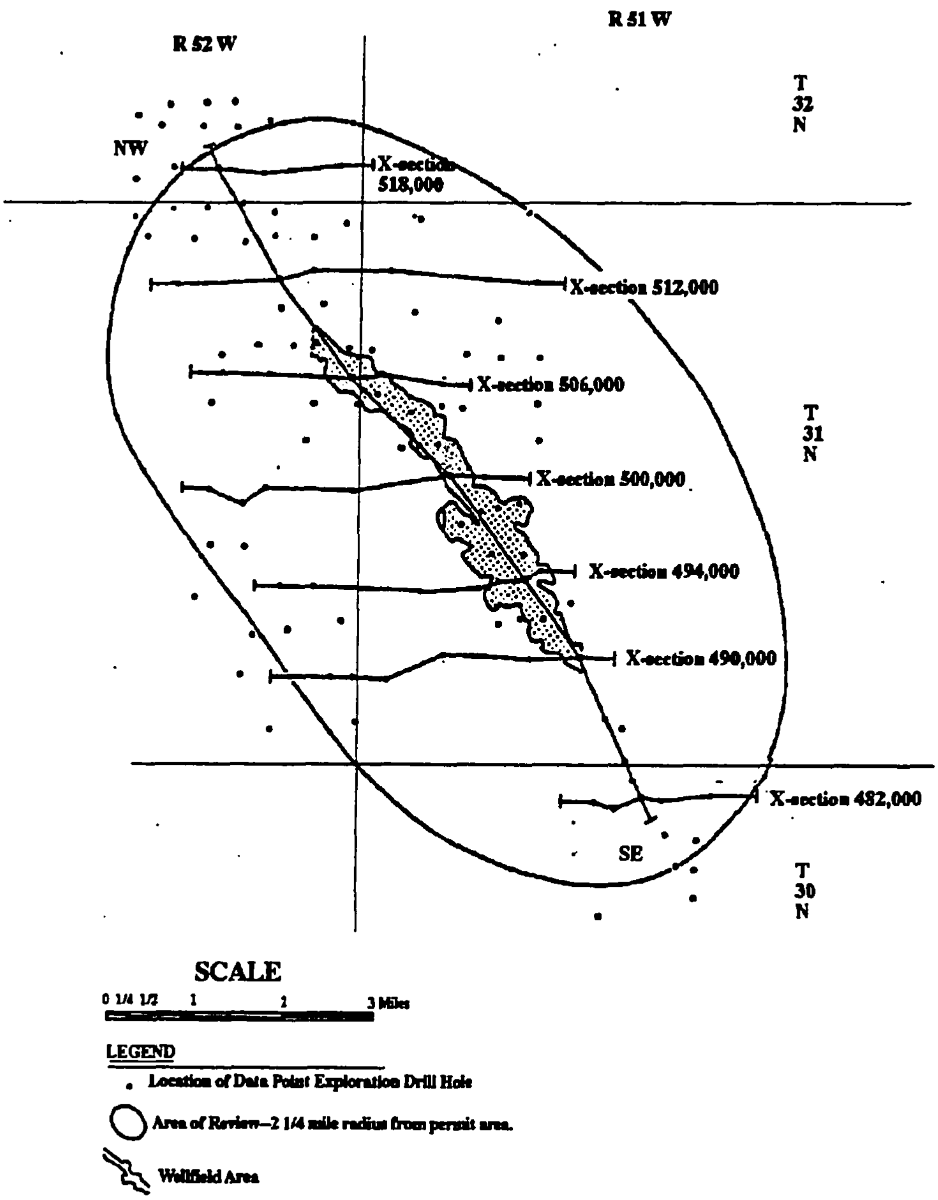
Spalding, R. (1982). Baseline hydrogeochemical investigation in a part of northwest Nebraska. Lincoln: University of Nebraska-Lincoln. Nebraska Department of Environmental Control, Conservation and Survey Division, Institute of Agriculture and Natural Resources.

Staub, W. P., Hinkle, N. E., Williams, R. E., Anastasi, F., Osiensky, J., & Rogness, D. (1986). An analysis of excursions at selected in situ uranium mines in Wyoming and Texas (Report No. NRC FIN B0279). Washington, DC: United States Nuclear Regulatory Commission.

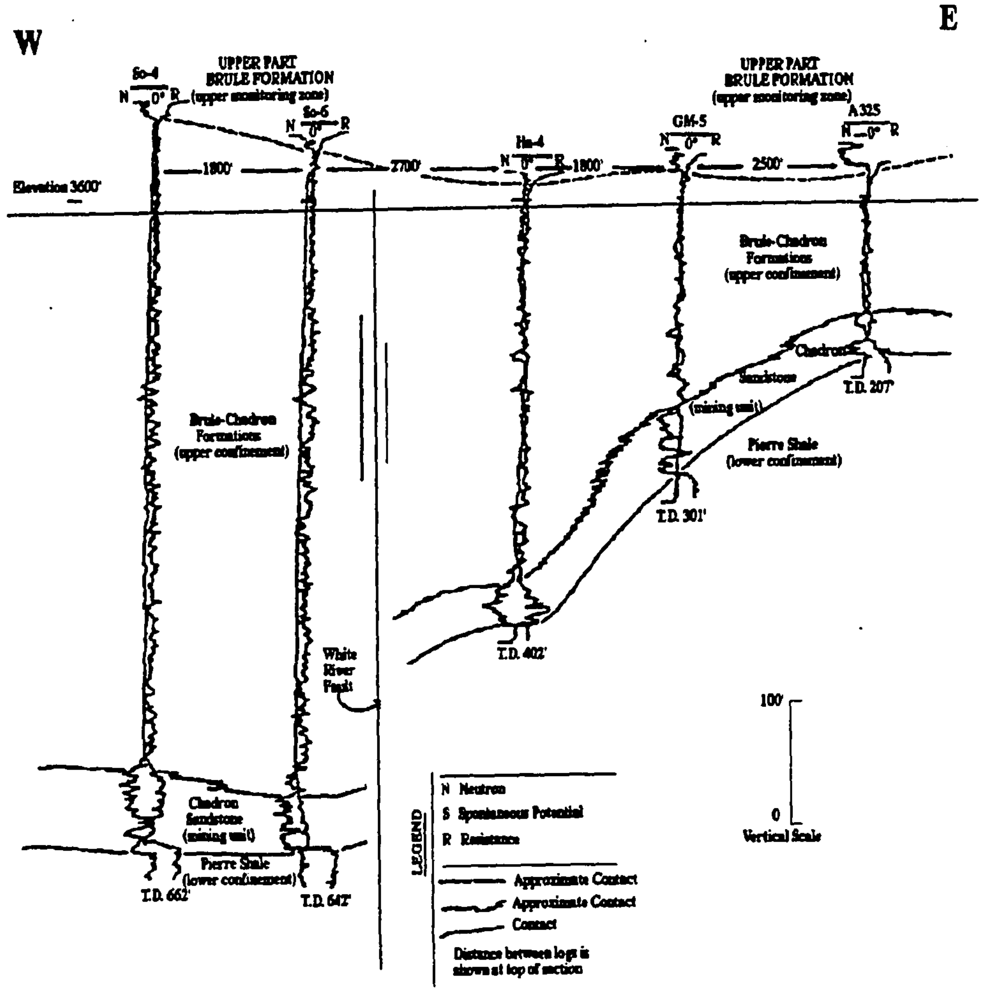
Swinehart, J. B., Souders, V. L., DeGraw, H. M., & Diffendal, R. F. Jr. (1985). Cenozoic paleography of western Nebraska. In R. M. Flores & S. S. Kaplan (Eds.), Cenozoic paleography of the west-central United States (pp. 187-206). Denver, CO: Rocky Mountain Section, SEPM.

Tweeton, D. R., Cumerlato, C., Hanson, J., & Kuhlman, H. (1989). Predicting and monitoring leach solution flow with geophysical techniques. In-Situ All Mineral Symposium, Casper, WY and Danbury, CN: Society of Mining Engineers, Inc.

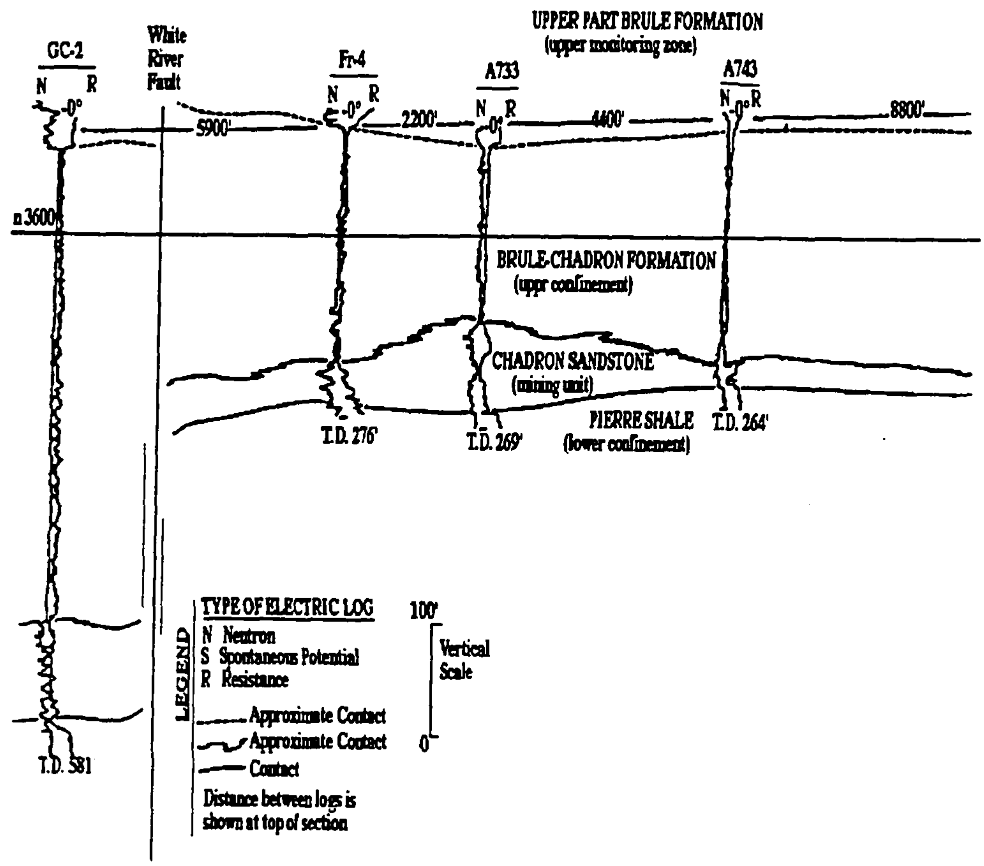
Appendix A. Cross-section Location.



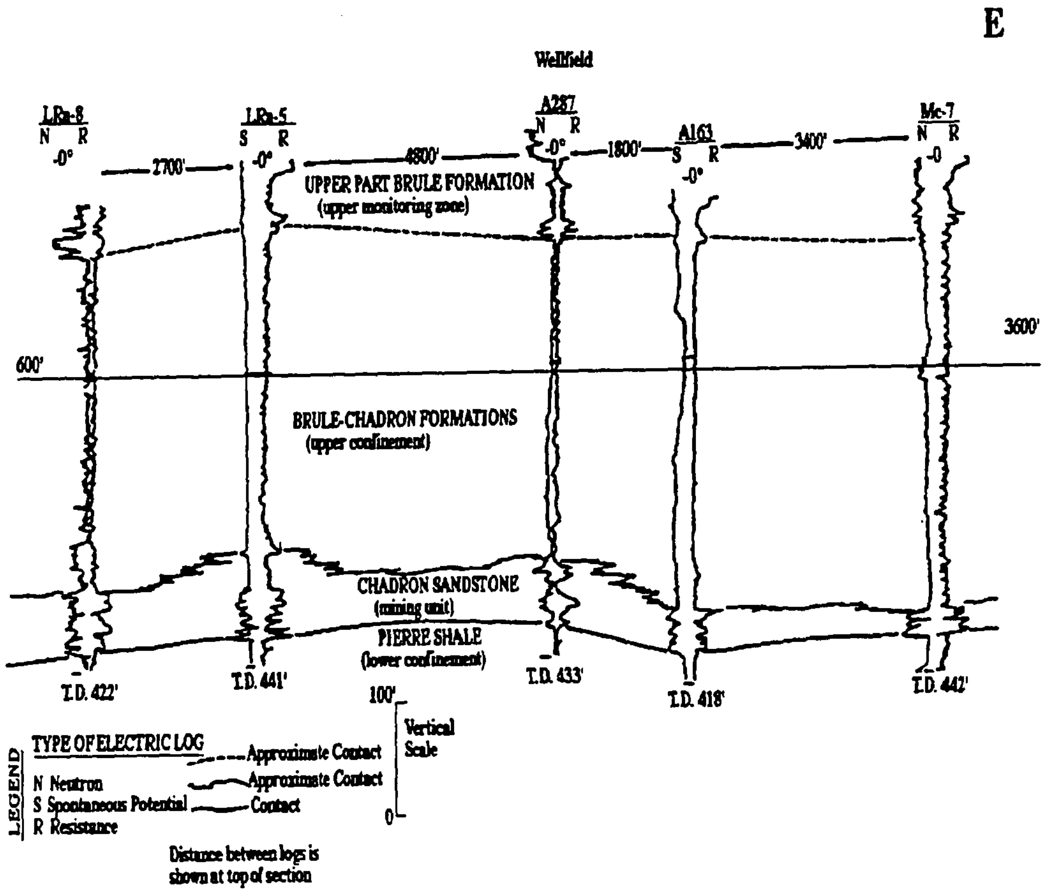
Appendix B. Cross-section 518,000 E-W.



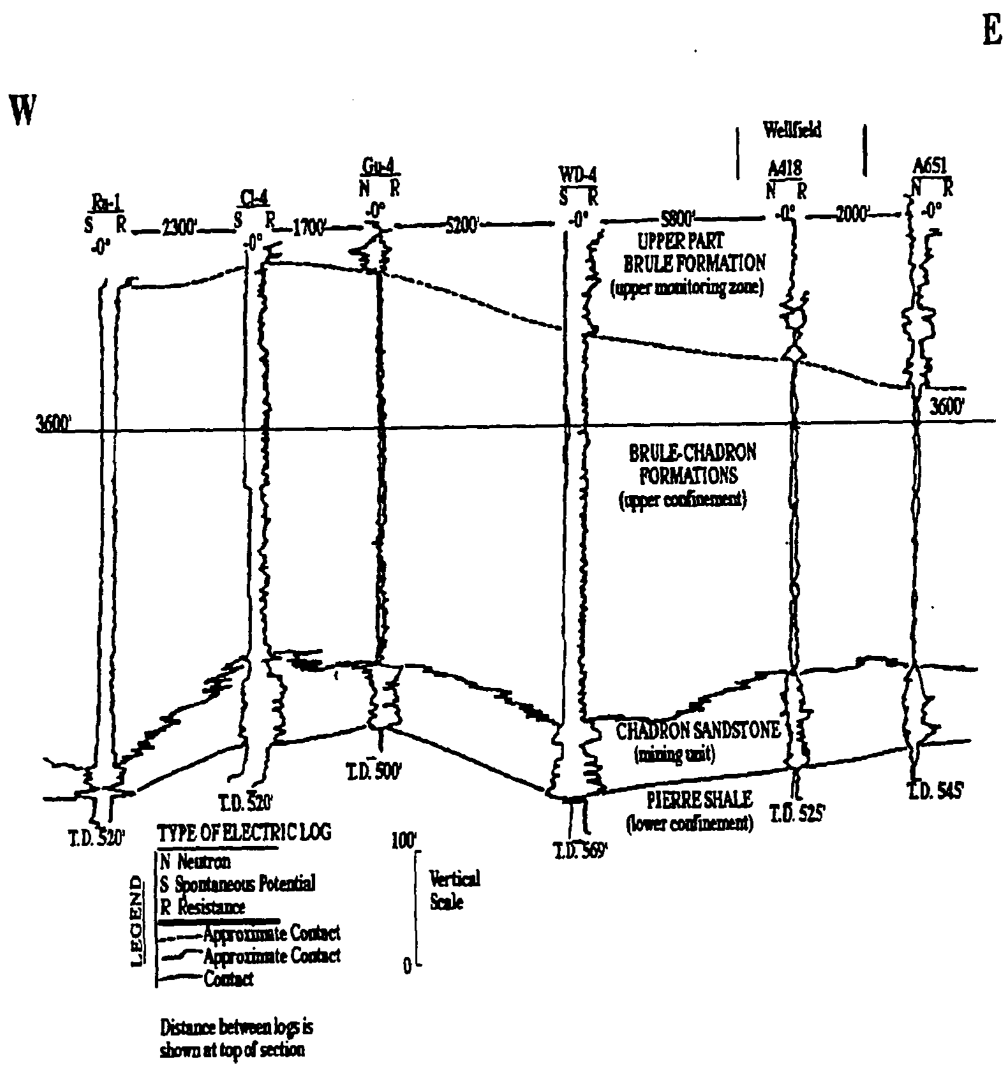
Appendix C. Cross-section 512,000 E-W.



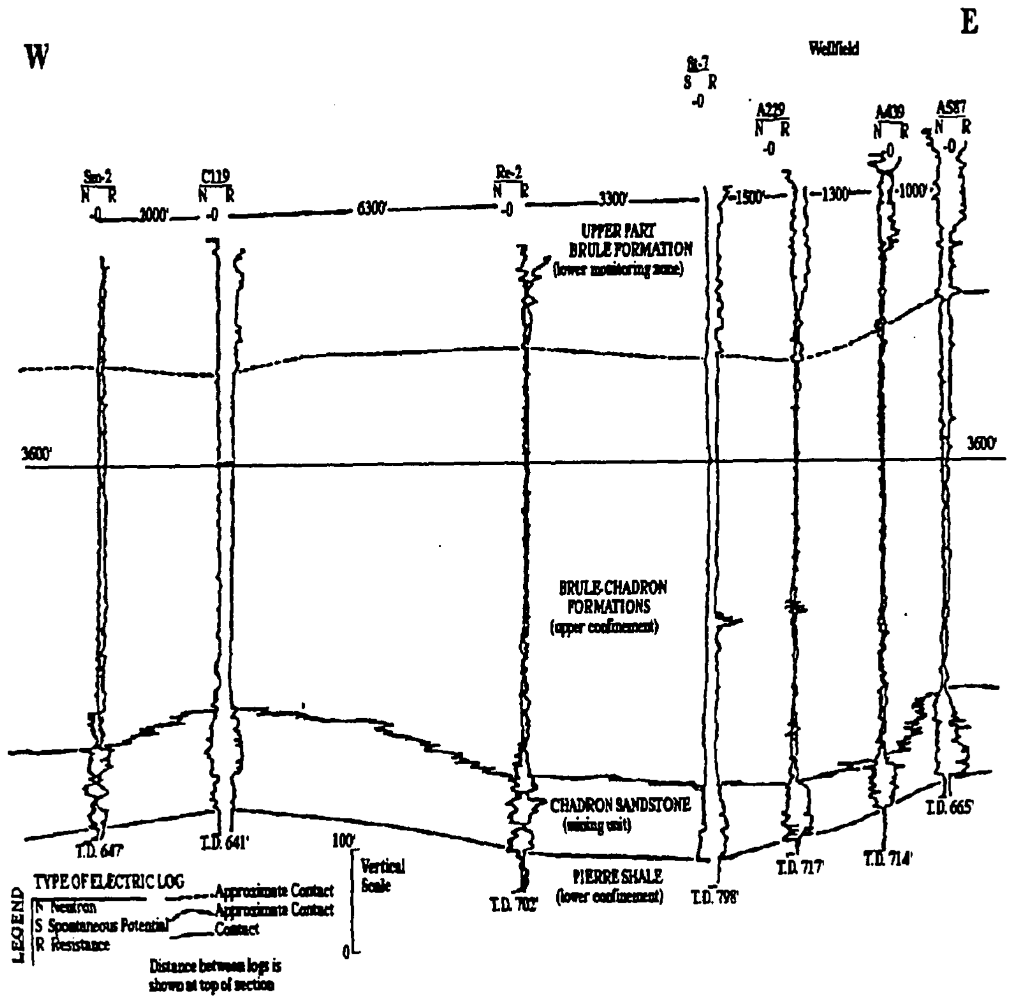
Appendix D. Cross-section 506,000 E-W.



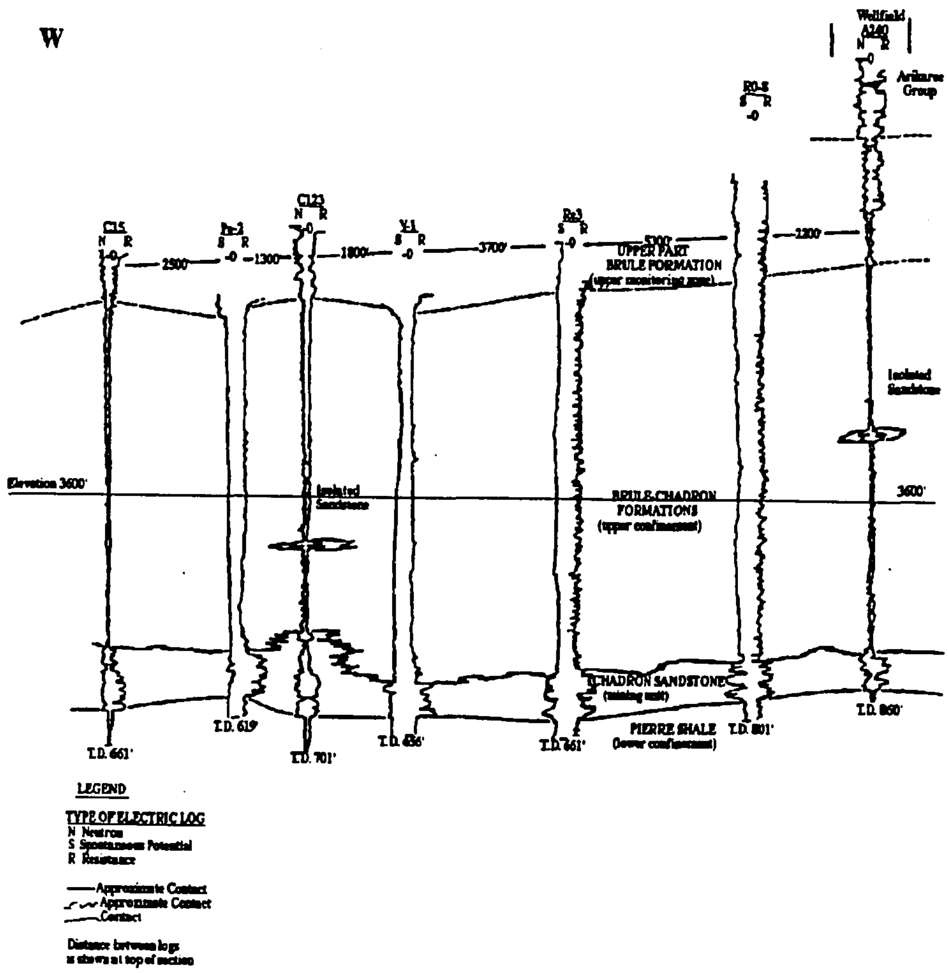
Appendix E. Cross-section 500,000 E-W.



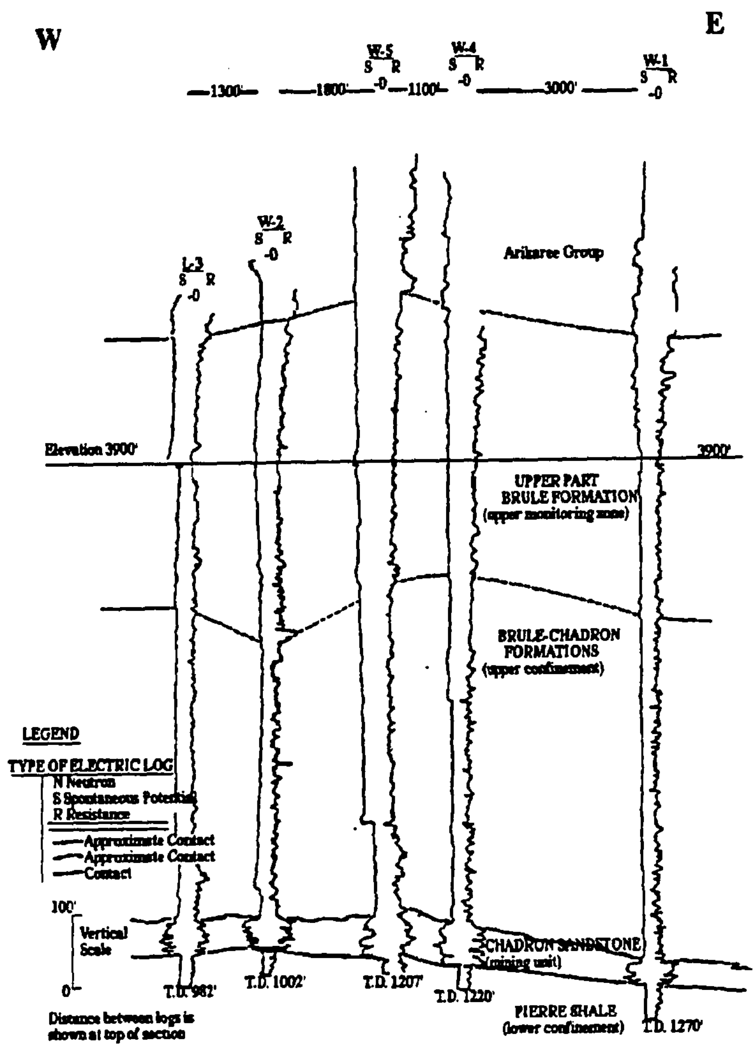
Appendix F. Cross-section 494,000 E-W.



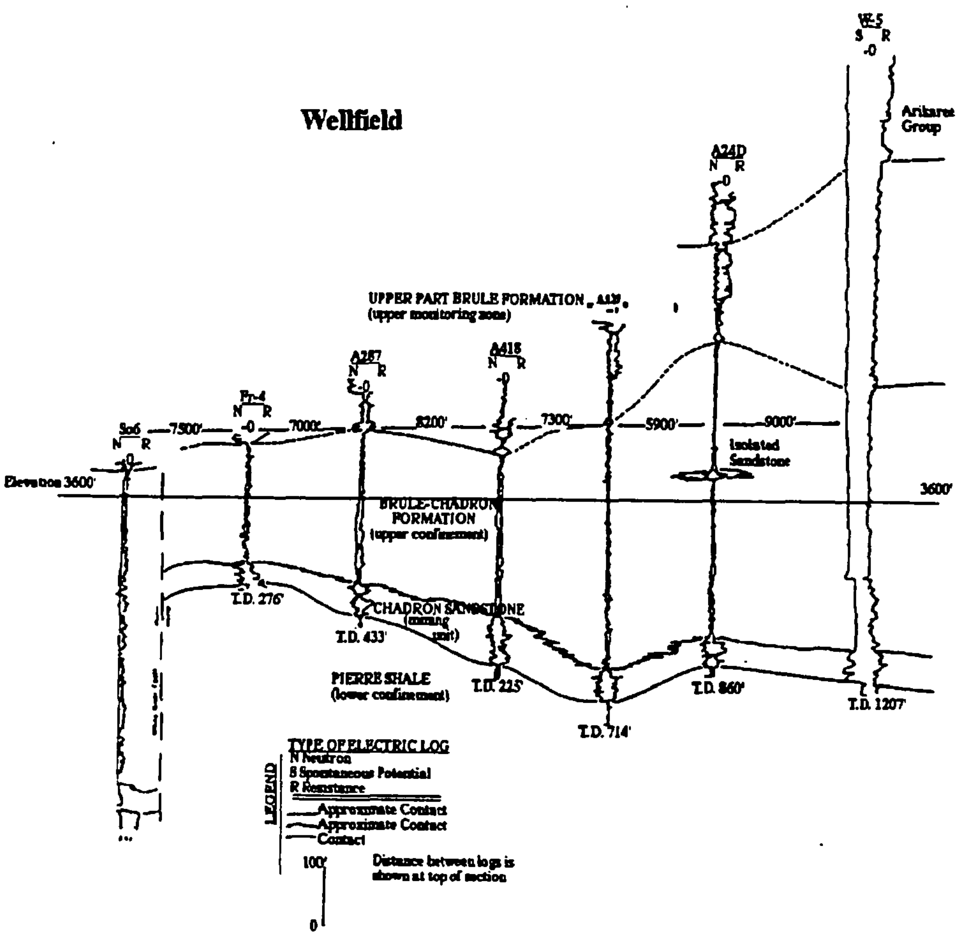
Appendix G. Cross-section 490,000 E-W.



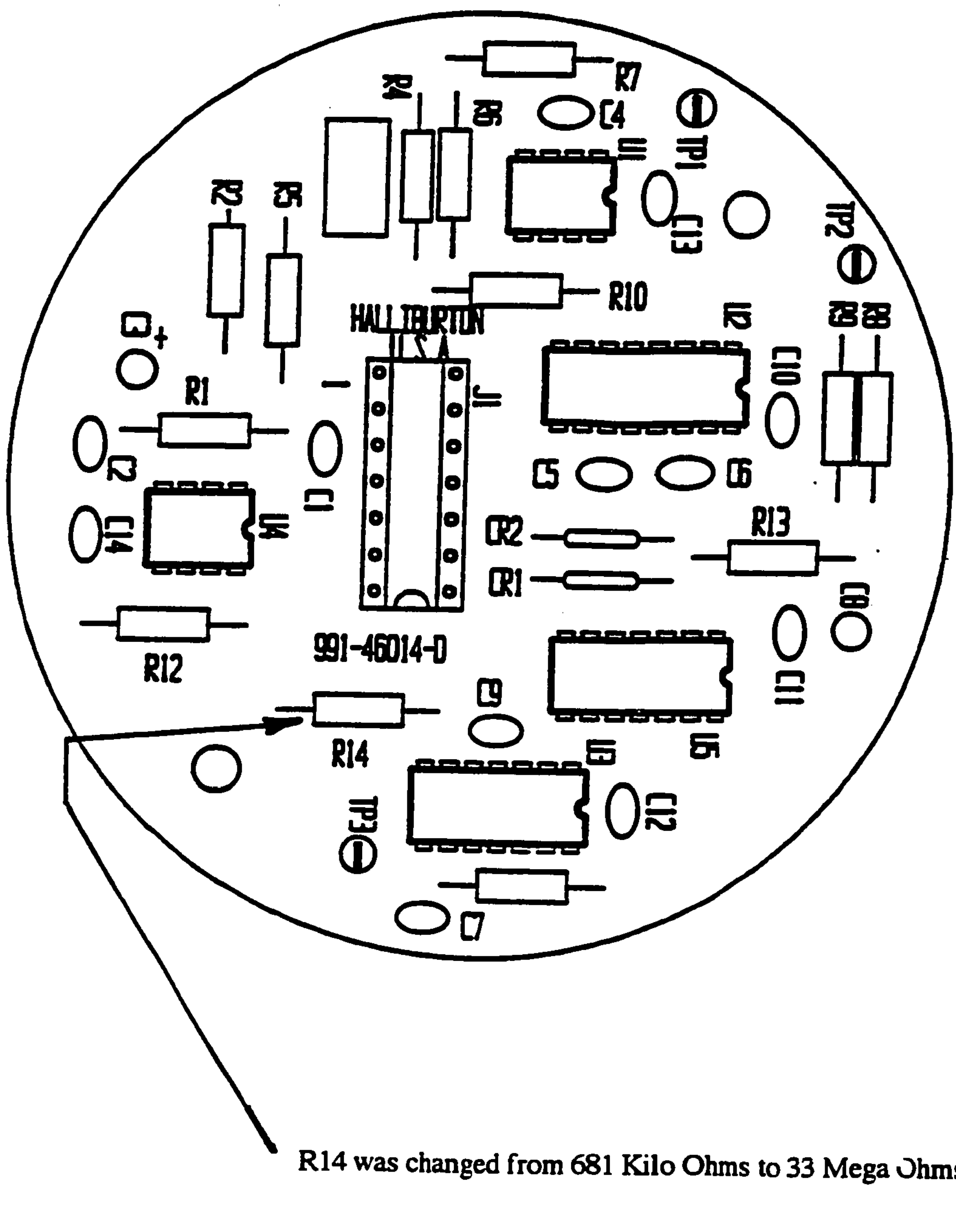
Appendix H. Cross-section 482,000 W-E.



Appendix I. Cross-section NW-SE.



Appendix J. Location HPO-RTU Component Change.



R14 was changed from 681 Kilo Ohms to 33 Mega Ohms.

Appendix K. Sample of Interger File Word Number Two as seen by the PLC 5/25.

ALLEN-BRADLEY
PLC-5 Family
Programmable Controller
DATA TABLE BIT ASSIGNMENTS

PAGE 1 OF 7
ADDRESS N12:10 TO N12:40

PROJECT NAME Plant HOSTPLC
DESIGNER Jim Stokey
PROCESSOR NAME PLC 5/25
DATA FILE NO. N12 TYPE Integer

ELEMENT	BIT	DESCRIPTION	ELEMENT	BIT	DESCRIPTION
N12:10	00	1	N12:30	00	1
	01	0		01	1
	02	0		02	0
	03	0		03	0
	04	0		04	0
	05	0		05	0
	06	Underflow Well # 1		06	Underflow Well # 7
	07	Overflow Well # 1		07	Overflow Well # 7
	10	Underflow Well # 2		10	Underflow Well # 8
	11	Overflow Well # 2		11	Overflow Well # 8
	12	Underflow Well # 3		12	Underflow Well # 9
	13	Overflow Well # 3		13	Overflow Well # 9
	14			14	
	15			15	
	16			16	
	17			17	
N12:20	00	0	N12:40	00	0
	01	1		01	0
	02	0		02	1
	03	0		03	0
	04	0		04	0
	05	0		05	0
	06	Underflow Well # 4		06	Underflow Well # 10
	07	Overflow Well # 4		07	Overflow Well # 10
	10	Underflow Well # 5		10	Underflow Well # 11
	11	Overflow Well # 5		11	Overflow Well # 11
	12	Underflow Well # 6		12	Underflow Well # 12
	13	Overflow Well # 6		13	Overflow Well # 12
	14			14	
	15			15	
	16			16	
	17			17	

NOTE: For I/O files, skip bits 08 and 09. For all other files, skip bits 16 and 17.

Comments

Appendix L. Sample of Interger File Seven Word Group as seen by the PLC 5/25.

ALLEN-BRADLEY
PLC-5 Family
Programmable Controller
DATA TABLE WORD ASSIGNMENTS
(80 DECIMAL WORDS OR
64 OCTAL WORDS)

PAGE 1 OF 5
ADDRESS N12:0 TO N12:70

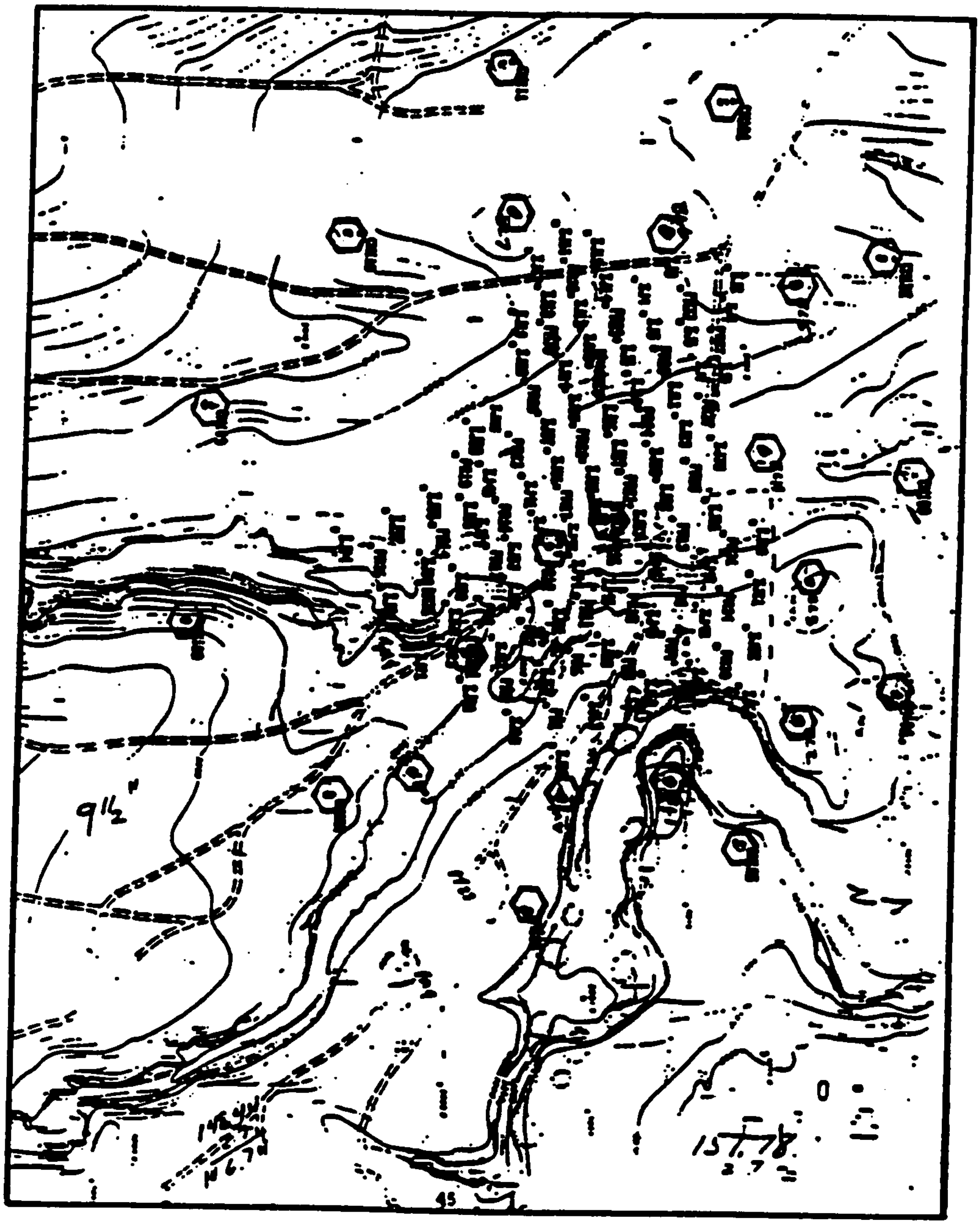
PROJECT NAME Plant HostPLC
PROCESSOR NAME PLC 5/25
DESIGNER [illegible]
DATA FILE NO. N12 TYPE Integer

ELEM ADDR	DESCRIPTION	ELEM ADDR	DESCRIPTION
N12:0 0		N12:4 0	Group #4 ID / I/O Bits
1		1	Well #10 } Totalizer
2		2	Well #10 }
3		3	Well #11 } Totalizer
4		4	Well #11 }
5		5	Well #12 } Totalizer
6		6	Well #12 }
7		7	
8		8	
9		9	
N12:1 0	Group #1 ID / I/O Bits	N12:5 0	Group #5 ID / I/O Bits
1	Well #1 } Totalizer	1	Well #13 } Totalizer
2	Well #1 }	2	Well #13 }
3	Well #2 } Totalizer	3	Well #14 } Totalizer
4	Well #2 }	4	Well #14 }
5	Well #3 } Totalizer	5	Well #15 } Totalizer
6	Well #3 }	6	Well #15 }
7		7	
8		8	
9		9	
N12:2 0	Group #2 ID / I/O Bits	N12:6 0	Group #6 ID / I/O Bits
1	Well #4 } Totalizer	1	Well #16 } Totalizer
2	Well #4 }	2	Well #16 }
3	Well #5 } Totalizer	3	Well #17 } Totalizer
4	Well #5 }	4	Well #17 }
5	Well #6 } Totalizer	5	Well #18 } Totalizer
6	Well #6 }	6	Well #18 }
7		7	
8		8	
9		9	
N12:3 0	Group #3 ID / I/O Bits	N12:7 0	Group #7 ID / I/O Bits
1	Well #7 } Totalizer	1	Well #19 } Totalizer
2	Well #7 }	2	Well #19 }
3	Well #8 } Totalizer	3	Well #20 } Totalizer
4	Well #8 }	4	Well #20 }
5	Well #9 } Totalizer	5	Well #21 } Totalizer
6	Well #9 }	6	Well #21 }
7		7	
8		8	
9		9	

NOTE. [illegible]

Comments ______

Appendix M. Location of Wellfield Monitor Wells.



Appendix N. Excursion Monitoring Tables.

Table 12

Excursion Monitoring Data Obtained for CM 1-1 During the Sampling Period: March 7, 1991 Through January 7, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	430	385	436	516	619
Sulfate	375	349	393	450	540
Chloride	234	179	221	281	337
Conductivity	2106	1920	2020	2528	3034
Alkalinity	299	240	303	359	431

Number of biweekly samples: 49
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 13

Excursion Monitoring Data Obtained for CM 1-2 During the Sampling Period: March 7, 1991 Through January 7, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	410	378	431	492	590
Sulfate	345	323	379	415	498
Chloride	193	175	192	232	278
Conductivity	1995	1870	1930	2395	2874
Alkalinity	298	200	310	358	429

Number of biweekly samples: 49
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 14

Excursion Monitoring Data Obtained for CM 1-3 During the Sampling Period: March 7, 1991 Through March 19, 1992.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	400	386	435	480	576
Sulfate	364	333	429	437	524
Chloride	193	172	187	232	278
Conductivity	1995	1920	1940	2395	2874
Alkalinity	300	265	307	361	433

Number of biweekly samples: 28
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 15

Excursion Monitoring Data Obtained for CM 1-5 During the Sampling Period: March 7, 1991 Through March 19, 1992.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	500	382	500	600	720
Sulfate	374	330	367	449	539
Chloride	360	176	325	433	520
Conductivity	2553	1890	2360	3064	3676
Alkalinity	306	260	316	368	442

Number of biweekly samples: 28
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 16

Excursion Monitoring Data Obtained for CM 1-6 During the Sampling Period: March 7, 1991 Through March 19, 1992.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	390	376	419	468	562
Sulfate	355	305	356	426	511
Chloride	193	163	194	232	278
Conductivity	1964	1740	1910	2357	2828
Alkalinity	309	288	308	371	445

Number of biweekly samples: 28
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 17

Excursion Monitoring Data Obtained for CM 1-7 During the Sampling Period: March 7, 1991 Through March 19, 1992.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	400	376	421	480	576
Sulfate	356	330	356	428	514
Chloride	193	173	192	232	278
Conductivity	1965	1880	1900	2359	2831
Alkalinity	303	270	306	364	436

Number of biweekly samples: 28
Note: Chemical values are in Mg/L, Conductivity is in umhos

Table 18

Excursion Monitoring Data Obtained for CM 1-10 During the Sampling Period: March 7, 1991 Through January 7, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	480	397	449	576	691
Sulfate	358	318	374	430	516
Chloride	324	192	239	389	467
Conductivity	2341	1950	2050	2810	3372
Alkalinity	304	269	305	365	438

Number of biweekly samples: 49
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 19

Excursion Monitoring Data Obtained for CM 1-11 During the Sampling Period: March 7, 1991 Through January 7, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	410	388	438	492	590
Sulfate	380	350	393	456	547
Chloride	189	174	215	227	272
Conductivity	2015	1920	1960	2418	2902
Alkalinity	291	240	308	350	420

Number of biweekly samples: 49
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 20

Excursion Monitoring Data Obtained for CM 2-1 During the Sampling Period: April 2, 1992 Through December 24, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	416	396	440	500	600
Sulfate	348	328	372	418	501
Chloride	253	175	223	304	364
Conductivity	2340	1870	2010	2808	3370
Alkalinity	296	299	310	356	428

Number of biweekly samples: 46
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 21

Excursion Monitoring Data Obtained for CM 2-2 During the Sampling Period: April 2, 1992 Through December 24, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	403	399	473	484	580
Sulfate	335	319	366	402	482
Chloride	215	178	252	259	311
Conductivity	2133	1860	2080	2560	3072
Alkalinity	294	277	314	353	423

Number of biweekly samples: 46
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 22

Excursion Monitoring Data Obtained for CM 2-3 During the Sampling Period: April 9, 1992 Through December 30, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	405	398	426	487	585
Sulfate	338	319	364	406	487
Chloride	199	174	197	239	287
Conductivity	2118	1860	1890	2542	3050
Alkalinity	306	287	314	368	442

Number of biweekly samples: 44
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 23

Excursion Monitoring Data Obtained for CM 2-4 During the Sampling Period: April 9, 1992 Through December 30, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	410	398	452	492	590
Sulfate	345	322	360	415	498
Chloride	220	175	249	265	318
Conductivity	2138	1860	2080	2566	3079
Alkalinity	305	300	319	367	441

Number of biweekly samples: 44
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 24

Excursion Monitoring Data Obtained for CM 2-5 During the Sampling Period: April 9, 1992 Through December 30, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	445	398	473	535	642
Sulfate	350	325	352	421	505
Chloride	266	176	259	320	384
Conductivity	2356	1860	2130	2828	3394
Alkalinity	340	289	319	408	490

Number of biweekly samples: 44
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 25

Excursion Monitoring Data Obtained for CM 2-6 During the Sampling Period: April 9, 1992 Through December 30, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	403	400	436	484	580
Sulfate	354	331	388	425	510
Chloride	205	178	217	246	295
Conductivity	2184	1860	2060	2621	3145
Alkalinity	300	298	338	360	432

Number of biweekly samples: 44
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 26

Excursion Monitoring Data Obtained for CM 2-7 During the Sampling Period: April 9, 1992 Through December 30, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	405	399	425	486	583
Sulfate	368	335	381	442	530
Chloride	199	177	190	239	287
Conductivity	2124	1880	1930	2549	3059
Alkalinity	303	297	315	364	436

Number of biweekly samples: 44
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 27

Excursion Monitoring Data Obtained for CM 2-8 During the Sampling Period: April 9, 1992 Through December 30, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	430	405	446	516	619
Sulfate	368	344	372	442	530
Chloride	249	178	229	299	359
Conductivity	2311	1890	2080	2774	3329
Alkalinity	298	291	310	358	429

Number of biweekly samples: 44
Note. Chemical values are in ppm, Conductivity is in umhos

Table 28

Excursion Monitoring Data Obtained for CM 2-10 During the Sampling Period: April 9, 1992 Through December 23, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	416	410	481	500	600
Sulfate	371	341	430	446	536
Chloride	209	183	240	251	301
Conductivity	2183	1910	2240	2620	3144
Alkalinity	265	269	319	365	438

Number of biweekly samples: 44
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 29

Excursion Monitoring Data Obtained for CM 3-2 During the Sampling Period: January 21, 1993 Through December 23, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	444	410	461	533	639
Sulfate	414	356	388	497	596
Chloride	200	186	212	241	289
Conductivity	1925	1930	2040	2310	2772
Alkalinity	305	295	313	367	441

Number of biweekly samples: 24
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 30

Excursion Monitoring Data Obtained for CM 3-3 During the Sampling Period: January 21, 1993 Through December 23, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	426	406	432	512	615
Sulfate	419	360	383	503	603
Chloride	199	183	196	239	287
Conductivity	1904	1900	1950	2285	2742
Alkalinity	290	280	308	349	419

Number of biweekly samples: 24
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 31

Excursion Monitoring Data Obtained for CM 3-4A During the Sampling Period: January 21, 1993 Through December 23, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	433	410	432	520	624
Sulfate	418	364	386	502	602
Chloride	195	184	196	234	281
Conductivity	1934	1930	1940	2321	2785
Alkalinity	291	295	295	350	420

Number of biweekly samples: 24
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 32

Excursion Monitoring Data Obtained for CM 3-5 During the Sampling Period: January 21, 1993 Through December 23, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	449	418	458	539	647
Sulfate	405	360	394	487	585
Chloride	220	187	214	265	318
Conductivity	1954	1940	2010	2345	2814
Alkalinity	300	295	310	361	433

Number of biweekly samples: 24
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 33

Excursion Monitoring Data Obtained for CM 3-6 During the Sampling Period: January 21, 1993 Through December 23, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	435	414	449	522	626
Sulfate	399	362	390	479	575
Chloride	208	182	198	250	300
Conductivity	1944	1930	1980	2333	2799
Alkalinity	305	290	309	367	441

Number of biweekly samples: 24
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 34

Excursion Monitoring Data Obtained for CM 3-7 During the Sampling Period: January 23, 1993 Through December 24, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	445	401	431	535	642
Sulfate	393	348	388	472	566
Chloride	194	179	198	233	279
Conductivity	1926	1930	1960	2312	2775
Alkalinity	309	290	310	371	445

Number of biweekly samples: 25
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 35

Excursion Monitoring Data Obtained for CM 3-8 During the Sampling Period: January 22, 1993 Through December 24, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	470	425	514	564	677
Sulfate	408	358	394	490	588
Chloride	241	196	317	290	348
Conductivity	2108	1970	2380	2530	3036
Alkalinity	293	290	312	352	422

Number of biweekly samples: 25
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 36

Excursion Monitoring Data Obtained for CM 3-9 During the Sampling Period: January 22, 1993 Through December 24, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	451	405	435	542	651
Sulfate	389	351	389	467	560
Chloride	200	183	194	241	289
Conductivity	1918	1910	1940	2302	2762
Alkalinity	293	290	310	352	422

Number of biweekly samples: 25
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 37

Excursion Monitoring Data Obtained for CM 3-10 During the Sampling Period: January 22, 1993 Through December 24, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	440	406	434	529	635
Sulfate	398	353	382	478	573
Chloride	193	176	194	232	278
Conductivity	1874	1910	1950	2249	2699
Alkalinity	295	298	310	355	426

Number of biweekly samples: 25
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 38

Excursion Monitoring Data Obtained for SM 1-1 During the Sampling Period: March 7, 1991 Through December 24, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	110	94	108	133	160
Sulfate	44	29	37	53	64
Chloride	12	3	9	15	18
Conductivity	500	380	470	600	720
Alkalinity	195	170	203	234	281

Number of biweekly samples: 74
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 39

Excursion Monitoring Data Obtained for SM 1-2 During the Sampling Period: March 7, 1991 Through December 24, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	150	122	136	180	216
Sulfate	60	57	64	72	86
Chloride	41	12	19	50	59
Conductivity	739	570	600	887	1064
Alkalinity	240	190	216	288	346

Number of biweekly samples: 74
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 40

Excursion Monitoring Data Obtained for SM 1-3 During the Sampling Period: March 7, 1991 Through December 24, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	148	97	127	178	213
Sulfate	43	39	46	52	62
Chloride	82	6	37	99	119
Conductivity	783	460	590	940	1128
Alkalinity	228	165	200	274	328

Number of biweekly samples: 74
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 41

Excursion Monitoring Data Obtained for SM 2-1 During the Sampling Period: April 9, 1992 Through December 30, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	135	122	130	163	196
Sulfate	53	49	53	64	77
Chloride	39	24	30	47	56
Conductivity	600	570	595	721	865
Alkalinity	211	186	200	254	305

Number of biweekly samples: 44
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 42

Excursion Monitoring Data Obtained for SM 2-2 During the Sampling Period: April 9, 1992 Through December 30, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	123	98	104	148	177
Sulfate	44	41	50	53	63
Chloride	44	7	12	53	64
Conductivity	840	470	495	1008	1210
Alkalinity	218	160	184	262	314

Number of biweekly samples: 44
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 43

Excursion Monitoring Data Obtained for SM 2-3 During the Sampling Period: April 9, 1992 Through December 30, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	128	121	127	154	184
Sulfate	53	46	56	64	76
Chloride	25	10	12	31	37
Conductivity	673	550	580	808	969
Alkalinity	214	199	217	287	344

Number of biweekly samples: 44
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 44

Excursion Monitoring Data Obtained for SM 3-2 During the Sampling Period: January 21, 1993 Through December 23, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	130	100	117	156	187
Sulfate	41	39	42	50	60
Chloride	28	4	15	34	40
Conductivity	559	460	530	671	805
Alkalinity	211	175	210	254	305

Number of biweekly samples: 24
Note. Chemical values are in Mg/L, Conductivity is in umhos

Table 45

Excursion Monitoring Data Obtained for SM 3-3 During the Sampling Period: January 21, 1993 Through December 23, 1993.

Excursion Indicator	Baseline Value	Minimum Value	Maximum Value	Multiple UCL	Single UCL
Sodium	119	98	113	143	171
Sulfate	45	38	44	54	65
Chloride	20	4	12	25	30
Conductivity	505	460	500	607	729
Alkalinity	205	170	184	247	297

Number of biweekly samples: 24
Note. Chemical values are in Mg/L, Conductivity is in umhos