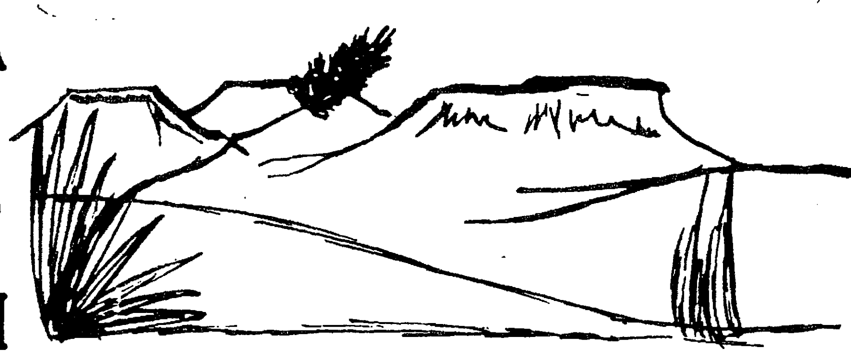
Attachment 1

Gallaher and Cary (1986)

IMPACTS OF URANIUM MINING ON
SURFACE AND SHALLOW GROUND WATERS
GRANTS MINERAL BELT, NEW MEXICO



HEALTH
& ENVIRONMENT
department

EID/GWH-86/2

IMPACTS OF URANIUM MINING ON SURFACE AND SHALLOW GROUND WATERS GRANTS MINERAL BELT, NEW MEXICO

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EXECUTIVE SUMMARY

The Grants Mineral Belt in northwest New Mexico has been, from the 1950s until recently, the major uranium-producing region in the United States. In 1980, there were 40 operating and about 100 abandoned or inactive uranium mine sites in the area. Because of the potential for regional-scale water quality impacts from these activities, the U.S. Environmental Protection Agency funded a multi-year study to evaluate the severity of the impacts and to assess the need for water pollution regulatory changes.

PRINCIPAL GOALS OF THE STUDY

- To describe and assess impacts of disposal of uranium mining wastes on the quality of surface waters and shallow ground waters in the Grants Mineral Belt.
- To evaluate strategies for controlling water pollution from uranium mining sources in the study area.

PRINCIPAL POTENTIAL SOURCES OF CONTAMINATION

Large volumes of liquid and solid wastes are disposed of on the land surface through the mining process. These wastes contain generally low levels of metals and radioactivity, but they nonetheless may be harmful to humans or livestock if ingested over a sustained period of time.

Mine Dewatering Effluents

Because most uranium ore deposits in the Grants Mineral Belt are below the regional water table, ground water must be controlled by pumping to prevent mines from flooding. Both underground and surface mines discharge this water to natural watercourses that are normally dry. Prior to its release, the discharged water (effluent) is treated to reduce the concentrations of radium, uranium, and suspended solids.

Potential impacts to water resources from such discharges are regional in scale. Continuous surface water flows from the mines may be sustained for distances as great as 60 miles. In 1980, a total length of more than 140 miles of naturally dry watercourses were continuously affected by Grants Mineral Belt discharges. The year-round presence of the effluents in the channels greatly has increased use of the water for livestock supply.

Mine Spoils Piles

Mining is done by excavating surface pits or underground shafts and tunnels to gain access to the ore. Waste rock and rock with uneconomical levels of uranium ore are stored at the surface as a waste pile. No reclamation is required or proposed at most mines, and wastes remain on the surface when mining ceases.

The potential for near-surface water quality problems to arise from the spoils is limited in time and area. Erosion of waste pile materials into watercourses largely occurs during periods of natural stormwater runoff. Because of the infrequency of such runoff events, the effects of the waste piles are more localized than those associated with the mine dewatering effluents. On the other hand, the contaminant concentrations associated with mine spoils pile runoff may be many of orders of magnitude greater than those associated with the effluents.

CONCLUSIONS

Degree of Contamination

- The analysis presented in this report reveals that discharge of mine dewatering effluents into surface watercourses and runoff from uranium mine spoils piles are significant water quality concerns.

- Uranium mine dewatering effluents have adversely affected surface water chemistry.

  - Affected surface waters contain elevated concentrations of gross alpha radioactivity, uranium, molybdenum, and selenium. These constituents may be found in effluents at concentrations exceeding natural levels by 100 times.

- Dewatering effluents have caused contamination of shallow alluvial aquifers.

  - Some alluvial ground waters have assumed the chemistry of dewatering effluents.

  - This is manifested in changes in the concentrations of total dissolved solids, gross alpha activity, uranium, selenium, and molybdenum, which may exceed natural levels by 10 to 40 times.

- Uranium mine spoils contribute pollutants to surface waters.

  - Spoils from many abandoned and active mines are eroding directly into surface drainages.

  - Mine spoils generate stormwater runoff that contains concentrations of gross alpha and beta activity, uranium, radium-226, lead-210, molybdenum, as well as other metals, that may exceed concentrations in natural runoff by up to 200 times.

- Open pit mining, exclusive of the waste piles generated, has caused increases in dissolved concentrations of gross alpha activity, uranium, and radium-226 in surface water.

- Treatment to remove radium-226 from raw minewaters prior to discharge has been generally effective, but the resulting treatment pond sludges are extremely contaminated with radium-226.

  - If improperly disposed of, these sludges may be eroded into watercourses where they could significantly impact water quality.

Potential Impacts of Contamination on Water Uses

- The chemical quality of much surface water and shallow ground water is inconsistent with regional water uses as a result of disposal of wastes from uranium mines in the Grants Mineral Belt.

  - Locally, precipitation runoff from uranium mine spoils is not suitable for ingestion by livestock; such waters may contain elevated concentrations of gross alpha activity, radium-226, arsenic, cadmium, lead, selenium and vanadium.

  - Treated mine dewatering effluents may not be suitable for livestock watering, irrigation, or domestic water supply due to consistently high selenium and radium-226, and sometimes to total dissolved solids, molybdenum, arsenic, barium, sulfate, and vanadium.

  - Shallow alluvial ground water along San Mateo Creek in the Ambrosia Lake Mining District has been chemically impaired for use in irrigation, livestock watering, and domestic supply because of elevated concentrations of molybdenum, selenium, and gross alpha activity. Along the Puerco River in the Church Rock Mining District, data are less conclusive, but similar impacts are suggested.

Regulatory Authority

- Two regulatory and administrative tools are presently available to the EID to improve controls on uranium mine dewatering effluents.

  - The existing National Pollutant Discharge Elimination System (NPDES) permitting program, run by the U.S. Environmental Protection Agency (EPA) with state certification, is probably the best available mechanism to control mine dewatering effluents. However, the NPDES is presently not as effective as it might be in controlling these effluents.

  - The New Mexico Regulations for Discharge to Surface Waters are not now an effective alternative for control of mine dewatering effluents because these regulations do not specify limits for any trace element or radionuclide.

- Surface water contamination resulting from uranium mine waste piles may be addressed by several legal means, although most are of uncertain applicability.

  - Presently, the best option for control of uranium mine waste piles is that portion of the New Mexico Water Quality Control Commission (WQCC) regulations governing disposal of refuse in a watercourse; this provision has precedent for such use.

  - Federal Superfund clean-up provisions may assist in reclamation of some of the more serious piles near population centers; other provisions of Superfund authorize EPA to compel cleanup of other sites and allow state suits for recovery of response costs and damages to natural resources. Current applicability of the federal Resource Conservation and Recovery

Act (RCRA), the state Abandoned Mine Reclamation Fund, and the state Radiation Protection Regulations is limited.

- Minewater treatment pond sludges contain large concentrations of radium-226 and other radionuclides.

  - At present, regulation of minewater sludges is inadequate.

RECOMMENDATIONS

- The EID should coordinate with the EPA so that new and renewal NPDES permits for uranium mine dewatering effluents in New Mexico include numeric effluent limits for radium-226 and other constituents that affect downstream uses of these waters.

- The New Mexico Regulations for Discharge to Surface Waters should be amended to include comprehensive numeric limits for constituents regulated by NPDES and for other constituents necessary to protect water quality for domestic and agricultural uses.

- Removal or stabilization should be pursued for the largest uranium mine waste piles eroding directly into surface drainages. The EID should require these actions based upon the provision in the WQCC Regulations regarding disposal of refuse in watercourses.

- If necessary, reclamation of uranium mine waste piles could also be pursued under Superfund or the Abandoned Mine Reclamation Fund.

- Waste piles generated by future uranium mining activity must be regulated. This may be accomplished by EPA through the Resource Conservation and Recovery Act. If not, the EID should pursue amendment of the New Mexico Radiation Protection Regulations to extend their applicability to mine wastes.

- The EID should pursue control of minewater treatment sludges. If RCRA regulations are found to be not applicable, then EID should seek to amend the New Mexico Radiation Protection Regulations to control these sludges.

PREFACE

This assessment was initiated to gather technical and legal inforamtion for regional water quality planning purposes. As a result, much of the study design focused on describing potential water quality impacts that may be common to most of the uranium mining industry. Much more detailed work would have to be performed before comprehensive impacts of a specific mining facility could be identified.

In a similar sense, in areas where ground water contamination was detected, no attempts were made to delineate the entire areal extent of contamination. Therefore, no estimates are made of the total volume of waters affected by industry activities.

Information in this report pertaining to regulatory requirements (Chapters X and XI) reflects conditions that existed at the end of 1985.

ACKNOWLEDGEMENTS

This study was undertaken by the New Mexico Environmental Improvement Division through grants under section 208 of the Federal Clean Water Act from the U.S. Environmental Protection Agency.

The authors extend their gratitude to the Navajo Tribe, the U.S. Bureau of Land Management, and to the Lee, Otero, Roundy and Sandoval families for their cooperation and assistance in allowing the EID to drill monitor wells and sample ground water on their properties. Numerous individuals in the uranium industry kindly provided their cooperation, criticisms and suggestions to the EID during the course of field and office visits.

Many EID personnel assisted in the field work, and report preparation and review. Particularly generous with their expertise and support were Mr. Don Ditmore, Mr. Steven Oppenheimer and Dr. Douglas Schneider. Don was present on many sampling trips and performed all of the computer data entry and STORET statistical analyses. Steve was involved in most of the drilling activities. Doug's five years of contributions to the overall project direction and, finally, to the report writing and editing can hardly be emphasized enough. Chapter IX was prepared entirely by Dr. Schneider. Mr. Pat Longmire is also acknowledged for his assistance in interpreting the geochemical computer modeling results.

Appreciation is expressed to the EID professionals in the Milan and Gallup field offices who assisted in collecting stormwater runoff samples.

We are greatly indebted to Ms. Patsy Sandoval for word processing this report and to Ms. Gigi Bayless for drafting the figures.

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FOREWORD

The New Mexico Environmental Improvement Division's regional assessment of uranium mining impacts is an outgrowth of active public and governmental interest in the environmental consequences of uranium industry activities in the Grants Mineral Belt in the mid-1970's. This interest was sparked by a joint U.S. Environmental Protection Agency-New Mexico Environmental Improvement Agency investigation of water quality. After the results of this state-initiated investigation were published by the U.S. Environmental Protection Agency in September 1975 as **Water Quality Impacts of Uranium Mining and Milling in the Grants Mineral Belt,** New Mexico governmental agencies assessed their knowledge of environmental, economic, and social conditions in the Grants Mineral Belt and identified areas for further research. More specifically, the Environmental Improvement Agency established its Grants Mineral Belt Task Force in 1976 to examine the wide range of environmental concerns associated with uranium development, including impacts on air and water quality, radiation and toxic chemical pollution, the adequacy of regulatory authority, and problems related to expanding population within the region.

Investigation of environmental impacts of the uranium industry was made a priority by the Environmental Improvement Agency in July 1976. One of the areas identified for further research by the Grants Mineral Belt Task Force was the water quality impacts of discharged minewaters (the mines lie within aquifers) on surface watercourses and underlying shallow alluvial aquifers. The decision was made to study such impacts with funding from the grant for water quality planning then being awarded to New Mexico under Section 208 of the federal Clean Water Act. Ultimately, study of water quality impacts was carried out under all three Section 208 grants received by the New Mexico Environmental Improvement Agency (after April 1978, the Environmental Improvement Division) supplemented with state funds.

The regional assessment was designed and initiated by John G. Dudley. After he left the agency in 1980, the project was carried to its conclusion by Bruce Gallaher, joined later by Steven Cary. Credit must be given to Bruce Gallaher and Steven Cary for their reevaluation on the scope and direction of the project. As a result information on runoff was collected both from areas unaffected by uranium mining and from mine waste piles and increased emphasis was given to collection data on total contaminant concentration as opposed to dissolved contaminant concentrations.

The major focus on the assessment is on the minewaters discharged to surface watercourses. The effect these have had on altering ephemeral watercourses to perennial, though artificially maintained, streams is examined as in the relation between surface flow and recharge of underlying shallow, alluvial aquifers. The discharge minewaters are characterized chemically and chemical impacts on both surface water quality and on alluvial ground water quality are assessed.

The regional assessment of uranium mining impacts, however, is much more than simply a study focused on mine dewatering. In order to evaluate the significance of dewatering, natural water quality (i.e., water quality unaffected by uranium industry mining or milling) had to be characterized. Sampling was not limited to perennially flowing streams and ground waters. As the water natural in such Grants Mineral Belt watercourses as the Puerco River, Arroyo del Puerto, and San Mateo Creek results from runoff, storms and snowmelt, natural runoff was sampled as well. In the Grants Mineral Belt, though, runoff may also result from areas affected by the uranium industry. Since mine waste piles have a potentially substantial effect on stream quality, characterization of natural runoff led to characterization of mine waste pile quality.

Field work for the regional assessment was performed over the period from 1977 to 1982. During the period from 1978 to 1980, processed uranium production peaked in the Grants Mineral Belt. Production declined in 1981, though it was still substantially higher than pre-1978 production, but by 1982 production had declined considerably to levels similar to the mid-1950's when the industry started in New Mexico. today, only the Homestake Mining Company mines, the Kerr-McGee (Quivera Mining Co.) Ambrosia Lake mine, and the Gulf Mt. Taylor mine are discharging minewaters in the Ambrosia lake mining district. Similarly, the only dewatering in the Church Rock district is from the Kerr-McGee (Quivera Mining Co.) Church Rock mines. No other mines in the Grants Mineral Belt are still dewatering.

That this assessment has been brought to fruition is the result of collective efforts of many individuals. Officials in both the regional office in Dallas and the Washington, D.C. headquarters of the U.S. Environmental Protection Agency have given support and encouragement. David Miller of Geraghty and Miller, Inc. provided guidance when the direction of the assessment was being reassessed. But more importantly this assessment represents the efforts of too many present and former members of the Environmental Improvement Division to acknowledge then all individually, or perhaps even to remember all their efforts. At the same time, it would not be fair not to acknowledge those individuals whose efforts have contributed most prominently to this assessment. Besides the already mentioned Steven Cary, John G. Dudley, and Bruce Gallaher, these include Catherine Callahan, Patrick Longmire, Charles Nylander, Steven Oppenheimer, Michael Snavely, and Richard L. Young. Lastly I coordinated the production of the final report and contributed substantially to its writing and editing and thus must accept part of the responsibility for the contents.

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Water Quality Planning Section
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List of Abbreviations

EIB, NM EIB	New Mexico Environmental Improvement Board
EID, NM EID	New Mexico Environmental Improvement Division
EPA, U.S. EPA	U.S. Environmental Protection Agency
NAS/NEA	National Academy of Sciences-National Academy of Engineering
WQCC, NM WQCC	New Mexico Water Quality Control Commission
mg/l	milligrams per liter
ug/l	micrograms per liter
pCi/l	picocuries per liter
cfs	cubic feet per second
TDS	total dissolved solids
TSS	total suspended solids
Ca	calcium
K	potassium
Mg	magnesium
Na	sodium
Cl	chloride
CO_3	carbonate
HCO_3	bicarbonate
SO_4	sulfate
As	arsenic
Ba	barium
Cd	cadmium
Mo	molybdenum
Pb	lead
Se	selenium
U,U-natural	uranium, natural uranium
V	vadadium
Zn	zinc
gross alpha	gross alpha particle activity
gross beta	gross beta particle activity
Pb-210	lead-210
Po-210	polonium-210
Ra-226, Ra-228	radium-226, radium-228
Th-228, Th-230, Th-232	thorium-228, thorium-230 thorium-232

I. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

A. Uranium mine dewatering effluents have altered surface water chemistry.

Uranium mine dewatering has transformed ephemeral arroyos into perennial streams. In natural runoff, trace elements and radionuclides are primarily associated with suspended sediments and precipitates. In treated minewaters, trace elements and radionuclides are usually present in the dissolved form. Dissolved gross alpha activity in dewatering effluents exceeds levels in natural runoff by up to 100 times. Molybdenum, selenium, and uranium are consistently higher in minewaters than in natural runoff. Arsenic, barium, and vanadium are occasionally elevated as well.

Uranium, molybdenum, selenium, and principal dissolved salts generally are not attenuated in channels that receive minewaters; instead they remain in solution. In drainages that are relatively sediment-free such as Arroyo del Puerto, radium-226 and lead-210 tend to stay in solution. However, most regional watercourses have plentiful sediment; under these circumstances radium-226 and lead-210 in minewaters are usually lost from solution shortly after their release. In sediment-rich streamflows, sediments carrying minewater contaminants are diluted by clean sediments and levels of radioactivity associated with arroyo sediments eventually become indistinguishable from natural conditions.

B. Uranium mine dewatering effluents have contaminated shallow alluvial ground waters.

Infiltration of large volumes of dewatering effluents has changed the chemistry of shallow alluvial ground waters. In reaches where stream-bottom leakage is great, alluvial ground waters now bear a stronger chemical resemblance to minewaters than to natural surface waters. This change is particularly evident in terms of general ionic chemistry and total dissolved solids. Trace minewater constituents that remain in solution, such as uranium, selenium, and molybdenum, are also found in shallow ground waters in concentrations approaching those of undiluted minewaters. Alluvial aquifers recharged primarily by dewatering effluents have thus assumed the chemistry of the minewaters.

Dewatering effluents have had these effects on alluvial ground water throughout the GMB. Locally, concentrations of uranium, molybdenum, selenium, and gross alpha activity exceed natural levels by 10 to 40 times. Ground water degradation is most pronounced in the Ambrosia Lake Mining District because most mine dewatering has occurred there, the chemical quality of minewaters is poor, and alluvium in local drainages promotes infiltration. Effluents have degraded the Puerco River alluvium with trace elements and radionuclides, but not to the same degree as in Ambrosia Lake. Limited impacts are attributable to low infiltration rates along the Puerco River.

Contaminant concentrations in shallow ground water may be mitigated through dilution, adsorption, cation exchange, and chemical equilibrium. Because uranium, molybdenum and selenium all tend to form anions in solution, these constituents are mobile in the subsurface and their concentrations are unlikely to be reduced except by dilution with cleaner water. Moreover, geochemical computer modelling suggests that uranium concentrations in regional alluvial aquifers will not decline solely as a result of long term chemical equilibrium adjustments. In contrast, radium-226 forms a cation in solution. Consequently, it is attenuated so effectively in regional alluvium that infiltration of minewaters has increased the dissolved radium-226 content of shallow ground water only by about 0.1 pCi/l.

C. Uranium mine spoils piles adversely affect the quality of surface waters.

Ten to 20 abandoned mines, as well as some large active mines, have waste piles that are eroding directly into local drainage channels. Although suspended sediment concentrations in mine-waste runoff are similar to natural sediment loads, mine-waste runoff contains contaminants in concentrations that exceed natural levels by up to several hundred times. Uranium mine waste piles are major contributors of heavy metals to surface waters; uranium and molybdenum are of the greatest regional concern, while arsenic, selenium, and vanadium may be locally elevated. Of even greater significance are several radioactivity parameters: gross alpha activity in mine waste runoff exceeds natural activity by up to 200 times; levels of natural uranium and radium-226, two major alpha emitters, exceed natural runoff levels by over 100 times; and gross beta activity and its chief contributor, lead-210, are also far in excess of natural runoff levels. In spite of the high contaminant concentrations in waste-pile runoff, however, the limited duration of these runoff events moderates the potential for regional scale contamination to occur.

Open pit mining, exclusive of waste piles, has caused degradation of water quality in the perennial Rio Paguate. The greatest increases in dissolved concentrations were exhibited by radioactive constituents: gross alpha activity, radium-226, and natural uranium. There were no statistically significant increases in dissolved trace element concentrations, except for uranium. Impacts on the Rio Paguate of stormwater runoff from open pit mine waste piles was not evaluated, but is probably similar to the effects identified at other waste piles.

D. Widespread treatment of raw minewaters to remove radium-226 has been generally effective in improving the quality of minewater effluents, but the resulting treatment pond sludges are extremely contaminated.

Raw minewaters may contain elevated concentrations of several constitutents, such as gross alpha and beta activity, radium-226, lead-210, uranium, molybdenum, selenium, sulfate, total dissolved solids, and occasionally barium, arsenic, and vanadium. Treatment of these waters through coagulation and settling reduces concentrations of radium-226 and uranium by many fold. However, large influxes of dissolved radium-226 may be introduced to surface waters during treatment process failures. Moreover, sludges which accumulate in minewater treatment pond bottoms are highly concentrated in radium-226, and may require special disposal practices.

E. As a consequence of uranium mining in the GMB, the chemical quality of much surface and ground water is inconsistent with regional water uses.

Stormwater runoff from uranium mine waste piles is definitely not suitable for watering livestock. Total unfiltered concentrations of arsenic, cadmium, lead, selenium, vanadium, gross alpha activity and radium-226 are not consistent with ingestion of this water by livestock. The quality of natural runoff in the Ambrosia Lake Mining District admittedly is poor, but the quality of mine waste pile runoff is worse. This conclusion is also expected to apply in the Church Rock mining district.

While certain radioactivity parameters are elevated in the Rio Paguate below the Jackpile open pit mine, overall water quality both upstream and downstream of the mine is consistent with livestock use.

Treated minewaters may not be suitable for livestock watering, irrigation or domestic water supply. The chief constituents rendering minewaters unsuitable for livestock watering are selenium and radium-226. Principal constituents making minewaters undesirable for irrigation include selenium, radium-226, molybdenum, and total dissolved solids. Minewaters are generally unsuitable for domestic water supply because of elevated levels of selenium, radium-226, and total dissolved solids. Other constituents, such as arsenic, barium, sulfate, and vanadium, may be problematic locally. In general, treated minewaters in the Ambrosia Lake District are of poorer quality than those in the Church Rock District.

The shallow alluvial aquifer along San Mateo Creek has definitely been chemically impaired for use in irrigation, watering of livestock, or domestic water supply. Molybdenum, selenium, and gross alpha activity are found at high enough concentrations to render this water unsuitable. Along the Puerco River, conclusions are less obvious because the alluvium is less permeable and a uranium mill tailings spill has obscured some minewater impacts. Nevertheless, selenium and molybdenum levels in one well suggest that ground water uses along the Puerco River may be impaired.

F. Several regulatory tools, in place or anticipated, may be useful in controlling uranium mining impacts on regional water resources.

Appropriate water pollution control statutes are the federal Clean Water Act (CWA) and the New Mexico Water Quality Act (WQA). Other statutes that may bear on the effort to protect water resources in the GMB include the New Mexico Radiation Protection Act (RPA), the federal Resource Conservation and Recovery Act (RCRA), the federal Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and the New Mexico Abandoned Mine Reclamation Act (AMRA).

The National Pollutant Discharge Elimination System (NPDES), authorized by the CWA, has not yet proved to be an totally effective means to regulate minewater discharges. First, key minewater constituents, such as selenium and molybdenum are not covered. Second, legal challenges by mine operators have caused many permits to be temporarily stayed, during which time they are unenforceable. Technically, the EID can add parameters to NPDES permits via the state certification process. However, development of limitations for toxic trace elements in minewater discharges is hampered by state surface water quality standards and procedures that are technically burdensome and of uncertain applicability.

State of New Mexico regulations, promulgated under the Water Quality Act, have also been ineffective in controlling minewater discharges. Virtually all key minewater constituents, including uranium and radium-226, have remained uncontrolled under these regulations.

Control of contamination by solid mine wastes, including pond sludges, may be best achieved through application of regulations promulgated under the Water Quality Act. One provision of this Act prohibits disposal of refuse in a natural watercourse. Further, this provision has precedent for use in compelling cleanup of molybdenum and copper mine wastes.

Uranium mine wastes are not adequately covered by the Abandoned Mine Reclamation Act, the Radiation Protection Act or the Resource Conservation and Recovery Act. The AMRA will probably not be used in the immediate future for addressing water quality problems associated with uranium mines. However, both the Radiation Protection and the RCRA regulations could be amended to cover such materials. The EPA is presently studying just such proposed changes to the RCRA.

At the present time, the Comprehensive Environmental Response, Compensation and Liability Act is generally anticipated to have limited utility in ameliorating problems associated with uranium mine wastes in New Mexico, at least as far as Superfund-financed cleanups are concerned. However, CERCLA empowers U.S. EPA to enforce against site owners in order to compel cleanup. Also, CERCLA authorizes legal action by states against site owners in order to recover response costs and damage to natural resources.

RECOMMENDATIONS

Analysis of water quality impacts of uranium mining in the Grants Mineral Belt has revealed three major concerns that require regulatory or administrative action. In order of importance, these three major concerns are: discharge of mine dewatering effluents into ephemeral surface waters; stormwater runoff from unreclaimed uranium mine waste piles; and the potential for radionuclide-rich minewater treatment sludges to enter surface watercourses. Surface waters and associated alluvial ground waters are potentially affected. A variety of regulatory and administrative tools may be useful in addressing these concerns. Specific recommendations are discussed below.

A. Uranium Mine Dewatering Effluents

1. New and renewal NPDES permits for discharge of uranium mine dewatering effluents in New Mexico should incorporate stringent numeric effluent limitations for radium-226 and other parameters related to downstream uses of these waters. Such effluent limitations may be incorporated in permits through state certification by the EID or through case-specific analysis by the EPA. Needed effluent limitations can be developed only after consideration of present water uses, likelihood of future uses, and available water treatment technologies. Successful implementation of this recommendation will require coordination between the EID and the EPA.

2. The New Mexico Regulations for Discharges to Surface Waters should be substantially amended to serve as an effective mechanism for regulating discharges of uranium mine dewatering effluents to surface watercourses. Amendments should include comprehensive numeric discharge limits, not only for those chemical constituents regulated by NPDES, but for all constituents necessary to protect water quality for agricultural and domestic use.

B. Unreclaimed Uranium Mine Waste Piles

1. Removal or stabilization should be implemented at the largest uranium mine waste piles eroding directly into surface drainages. Priority sites include the Old San Mateo Mine near San Mateo Creek and the Jackpile-Paguate mine areas along the Rio Paguate. These actions could be based on the provision of the WQCC regulations regarding Disposal of Refuse (Section 2-201). State suits under CERCLA then should be used to recover cleanup costs. Alternatively, the EID could pursue cleanup using EPA enforcement under CERCLA, or using state resources acquired through state suits under CERCLA.

2. The EID should postpone action to regulate future uranium mine waste piles directly. It is anticipated that the EPA will decide during 1986 whether to regulate uranium mine waste under RCRA. Should the EPA decide not to regulate mine waste piles under RCRA, the EID should recommend that the EIB amend the New Mexico Radiation Protection Regulations to extend their applicability to mine waste piles.

C. Minewater Treatment Pond Sludges

1. If the U.S. EPA chooses not to regulate mine wastes under RCRA, the EID should recommend that the EIB amend the New Mexico Radiation Protection Regulations to control these sludges fully and effectively.

II. INTRODUCTION

2.1 BACKGROUND

Uranium mining and milling has been a major industry in New Mexico since the 1950s. The state has consistently led the country in total yearly production and has the largest amount of recoverable reserves. For the years 1966 through 1977, for example, New Mexico contributed an average of 46 percent of the total uranium concentrate production in the U.S. (Perkins, 1979). Nearly all the uranium production in New Mexico has come from the Grants Mineral Belt in the northwest quarter of the state, predominantly in McKinley and Cibola Counties (Figure 2.1).

As in most large-scale mining and milling operations, facilities in the Grants Mineral Belt produce significant quantities of liquid and solid wastes. While substantial volumes of the generated wastes are not hazardous, e.g., barren overburden and stockpiled topsoil, noteworthy volumes of certain waste products are potentially toxic (Kaufmann, Eadie and Russell, 1976).

Sources of potentially hazardous wastes in the Grants Mineral Belt include effluents from tailings ponds at active uranium mills, mine dewatering effluents discharged to surface waters directly or via settling lagoons, seepage from inactive mine and mill tailings piles, and runoff from nonpoint sources such as abandoned tailings piles, and natural uranium ore outcrops (Clark, 1974; Gallaher and Goad, 1981). These sources generate water that may contain relatively significant amounts of radionuclides, trace elements, and dissolved solids.

Comprehensive attempts to examine water quality impacts attributable to these wastes were not initiated until the mid-1970s. In 1975, the U.S. Environmental Protection Agency (EPA) and the New Mexico Environmental Improvement Division (EID) jointly conducted an intensive sampling survey of ground and surface waters in the Grants Mineral Belt (U.S. EPA, 1975).

This joint study identified sources of contamination, made preliminary evaluations of water quality impacts of contaminant sources, and developed recommendations on the need for future, more detailed study of this uranium producing area. The present regional assessment, conducted by the EID from 1978 through 1982, is an outgrowth of the 1975 joint study. Its focus is on the impacts of the uranium mining industry on the quality of surface waters and associated near-surface ground waters with specific focus on impacts resulting from dewatering of mines and runoff from mine waste piles.

2.2 OBJECTIVES OF THE REGIONAL ASSESSMENT

The present regional assessment has two major goals. The first goal of is to document the water quality effects of the uranium mining industry on surface waters and shallow ground-water systems. Specific objectives include

1. Characterization of the quality of natural surface waters in three principal mining districts of the the Grants Mineral Belt.

2. Characterization of the quality of natural shallow ground waters in two of three mining districts.

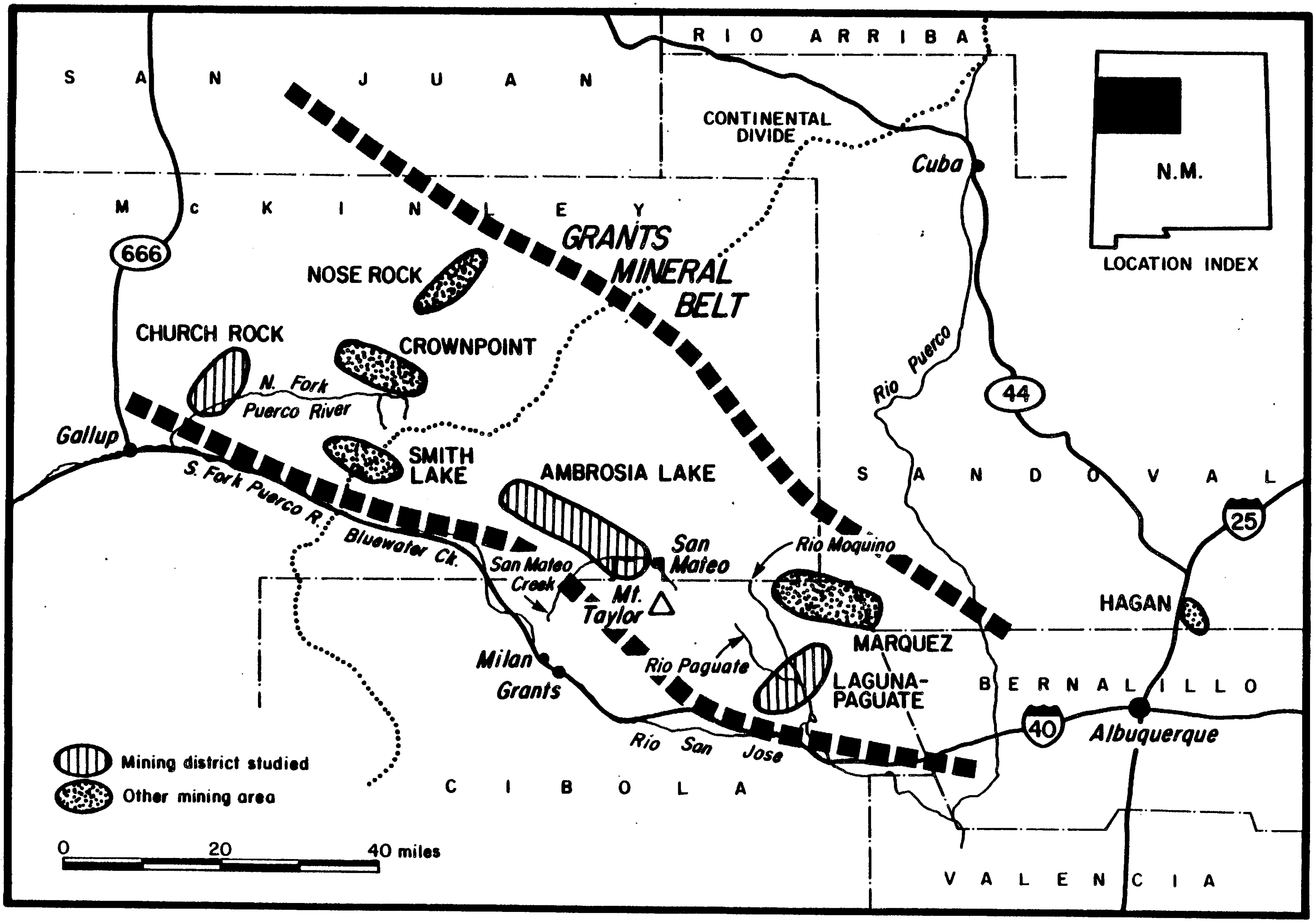


FIGURE 2.1 Major features of the Grants Mineral Belt

3. Evaluation of hydraulic relationships between surface waters and shallow ground waters in the two districts.

4. Characterization of chemical and hydraulic impacts of mine dewatering effluents on surface waters and shallow ground waters in the two districts.

5. Analysis of the vulnerability of shallow ground waters in the two districts to contamination from uranium industry activities.

6. Characterization of the quality of runoff from uranium mine waste piles.

The second goal of this assessment is to develop recommendations for the solution of identified problems. Strategies evaluated for controlling pollution from uranium mining sources are

1. Application of the federal National Pollutant Discharge Elimination System (NPDES) permits and of state surface and ground water quality regulations to address water pollution problems in the Grants Mineral Belt.

2. Use of the Resource Conservation and Recovery Act (RCRA) and the federal "Superfund" to mitigate uranium mining impacts on water quality.

3. Use of state radiation protection regulations as water pollution control tools.

4. Use of land treatment practices to prevent nonpoint source pollution from uranium mine waste piles.

2.3 AREAL DESCRIPTION

2.3.1. Location and Major Features

The Grants Mineral Belt is an approximately rectangular area in northwest New Mexico, encompassing portions of McKinley, Cibola, Sandoval, and Bernalillo counties. The Mineral Belt is approximately 100 miles long and 25 miles wide (Figure 2.1). The name "Mineral Belt" refers primarily to the uranium ore found in this area. Locations of uranium mining areas within the Mineral Belt are indicated on the map.

The Belt encompasses portions of the Laguna and Canoncito Reservations along its southeast extent, and a corner of the Navajo Reservation at its northwest extent. Interstate-40 lies to the south of the Mineral Belt; located along I-40 are the local population centers of Grants-Milan and Gallup. Smaller communities in the area include Crownpoint, San Mateo, and Laguna. Just north of the Grants Mineral Belt is Chaco Canyon, a National Monument noted for its ancient pueblo ruins.

Major topographic features in the area include the Zuni Mountains southeast of Gallup, the Cebolleta Mountains in the southeast corner of McKinley County, and Mount Taylor northeast of Grants. The Continental Divide cuts approximately through the middle of the Belt, with stream courses to the east (e.g., Rio Paguate, Rio Moquino, and San Mateo Creek) being part of the Rio Grande drainage and stream courses to the west (e.g. Puerco River, and Coyote Wash) part of the Colorado River drainage. Characteristic landforms include rugged mountains, broad, flat valleys, mesas, cuestas, rock terraces, steep escarpments, canyons, lava flows, volcanic cones, buttes, and arroyos.

2.3.2. Climate and Vegetation

The climate in the region is arid to semiarid. Annual precipitation is 20-to-30 inches in the mountain areas and 8-to-10 inches in the lower areas. The majority of precipitation occurs in the summer as brief, intense thunderstorms. Mountain areas usually receive significant amounts of snow in the winter. Evaporation exceeds precipitation throughout the region.

Potential evapotranspiration is more than 30 inches of water in an average year. Because less than 17 inches of precipitation on the average is received annually, there is a large net water deficit. Although small water surpluses occur in winter (December thru February), large water deficits are incurred during the remainder of the year. The deficit is greatest during the warm growing season months of June through September.

Vegetation of the region is typical of that of other semiarid climates of the Southwest. Most of the low-lying area is grassland with some cacti and yucca. Pinon and juniper are the dominant trees found on upland and north-facing slopes. Ponderosa pines and firs are found in the high mountain areas. In much of the valley areas, vegetation is insufficient to prevent erosion. Riparian vegetation along stream courses is limited; where it does occur, it consists primarily of cottonwood and salt cedar trees.

2.3.3. Geology

The Belt lies along the southern edge of the San Juan Basin, which is in the eastern part of the Colorado Plateau physiographic province. It is a region of scarped tablelands with broad valleys, and local canyons cut in Mesozoic and younger sedimentary rocks (Stone and others, 1983). The rocks are comprised principally of alternating shales and sandstones and some limestones.

Primary structural geologic features in the Grants Mineral Belt area are the Chaco Slope, Zuni Uplift, and Acoma Sag (Figure 2.2). Along the Chaco Slope, Cretaceous and Tertiary rocks out crop. Mesozoic and Upper Palezoic sediment and Precambrian igneous and metamorphic rocks are exposed in the Zuni Uplift (Stone and others, 1983). These strata dip to the northeast toward the basin axis. Figure 2.3 is a cross-section of the San Juan Basin; the Grants Mineral Belt falls in the region between the southwest edge and Crownpoint. Figure 2.4 is a stratigraphic column of the underlying geologic formations in the principal mining districts.

Of significance to this study is the Morrison Formation, of Upper Jurassic age. In descending order, it consists of the Brushy Basin member, the Westwater Canyon member, and the Recapture member. The Westwater Canyon member is host to the major uranium ore deposits and also to a major aquifer of the Grants Mineral Belt. It consists of interbedded fluvial arkosic sandstone, claystone, and mudstone. Its average thickness is 250 feet, but it thins to 100 feet southward and eastward. The Brushy Basin member, which overlies the Westwater, consists of a relatively impervious shale. Included in the Brushy Basin member, is the Jackpile Sandstone which bears the uranium ore body that is mined near Laguna and the Poison

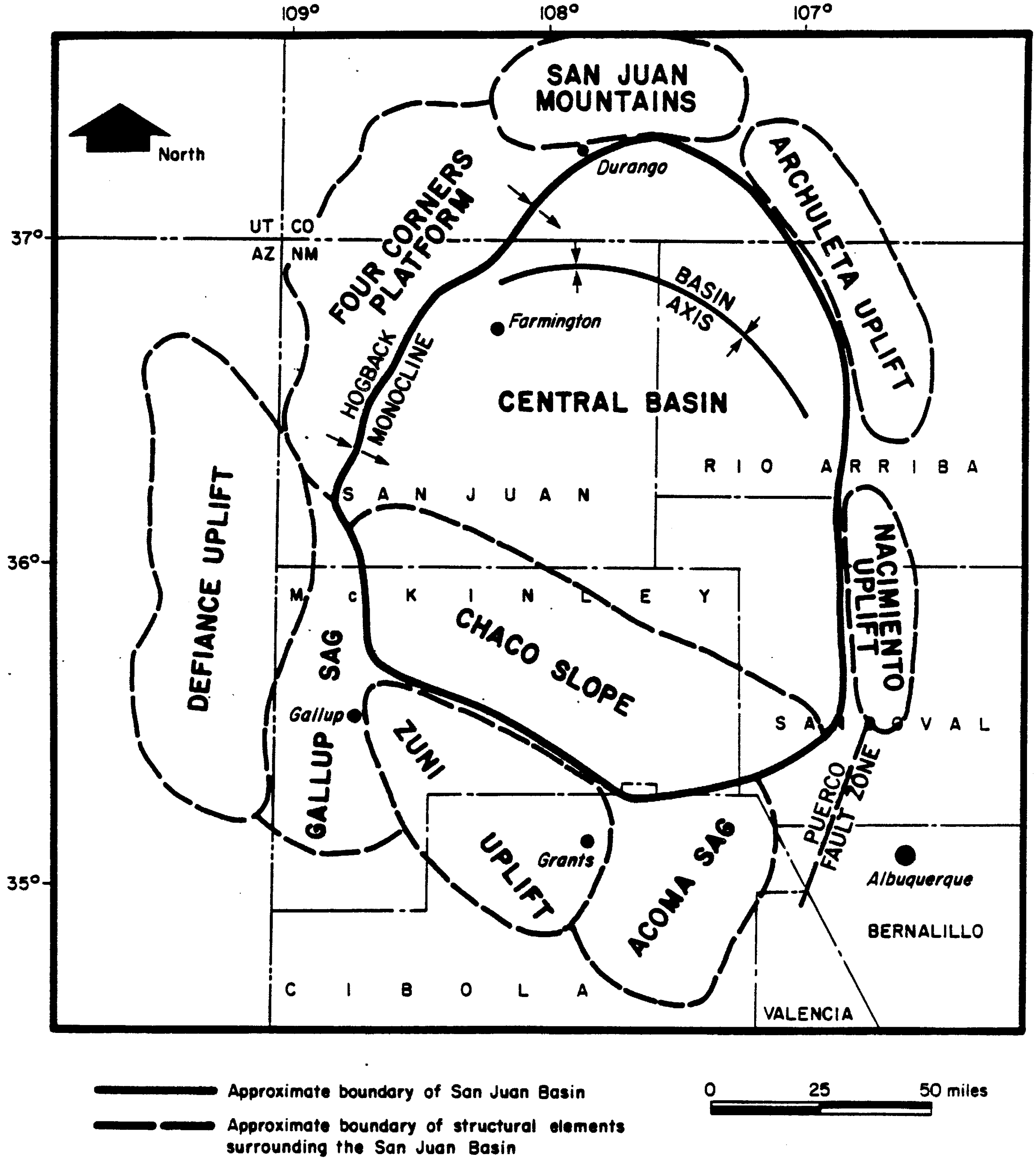


FIGURE 2.2 Location of the San Juan Basin and surrounding structural elements (after U.S. Dept of the Interior, 1980).

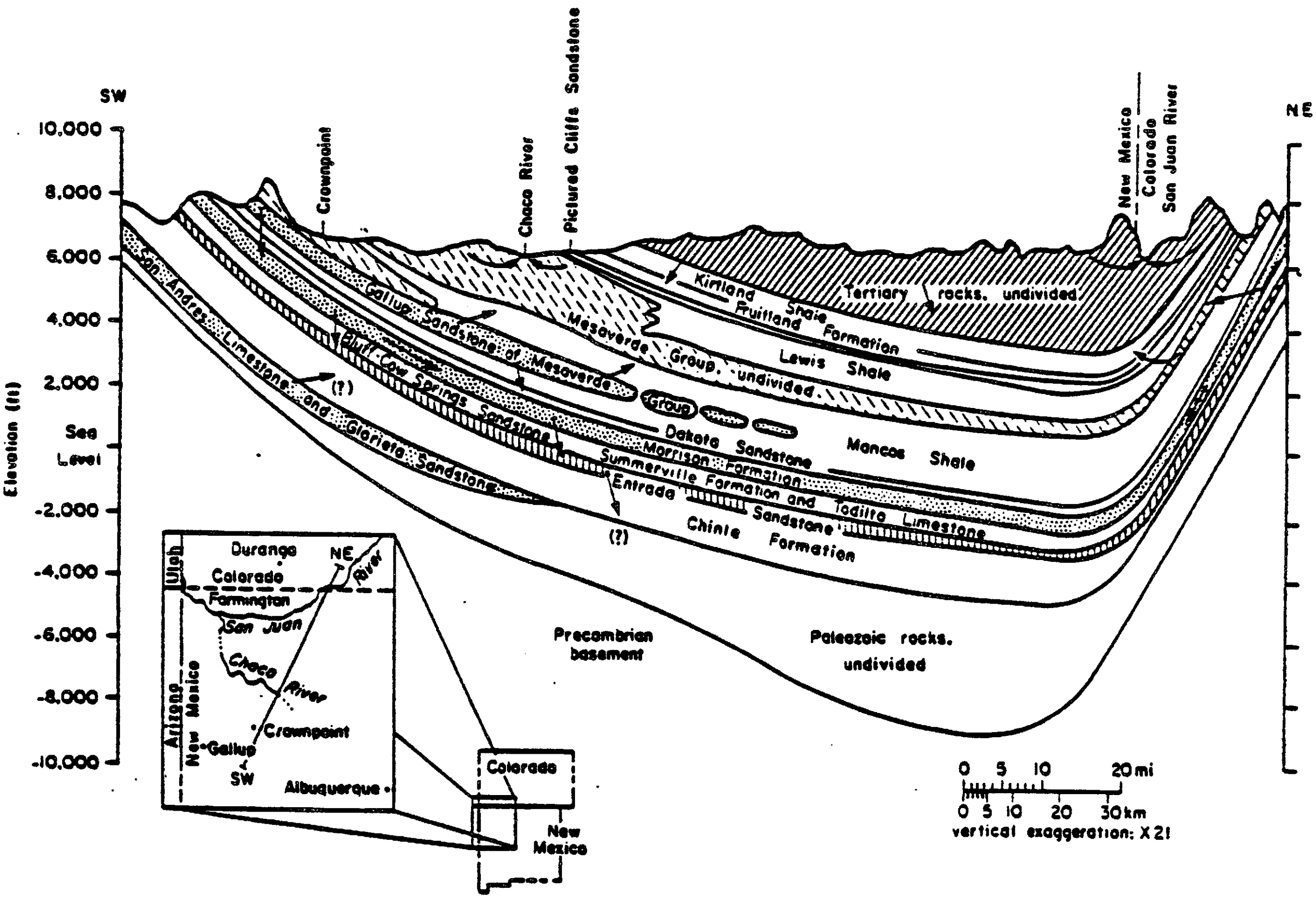


FIGURE 2.3 Generalized hydrogeologic cross-section of the San Juan Basin, showing major aquifers(stippled), confining beds (blank), and directions of ground-water flow (arrows) (after U.S. Dept. of the Interior, (1980).

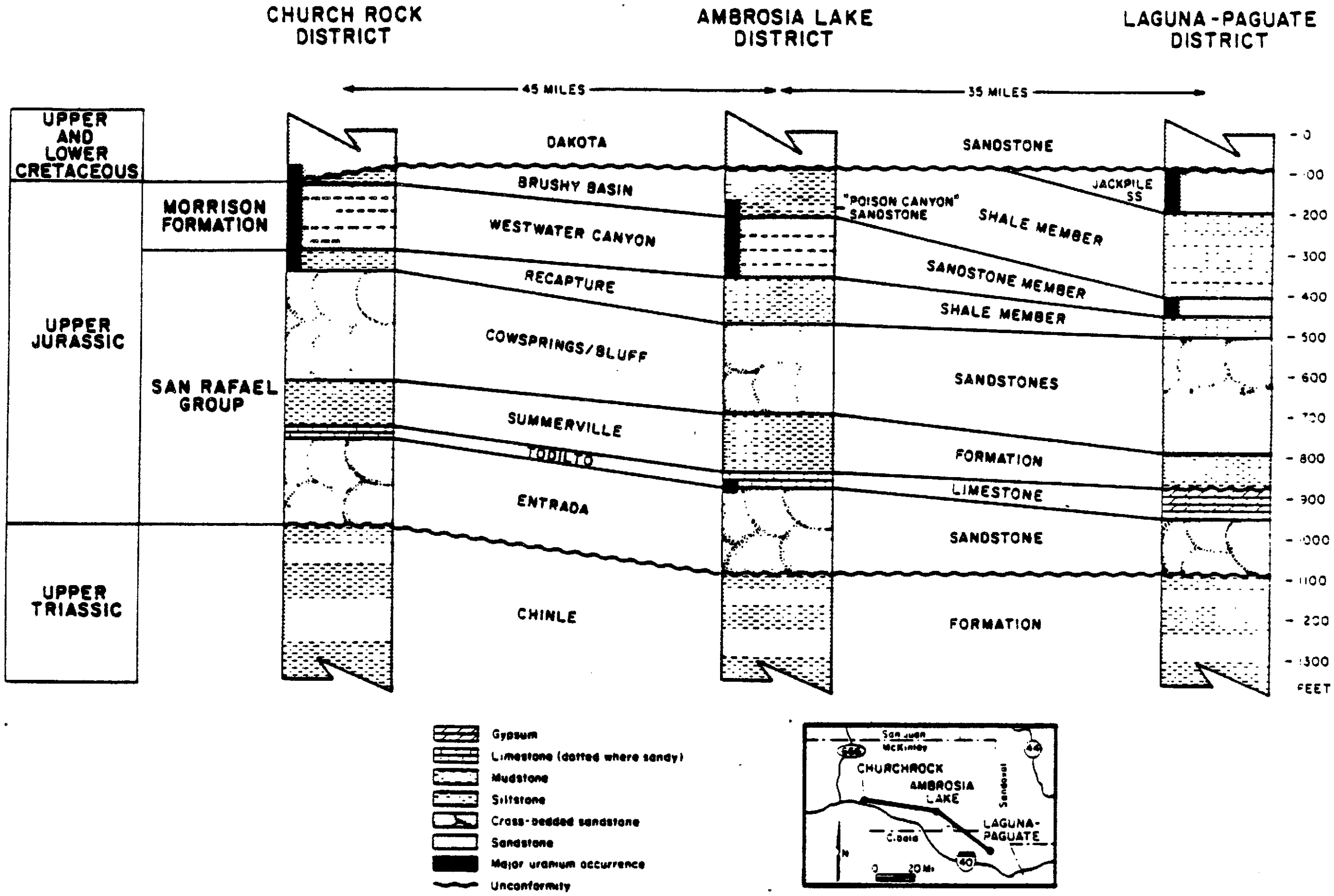


FIGURE 2.4 Stratigraphic sections of the Church Rock, Ambrosia Lake, and Laguna-Paguate mining district (after N.M. Energy and Minerals Dept., 1984).

Canyon Sandstone which bears uranium that is mined near Grants. The average thickness of the Brushy Basin member is 185 feet; toward the southwest part of the San Juan Basin, in the vicinity of Gallup, the Brushy Basin member is absent. Underlying the Morrison Formation is the San Raphael Group which includes the Todilto Limestone, a uranium bearing unit that is mined near Grants.

The Dakota Sandstone is a Lower Cretaceous formation overlying the Morrison Formation. It consists of massive quartz sandstone interbedded with coal lenses. In the southwest part of the San Juan Basin, where the Brushy Basin member is absent, the Dakota Sandstone and Westwater Canyon member form a single hydrologic unit.

Much of the emphasis of this study is on the relatively thin veneers of Quaternary unconsolidated to semi-consolidated alluvial, eolian, and terrace deposits that overlie the consolidated rock units in the valley bottoms. These deposits are predominantly silty or clayey fine sand, with occasional concentrations of coarse sand or gravel. Alternating periods of erosion and deposition have resulted in marked disconformities within the alluvium (Leopold and Snyder, 1951). Thickness of the alluvial deposits in the area of concern is usually less than 200 feet.

2.3.4. Water Resources

Surface Water.

Prior to uranium mining and discharge of dewatering effluents, most streams in the Grants Mineral Belt area were ephemeral. Peak flows occurred in the late summer, during heavy thunderstorms. Somewhat less intense flows also occurred in the late winter and early spring, due to melting of snow in the mountains. Because vegetation in the area is insufficient to impede erosion, runoff from these waters carries a heavy sediment load.

The only significant naturally perennial waters are a few small springs along the Puerco River, and streams draining the flanks of Mt. Taylor. The most significant of the perennial streams are Rio Paguate and Rio Moquino which drain the northeast slope of Mt. Taylor and traverse the Laguna-Paguate mining district (see Figure 2.1). Since construction of San Mateo Reservoir, San Mateo Creek has flowed continuously near the community of San Mateo, located on the northwest side of Mt. Taylor in the Ambrosia Lake district. Because of streamflow losses, however, San Mateo Creek normally becomes ephemeral within one mile below San Mateo.

The water in these channels is eventually lost to evaporation and infiltration to shallow alluvial aquifers. Recharge of bedrock aquifers also occurs in short stretches where the streams intersect bedrock outcrops.

Ground Water.

As stated previously, the Westwater Canyon member of the Morrison Formation is a principal aquifer in the area, with yields to wells of up to several hundred gallons per minute. Reliable water supplies are also available from the Gallup Sandstone, the Dakota Sandstone, the Glorieta Sandstone, and the San Andres Limestone. Dewatering of uranium mines has resulted in a significant decline in water levels in the aquifers tapped (mainly the Morrison Formation) and in adjacent formations

Other aquifer systems occur in the unconsolidated valley fills (alluvium) along the San Mateo Creek and the Puerco River, with yields to wells usually less than fifty gallons per minute. The alluvial deposits range from 0 to about 170 feet in thickness; water is found anywhere from a few feet to 100 feet below the surface. Recharge of the alluvial aquifers occurs both from infiltration of surface flow and from bedrock discharges in the form of seeps and springs.

Alluvial ground water-level maps for the Puerco River and the San Mateo Creek valleys are shown in Figures 2.5 and 2.6, respectively. The general direction of alluvial ground water flow in both valleys is to the southwest, corresponding to the slope of the land surface.

Water Use.

Historically, the principal uses of water in the Grants Mineral Belt have been domestic use and livestock watering. Domestic and municipal wells tap both alluvial and bedrock aquifers throughout the area. Numerous shallow domestic

wells are located around the municipalities of Milan and Gallup. Milan derives its municipal water supply from wells tapping the San Andres Limestone. The adjacent community of Grants produces municipal water from wells tapping basalt, alluvium, the San Andres Limestone, and the Glorieta Sandstone. Most of the water supply for the City of Gallup comes from the Gallup Sandstone. Crownpoint derives its water supply from the Morrison Formation. Water for livestock is primarily derived from the shallow alluvial aquifer.

Irrigated agriculture is limited, but occurs to some extent along the valleys of Bluewater Creeks the Rio San Jose, and San Mateo Creek, and along the North Fork of Puerco River from the state road 566 bridge downstream to Gallup (see Figure 3.1). The main crops are vegetables and forage.

The advent of uranium mining has brought support industries which utilize ground water to some extent to the area; examples include cement and caustic soda plants. Moreover, large amounts of ground water are pumped from the uranium mines and discharged to surface watercourses or utilized by uranium mills.

Use of surface water has been limited due to its predominantly ephemeral nature. The discharge of mine dewatering effluents, however, has caused the now perennial streams to become important livestock water supplies.

2.3.5. Land Use

The Grants Mineral Belt is a complex mixture of Indian reservations and Federal, state, and private lands. The land is primarily used for livestock grazing by Indian and private ranchers. Logging occurs to a small extent in the mountain areas. In the Gallup area, coal mining has occurred since the 1880s.

Uranium mining began in the 1950s. The uranium companies have both leased lands from the Federal government, the state, and Indians tribes, and bought some lands outright.

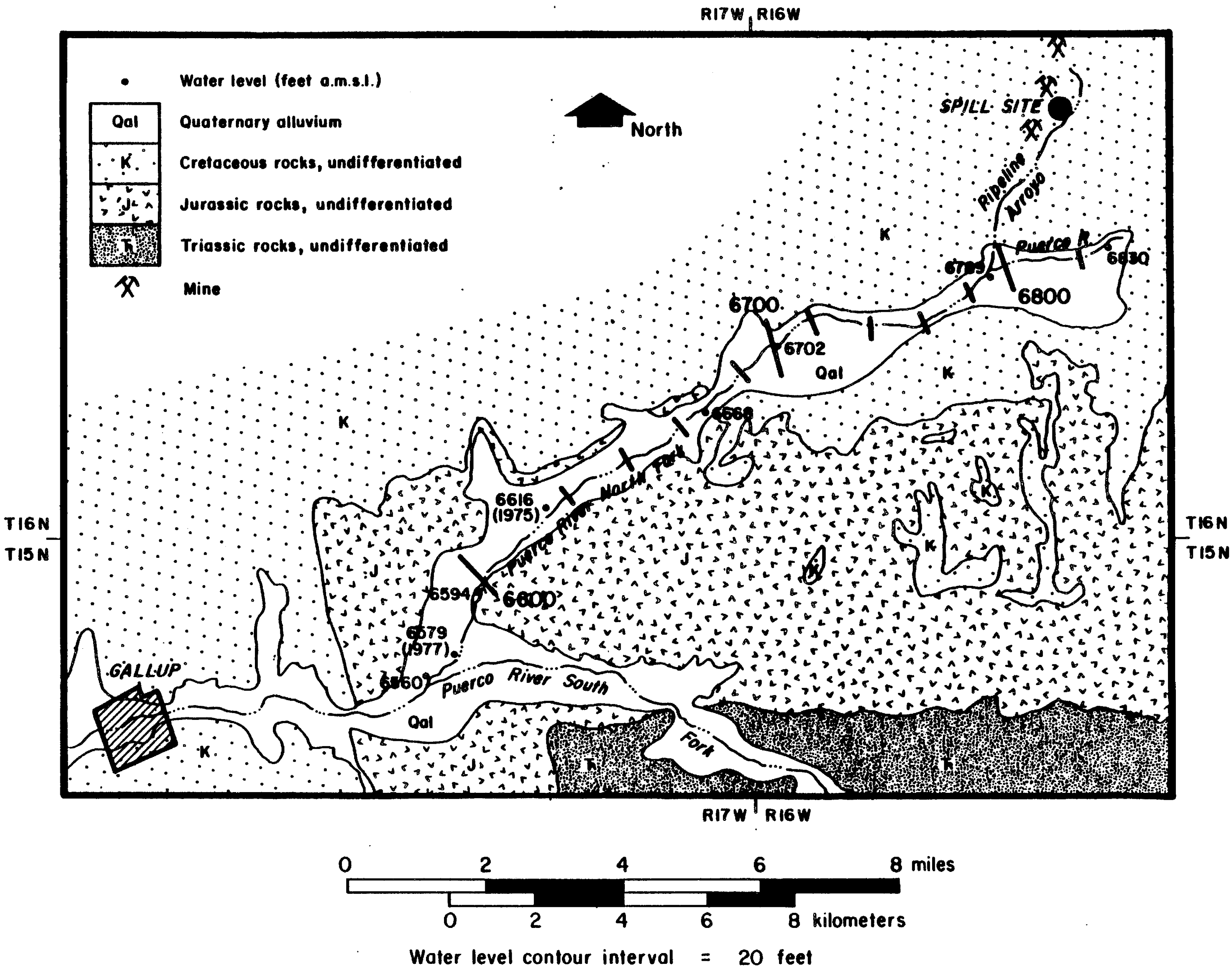


FIGURE 2.5 Alluvial ground water levels along the North Fork of the Puerco River

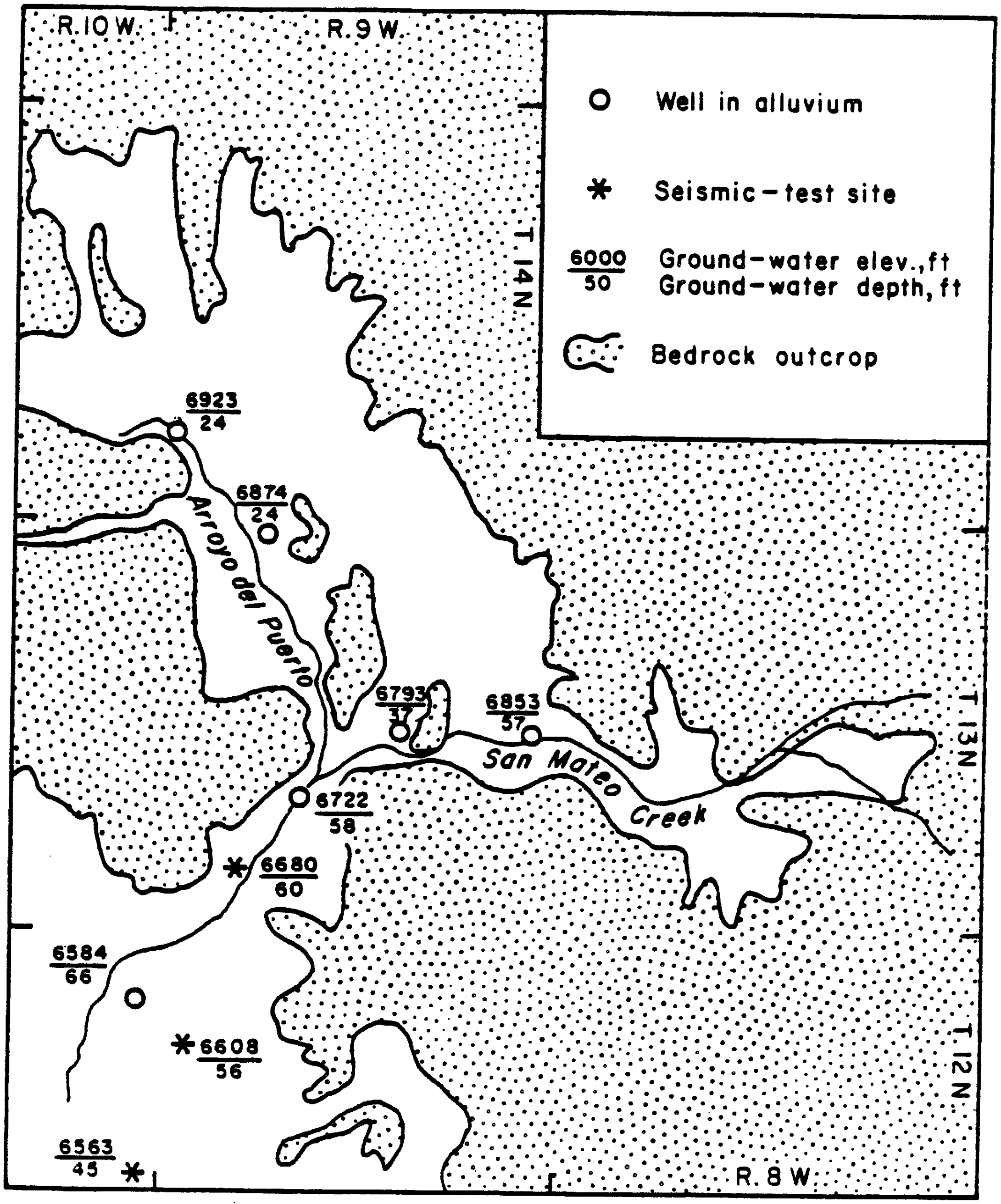


FIGURE 2.6 Alluvial ground water levels along San Mateo Creek and the Arroyo del Puerto (after Brod and Stone, 1981).

2.4 HISTORY OF THE URANIUM INDUSTRY IN THE STUDY AREA

Four mining districts have been developed within the Grants Mineral Belt, and are, from east to west, the Laguna-Paguate, Ambrosia Lake, Smith Lake, and the Church Rock mining districts (see Figure 2.1). There has been extensive exploration and new mine development in areas such as the Crownpoint, Nose Rock, and Marquez.

Extraction of uranium ore from the Laguna-Paguate and Ambrosia Lake mining districts began in the early 1950s using strip and open-pit mining methods. At that time most of the ores were extracted from sandstones of the Morrison Formation in the Laguna-Paguate district and the Todilto limestone in Ambrosia Lake district (see Figure 2.4). By 1954, the Laguna-Paguate district had become host to the largest open pit uranium mine in the United States, the Jackpile-Paguate mine (NM Energy and Minerals Department, 1981). By its closure in 1980, over 2700 acres of land had been disturbed (U.S. Department of the Interior, 1980). As late as 1979, the Jackpile-Paguate mine contributed more than 40% of the uranium ore mined in the Grants Mineral Belt (NM Energy and Minerals Department, 1981).

After the initial discovery of uranium in the Todilto limestone in 1950, numerous open-pit mines dotted the landscape of Ambrosia Lake where the limestone was exposed near the ground surface. Drilling downdip from the initial surface discoveries led to the delineation of ore bodies within the Poison Canyon and Westwater Canyon members of the Morrison Formation (see Figure 2.4 for detailed descriptions of units).

Eventual discovery of large subsurface deposits within the Westwater Canyon member established the Ambrosia Lake mining district as a major uranium production area. In 1980, the Ambrosia Lake mining district contained over two-thirds of the active uranium mines in the state (NM Energy and Minerals Department, 1981). Virtually all of these mines are underground with depths averaging approximately 900 feet. Several major aquifers are penetrated by these shafts.

Delineation and development of ore bodies in the Church Rock mining district began in 1965. Zones of mineralization are recognized at depths exceeding 1800 feet with average shaft depths of approximately 1600 feet. Several major water-bearing strata also are penetrated by the Church Rock mine shafts. As is the present case in Ambrosia Lake, mining in the Church Rock area is conducted by the room and pillar method. This involves mining out blocks of ore while leaving adjacent pillars of ore or waste as support for the roof (Figure 2.7). The size of the rooms depends on the strength of the roof.

Activities of the New Mexico uranium mining industry peaked in 1978-80, following a world wide shortage of the metal and increasing demands for the metal as a electrical power generation fuel. At present, however, the industry is experiencing a severe decline. The following table summarizes the severity of this decline:

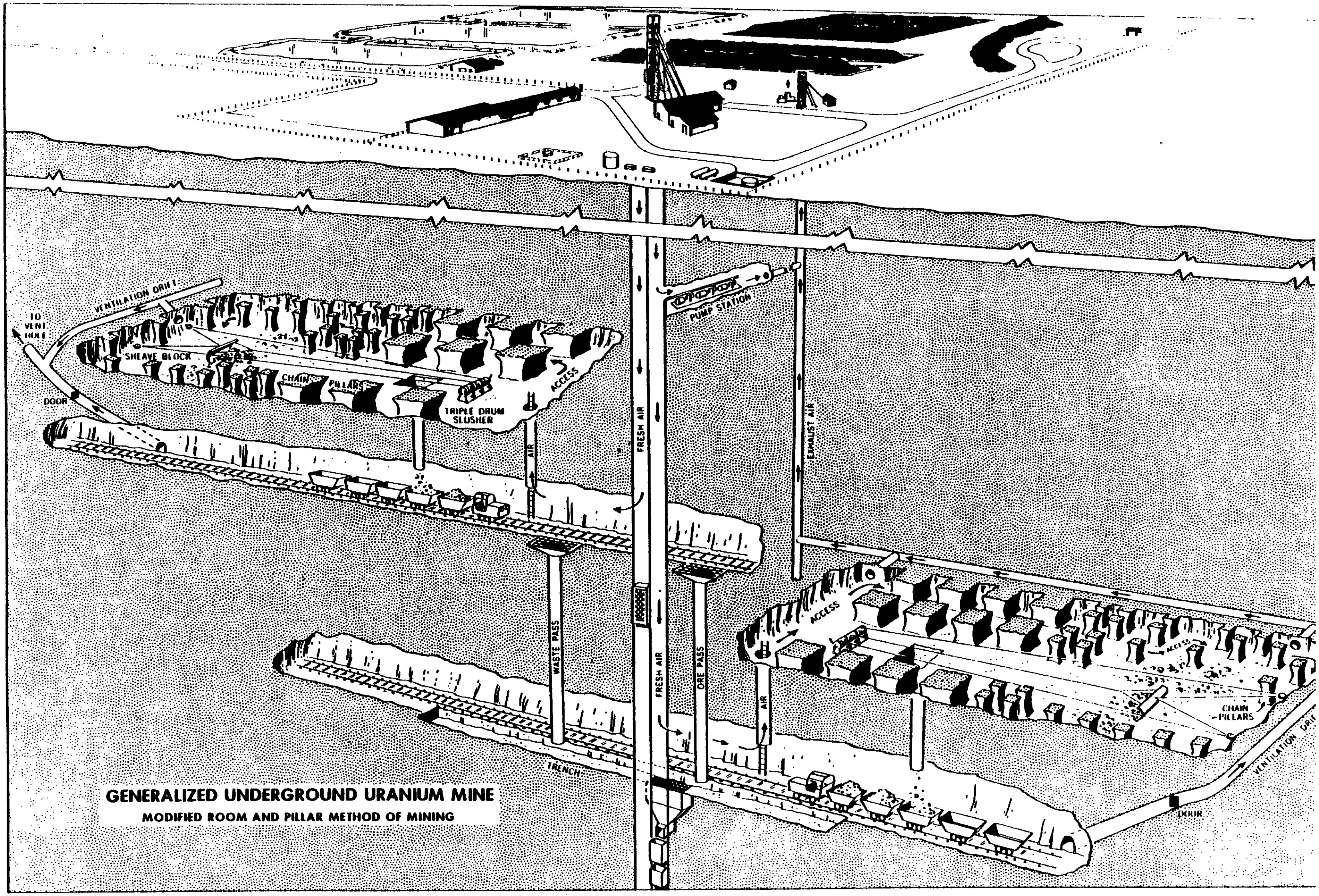


FIGURE 2.7 Generalized underground uranium mine (after U.S. Dept. of the Interior, 1980).

CATEGORY	1977-78[a]	1983[b]
Active Mines	40	13
Active Mills	5	2
Employment	8,000	1,533
Share of total U.S. production	46%	24%

a Chris Wentz, NM Energy and Minerals Department, personal communication (1983)

b NM Energy and Minerals Department (1984).

2.5 OVERVIEW OF URANIUM MINING OPERATIONS

Surface (open-pit) mining and underground mining have accounted for virtually all of the uranium mined in New Mexico. Solution mining has been found to be successful in pilot test projects, but commercial application of the technique has yet to have an impact on New Mexico's industry. Total production from surface and underground mines has been nearly equal.

Both types of mines contribute waste to natural surface drainage systems. Solid wastes are derived from both types while liquid wastes are almost exclusively derived from underground mines.

In the surface mining method,the topsoil and overburden overlying the ore are removed and stockpiled. The uranium ore is then removed and stored prior to shipment to a milling facility. Occasionally, berms and ditches are constructed around the waste and storage piles to control runoff from the piles as well as to divert upstream flood waters away from the piles.

As the mine is further developed, the overburden may be backfilled to fill mined-out areas of the pit. Ultimately, the mined area may be graded and seeded to restore the land surface to its pre-mined condition. Few active or inactive mines have been even marginally reclaimed.

Ore bodies that are located more than about one hundred feet below the land surface are accessed by vertical shafts (see Figure 2.7) The mine extends laterally from the vertical shafts, sometimes for distances greater than a mile.

Because underground mines are developed in a way that minimizes the amount of waste rock removed, far less solid waste is produced than in a surface mine. In terms of contaminant concentrations, however, the underground mine waste rock can be more enriched and can be of greater concern than surface mine waste rock. Underground waste rock is stored in a spoils area that may be, but usually is not, bermed to control runoff.

Since most of the deeper ore bodies lie beneath major bedrock aquifers, dewatering operations are required. Most of the produced water in the Grants Mineral Belt is pumped from within the mines and discharged to settling ponds and to drainage channels. Water also can be pumped from wells that are drilled into the water-bearing strata near the mine in an effort to depressurize the aquifer.

To comply with effluent limitations specified by the federal National Pollutant Discharge Elimination System (NPDES) permits, most mines treat water. Prior to discharge, a flocculant and barium chloride are added to reduce suspended solids concentrations and to coprecipitate radium. Elevated concentrations of dissolved uranium are reduced by a separate ion-exchange treatment.

The average underground mine in the Grants Mineral Belt continuously discharges more than 1000 gallons per minute of produced water. Collectively, more than 150 billion gallons of water were pumped from aquifers in the Grants Mineral Belt between 1956 and 1982 (Perkins and Goad, 1980). Lyford and others (1980) provide a comprehensive assessment of the hydrologic effects on the aquifer system of this sustained pumping. Local water-level declines in the Morrison Formation in excess of 500 feet have resulted from the dewatering.

III. METHODS AND APPROACH

Monitoring activities for this assessment were centered on the three major active mining districts in the Grants Mineral Belt: Laguna-Paguate, Ambrosia Lake, and Church Rock. In the former district, monitoring focused on characterization of natural surface water quality and the effects of open-pit uranium mining on surface water quality. In the latter two districts, monitoring involved characterization of the quality of both natural surface waters and natural ground waters and of the impacts of uranium mining activities on these waters. Instrumentation was installed at sites along representative stream segments in each of the two districts in order to characterize hydraulic and contaminant migration relationships between surface water and shallow ground-water flow systems. Water samples were collected and analyzed for general water-quality constituents as well as parameters specifically associated with uranium mining and milling. In all, over 440 samples were collected at a total of 74 monitoring stations. Chemical analyses of these samples have provided a body of over 10,000 data points.

Section 3.1 describes the monitoring locations for surface water and ground water and for runoff. This section also describes the types of data collected at each site and the frequency of water sampling and hydrological measurements. Section 3.2 explains the methodologies used to collect water quality samples, field data collection, and hydrological measurements. The water-quality constituents monitored and analytical methods for their determination are described in section 3.3. Data interpretation methods are reviewed in section 3.4. The actual data and interpretation of their significance are the subject of the remaining chapters of this report.

3.1 MONITORING SITE LOCATIONS AND INSTRUMENTATION

3.1.1. Surface Water

Monitoring at these stations began in 1977 and continued through 1982. Table 3.1 lists these stations; the stations locations are shown in Figures 3.1, 3.2, and 3.3. Most of these sites had continuous flow during the assessment. Flow at the Puerco River, San Mateo Creek at U.S. Geological Survey (USGS) gage, and the Arroyo del Puerto stations was attributable predominantly to the discharge of uranium mine dewatering effluents. Flow at San Mateo Creek at San Mateo Reservoir, and Rios Moquino and Paguate stations, on the other hand, was naturally perennial and not augmented by dewatering effluents. The two Arroyo del Puerto stations actually function as one station; the "Kerr-McGee cattails" site was sampled when there was no flow at the USGS gage site.

In addition to the stations listed in Table 3.1, a number of sites were sampled (1) during runoff events, and (2) along the Puerco River during and after the United Nuclear Corporation (UNC) uranium mill tailings spill on July 16, 1979. A detailed analysis of the consequences of this spill is presented in a separate report (Gallaher and Cary, 1986).

Through sampling efforts distinct from this assessment, EID staff have collected one grab sample per year from most uranium industry point sources. In 1980 and 1981, uranium industry point source discharges and the assessment stations were sampled concurrently.

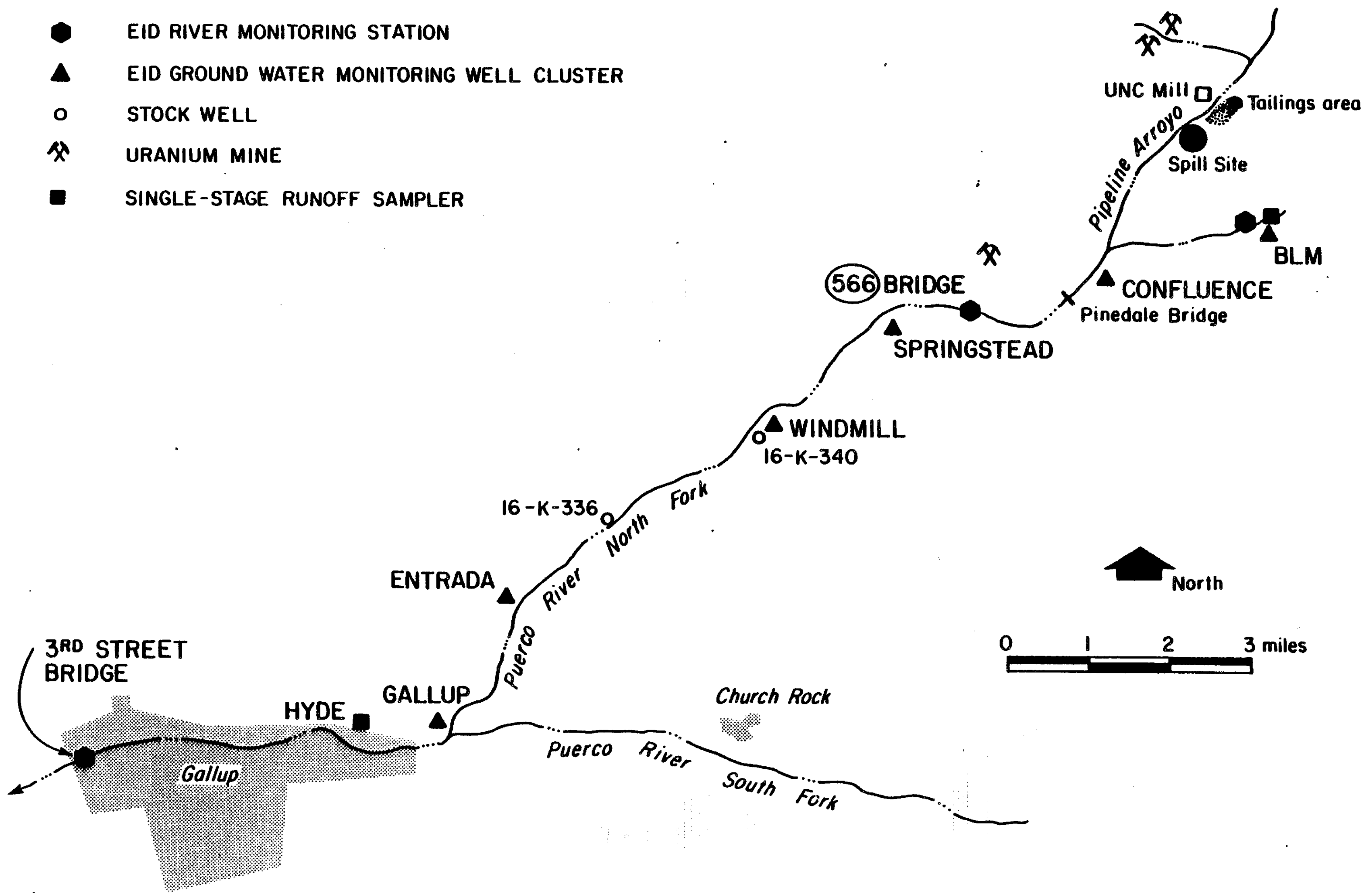


FIGURE 3.1 Monitoring sites in the Church Rock mining district and along the Puerco River

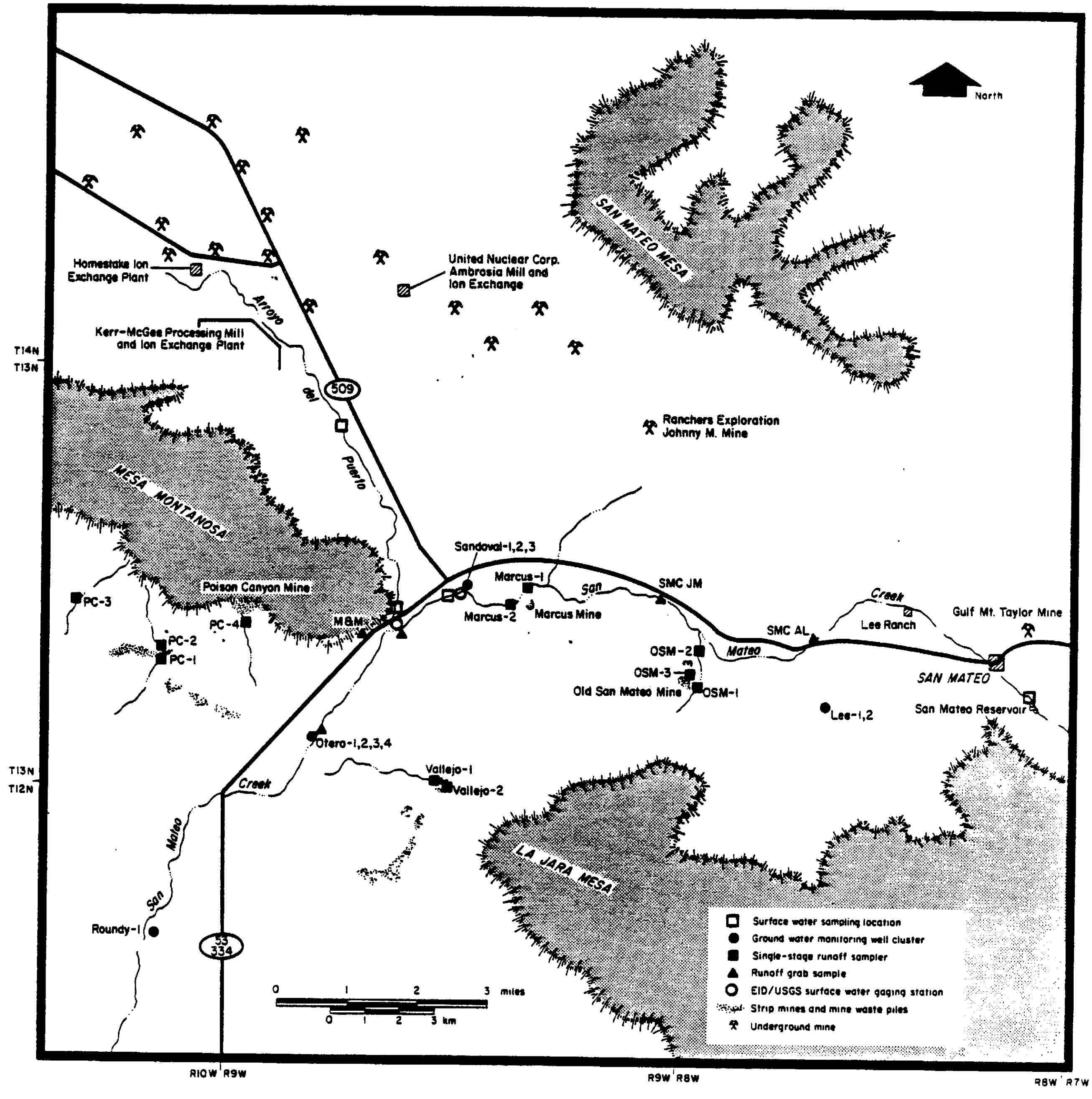


FIGURE 3.2 Monitoring sites in the Ambrosia Lake mining district

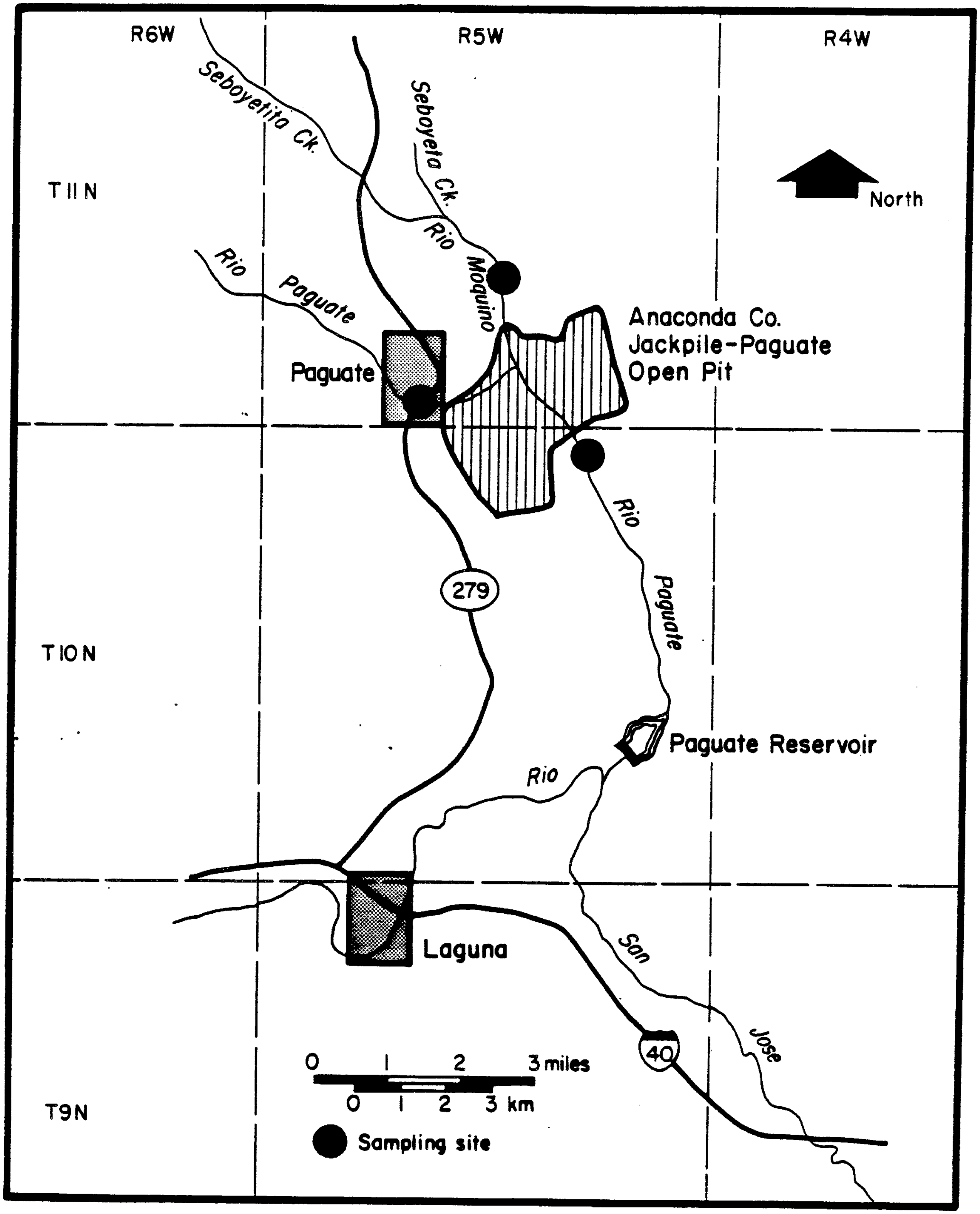


FIGURE 3.3 Monitoring sites in the Laguna-Paguate mining district

TABLE 3.1. Location of Surface Water Quality Monitoring Stations

NAME DESCRIPTION	LOCATION (Lat/Long)
North Fork Puerco River at Highway 566 Bridge 1/	35°36'41", 108°33'35"
Puerco River at USGS gage 09395500 at Gallup 1/	35°31'46", 108°44'40"
San Mateo Creek at San Mateo Res. 2/	35°19'20", 107°37'58"
San Mateo Creek at USGS gage 08342600 1/	35°20'45", 107°45'28"
Arroyo del Puerto at USGS gage 08342700 (Highway 53 Bridge) 1/	35°20'23", 107°47'37"
Arroyo del Puerto at Kerr McGee cattails 3/	35°20'23", 107°47'37"
Rio Moquino above Jackpile Mine 2/	35°09'00", 107°23'48"
Rio Paguate above Jackpile Mine 2/	35°08'10", 107°22'50"
Rio Paguate at USGS gage 08349800	35°07'09", 107°19'58"

1/ EID-funded gages operated by U.S. Geological Survey

2/ Located upstream of any uranium industry activities.

3/ Used only when no flow at Highway 53 bridge.

Water Quality.
Surface water samples were collected at each monitoring station on a quarterly basis, and occasionally during runoff events. More frequent sampling was conducted at the two Puerco River stations after the UNC tailings spill: daily or every two days for two weeks after the event; weekly for another two weeks; monthly through July 1980; and finally quarterly.

Hydrology.
Five of the stations listed in Table 3.1 are equipped with surface-flow gages. Gage 08349800, the Rio Paguate station below the Jackpile Mine, had been installed by the USGS in 1976 as part of their routine water measurement effort. The other four gages were installed, operated, and maintained by the USGS specifically for this study under funding from the EID. The USGS found that the site initially chosen at the Highway 566 bridge on the Puerco River was not favorable for obtaining accurate measurements or continuous records, because the channel is quite unstable at that location. Consequently, this station was moved in 1980 to a more favorable site a few miles downstream. Flow records for all five stations are summarized in the annual USGS publication, "Water Resources Data, New Mexico". (Water Data Report NM-76-1 to NM-82-1).

Instantaneous flow measurements at ungaged surface-water stations were taken while collecting water samples. Measurements were made with a Price pygmy meter according to procedures detailed by the U.S. Department of the Interior (1977).

3.1.2. Ground Water

Cluster Concept.
The purpose of ground-water monitoring was to study the hydrologic and water quality relationships between surface and ground water and to evaluate the movement of contaminants in the alluvial aquifer. The monitoring well clusters are designed to detect the early stages of contamination of the aquifer.

Figure 3.4 illustrates an idealized well cluster. One well is drilled about 10 feet from the channel edge to a deph of about 35 feet. Another well is drilled adjacent to the first, but about 70 feet deep. These two wells enable sampling of the aquifer at the same location, but at different depths. For some clusters, a single boring was drilled, but cased and perforated so that it can actually function as two wells -- one shallow and one deep. The well is given one number and the two depths are distinguished by putting a "U" for "upper" or an "L" for "lower" after the well number. A third well is placed about 200 feet upstream of the first, 10 feet from the channel edge and drilled to a depth of 35 feet. A final 35-foot-deep well is placed 200 feet from the first in a direction perpendicular to the channel. Thus the cluster design enables determination of water-quality differences along the stream channel, away from the stream channel, and at different depths in the aquifer. Not every cluster was constructed as shown in Figure 3.4, but only one cluster has less than two wells.

Locations of the ten cluster sites for this study are shown on Figures 3.1 and 3.2. Table 3.2 lists additional information for each well, such as depth, casing diameter, and screened interval. Well locations are described in accordance with New Mexico State Engineer Office procedures, illustrated on Figure 3.5. Gallup, Lee, Sandoval, Otero, and Roundy clusters were installed in 1977-1978, while additional clusters, Entrada,

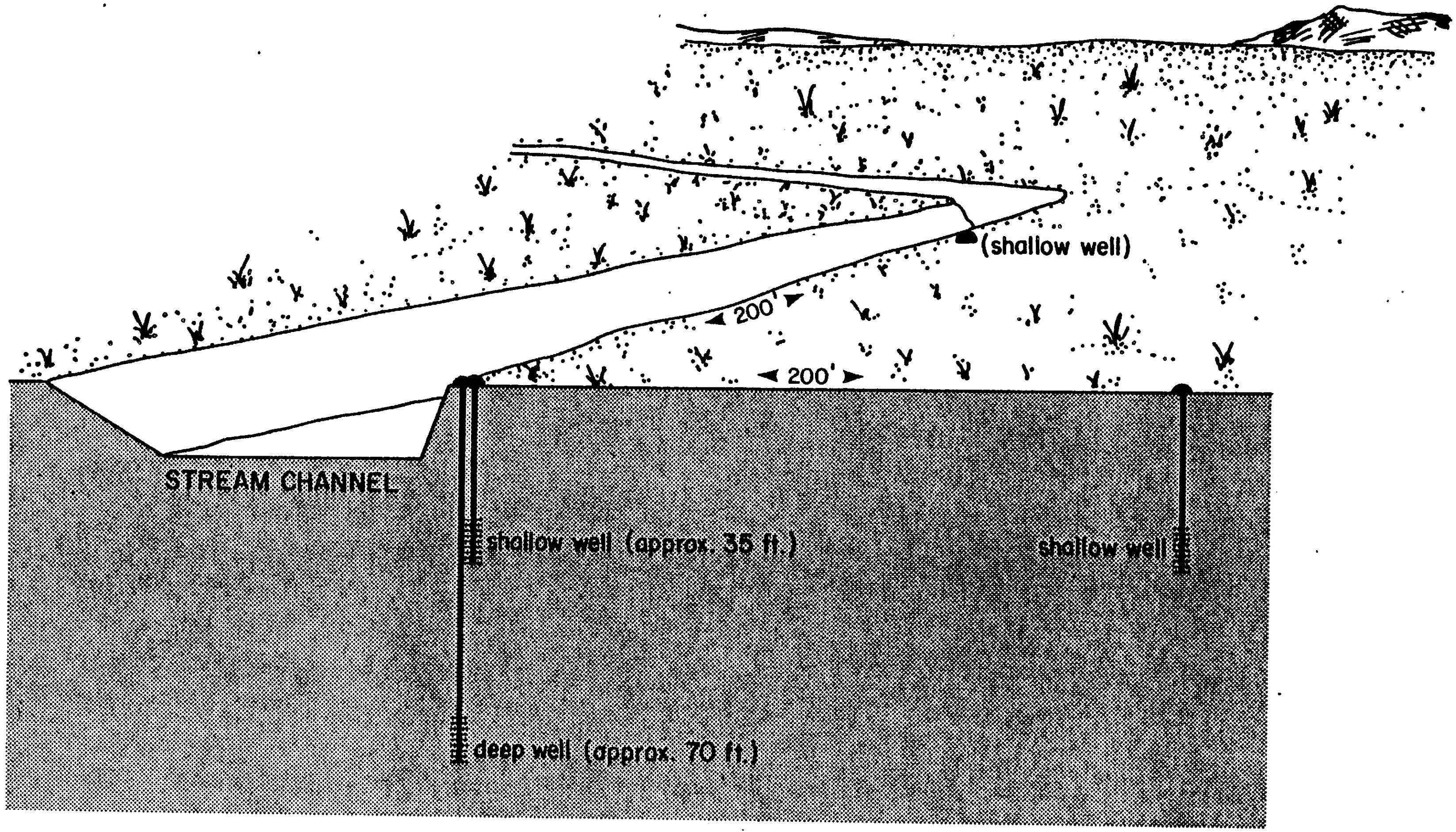


FIGURE 3.4 Idealized well cluster

TABLE 3.2. Location and Completion Details for EID Test Wells.

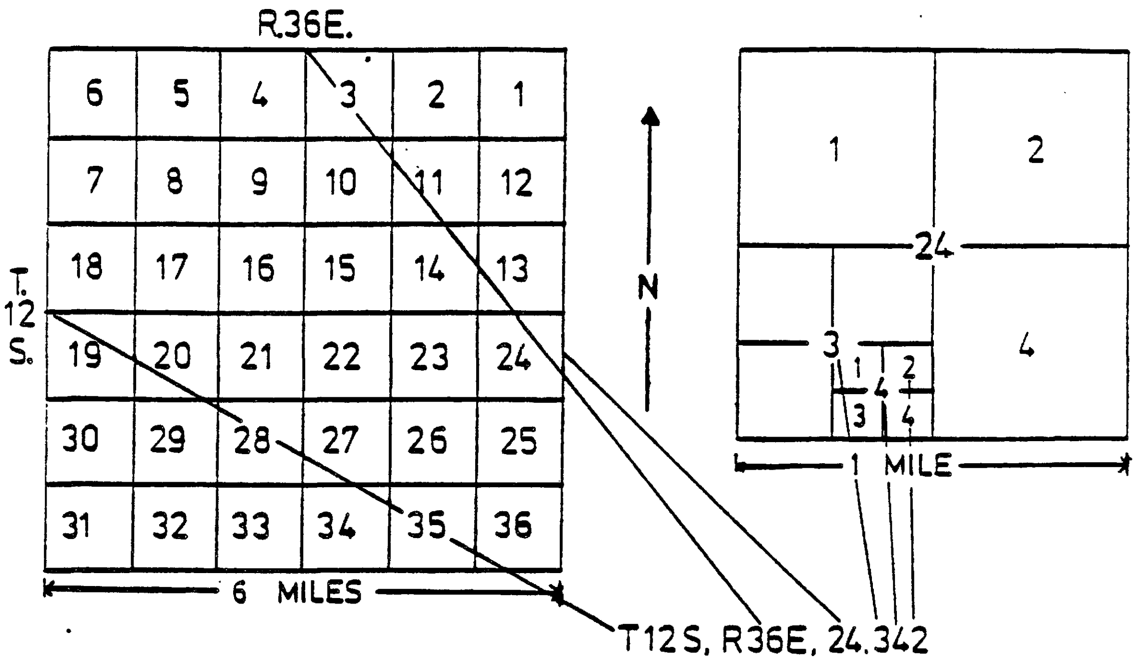
NAME	LOCATION	DIAMETER (inches)	TOTAL DEPTH (Feet below land surface)	SCREENED INTERNAL (Feet below land surface)
Entrada-1 (ENT-1)	T15N, R17W, 5.4242	5	40	25 - 35
ENT-2	T15N, R17W, 5.4242	5	59	24 - 39
ENT-3	T15N, R17W, 5.4242	2	50	30 - 40
Windmill-1 (WIN 1)	T16N, R17W, 25.1123	5	35	15 - 35
WIN 2	T16N, R17W, 25.1123	2	48	28 - 38
WIN-3 U	T16N, R17W, 25.1123	5	38	18 - 28
WIN-3 L	T16N, R17W, 25.1123	2	64	49 - 54
Springstead-1 (SPR-1)	T16N, R16W, 19.1142	2	40	20 - 30
SPR 2	T16N, R16W, 19.1142	5	38.5	19.5 - 29.5
SPR-3 U	T16N, R16W, 19.1142	5	32.5	17 - 27
SPR-3 L	T16N, R16W, 19.1142	2	54	39 - 49
Confluence-1 U (CON-1U)	T16N, R16W, 15.1342	2	35	23.5 - 28.5
CON-1 L	T16N, R16W, 15.1342	2	63.5	43.5 - 53.5

TABLE 3.2. (Continued)

NAME	LOCATION	DIAMETER (inches)	TOTAL DEPTH (Feet below and surface)	SCREENED INTERNAL (Feet below land surface)
CON-2	T16N, R16W, 15.1342	5	46	26 - 36
CON-3	T16N, R16W, 15.1342	5	43	28 - 38
BLM Ram-1 U (BLM-1U)	T16N, R16W, 12.3311	5	55	35 - 45
BLM-1 L	T16N, R16W, 12.3311	2	75	62 - 70
BLM-2	T16N, R16W, 12.3311	2	49	29 - 39
Gallup - 1 (GAL 1)	T15N,R17W, 8.3343	5	40	30 - 40
GAL-2	T15N,R17W, 8.3344	5	40	30 - 40
GAL-3	T15N,R17W, 8.3343	5	40	30 - 40
GAL-4	T15N,R17W, 8.3343	5	80	70 - 80
GAL 5	T15N,R17W, 8.3343	5	50	40-50
LEE-1	T13N,R8W,28.422	5	32	15 - 25
LEE-2	T13N,R8W,28.441	5	32	15 - 25
Sandoval 1 (SAN 1)	T13N,R9W,22.2141	5	95	85 - 90
SAN 2	T13N,R9W,22.2141	5	90	80 - 90
SAN-3	T13N,R9W,22.2141	5	80	70 - 80

TABLE 3.2 (Continued)

NAME	LOCATION	Diameter (inches)	TOTAL DEPTH (Feet below and surface)	SCREENED INTERNAL (Feet below land surface)
Otero-1 (OTE-1)	T13N,R9W,32.213 N1/2	5	54	44 - 54
OTE-2	T13N,R9W,32.213 N1/2	5	57	47 - 57
OTE-3	T13N,R9W,32.213 N1/2	5	59	49 - 59
OTE-4	T13N,R9W,32.213 N1/2	5	72	62 - 72
Roundy-1 (RDY-1)	T12N,R10W,13.121 N1/2	5	73.5	63.5 - 73.5



The State identification number locates the site's position to the nearest ten-acre tract in the land network. The number is divided into four segments. The first segment denotes the township north or south of the New Mexico Base Line; the second denotes the range east or west of the New Mexico Principal Meridian; the third denotes the section. The fourth segment, consisting of three digits, denotes the 160-, forty- and ten-acre tracts, respectively, in which the site is situated. For this purpose, the section is divided into four quarters, numbered 1, 2, 3 and 4, in the normal reading order, for the northwest, northeast, southwest and southeast quarters, respectively. The first digit of the fourth segment gives the quarter section which is a tract of 160 acres. Similarly, the quarter section is divided into four forty-acre tracts numbered in the same manner, and the second digit denotes the forty-acre tract. Finally, the forty-acre tract is divided into four ten-acre tracts, and the third digit denotes the ten-acre tract. Thus, site T12S, R36E, 24.342 in Lea County is in the NE¼, SE¼, SW¼, Section 24, T12S, R36E. If the site cannot be located accurately within a ten-acre tract, the third digit is absent; if it cannot be located accurately within a forty-acre tract, both the second and third digits are absent. If the site cannot be located more closely than a section, the entire fourth segment of the number is omitted.

FIGURE 3.5 Well-numbering system used in this report.

Windmill, Springstead, Confluence, and BLM, were installed in 1981. Gal-5 was drilled in 1980 in order to further investigate the UNC tailings spill impacts at that site.

All monitoring wells were installed with either air rotary or hollow-stem auger drilling rigs. To avoid introducing contaminants into the wells, no drilling muds or fluids were added during the drilling operation. PVC plastic was selected as well casing material.

Water Quality.
Ground water samples were collected quarterly, concurrent with collection of surface water samples. Additionally, for a year after the UNC tailings spill, the Gallup cluster was sampled on a monthly basis.

Hydrology.
A water-level recorder (continuous-reading) was installed on a single well at each of the original five clusters. As water-level readings at the Gallup cluster indicated that there is little water-level fluctuation along the Puerco River, continuous recorders were not installed at the Entrada, Windmill, Springstead, and Confluence sites. A recorder was installed at the BLM well cluster, however, because of its location above the river stretch receiving dewatering effluent. Water-level measurements were taken with a steel tape on all gaged wells monthly when the chart was changed on the recorders. The steel protective casings of the wells at each cluster were surveyed relative to one another, so that all water levels are measurements of relative depths within a cluster.

Short-term aquifer performance tests were performed on at least one well at each of the Puerco River clusters. Details on these tests are given in Gallaher and Cary (1986).

3.1.3. Runoff Sampling

Large quantities of materials associated with uranium ore are brought to the surface of the earth and deposited as mine tailings. These materials, when exposed to rainfall and snowmelt, have the potential to contaminate runoff with radionuclides and other trace elements associated with uranium mining. In 1982, a runoff sampling program was conducted to evaluate the runoff quality of these waste piles and the potential impact on surface and ground water quality in the region.

In order to sample the runoff, single-stage samplers were installed in tandem at a number of sites in ephermeral watercourses in ephemeral watercourses above and below mine waste piles (Table 3.3 and Figures 3.1 and 3.2). The sampler design was such that, when the water level of a runoff event reached a certain height, a sample of the runoff was collected in a quart bottle at the bottom of the sampler. The samplers were checked frequently by EID personnel during the summer of 1982; the longest period any sampler went unchecked was two weeks.

In addition to the single-stage samplers, grab samples were taken at miscellaneous sites above and below waste piles during runoff events. The locations and frequency of these samplings were dictated by the weather, by the presence of EID personnel, and by what seemed appropriate to the particular event and location.

3.1.4 Leach Tests.

In conjunction with the runoff sampling program, mine wastes themselves were subjected to leach tests in order to determine the potential for constituents to leach

Table 3.3. Location of Single-Stage Runoff Samplers.

MINE AREA	STATION	LOCATION (Lat/Long)
Old San Mateo	OSM-1*	35° 19'43", 107° 42'55"
	OSM-2	35° 20'03", 107° 42'59"
	OSM-3	35° 19'49", 107° 43'09"
Marcus	Marcus-1	35° 20'45", 107° 45'31"
	Marcus-2	35° 20'36", 107° 45'54"
Poison Canyon	PC-1	35° 19'58", 107° 51'84"
	PC-2	35° 20'06", 107° 51'03"
	PC-3*	35° 20'39", 107° 52'22"
	PC-4	35° 20'22", 107° 49'51"
Vallejo	Vallejo-1	35° 18'20", 107° 46'50"
Church Rock	BLM*	35° 37'40", 108° 29'36"
Hyde	Hyde-2	35° 32'51", 108° 41'26"

*These three samples were installed to collect naturally occurring runoff.

out of the waste piles and into runoff or ground water. Samples were collected from waste piles at the following six mine locations:

WASTE PILE LOCATION	NUMBER OF COMPOSITE SAMPLES*
United Nuclear Corporation-NE, Church Rock	4
Kerr McGee-I, Church Rock	4
Hyde	6
Vallejo	7
Poison Canyon	8
Old San Mateo	8

*See section 3.2.1.

The United Nuclear and Kerr-McGee sites had received mine wastes within the year before the time of sampling; the others sites were inactive or abandoned. Leach test methods are discussed in Section 3.3.3.

3.2 SAMPLING AND MEASUREMENT METHODOLOGIES

3.2.1. Water Quality

Field Data

Temperature, conductivity, and pH were measured in the field concurrent with collection of water samples. Temperature and conductivity were measured with a Yellow Springs Instruments model 33 S-C-T meter. Field pH was determined with a Hellige Color Comparator, if the sample was clear. Turbid samples were measured in the field with either an Orion pH meter or a Corning pH Meter. A two-point calibration was performed with standard pH buffers before each use of the meters.

Measurements of dissolved oxygen in ground water along the Puerco River were done to provide additional input data for a computer model utilized in the study (WATEQFC; see section 3.4.3). Measurements were taken twice on each 5-inch well with a Yellow Springs Instruments oxygen meter before and after pumping or sampling activities were initiated during a site visit. For these measurements the probe of the meter was lowered into the well so that it would be within the screened interval at the bottom of the well. The meter was calibrated with the Winkler method.

Surface Water Samples.

Grab samples were collected from the stream bank by hand-dipping water with a clean polyethlyene beaker from the stream into a 15-liter carboy. The polyethlyene, acid-washed carboys were rinsed with stream water prior to filling. The carboy samples were treated on-site as described below.

Ground Water Samples.

A truck-mounted electric submersible pump was used to collect samples from the fiveinch wells. A small-diameter bellows squeeze pump was used to sample two-inch wells. Each well was pumped until temperature, conductivity, and pH measurements of the pumped well water stabilized. Water was then pumped into a 15-liter carboy, prepared as described above for surface water sampling, and treated on-site as described below.

Sample Treatment and Preservation.
Water from the carboys was redistributed into new 1-quart polyethylene cubitainers. If the sample was to be analyzed for dissolved constituents, the water was pressure-filtered through a 0.45 micron filter. Samples to be analyzed for trace elements and radionuclides were preserved with 5 ml of concentrated nitric acid per liter of sample and samples to be analyzed for ammonia and nitrate plus nitrite, with 2 ml of concentrated sulfuric acid per liter of sample. If the sample was to be analyzed for dissolved constituents, filtration always preceded acidification. All filtering and preservation was performed within 12 hours of sample collection. Samples were kept on ice in a cooler until delivered to the laboratory, usually within three days.

Single-Stage Runoff Samples.
Two single-stage samplers were placed at each runoff monitoring site. Water from the two samplers was composited and transported to the laboratory without filtration or preservation.

Leach Test Samples.
Grid points 10-to-50 meters apart were established for each waste pile. Solid samples were taken from three depths at each grid point by troweling material from the surface and hand-augering material from both 18 inches and from 36 inches into the pile. The sample material was placed in sealed plastic bags for transport to the laboratory. Equal parts (300 grams dry weight each) from each depth were composited to form the sample. If more than 8 grid points were sampled at a waste pile, material from two adjacent grid points was composited into one sample.

3.3 WATER QUALITY ANALYSES

3.3.1 Constituents Monitored

Water Samples.
Table 3.4 lists the water quality constituents which were determined for each water sample. A literature search, conducted at the beginning of the study to determine constituents associated with uranium ore and the milling process (U.S. EPA, 1975; Clark, 1974), was the basis for selection of the radioactive elements, trace elements, and nitrogen parameters listed in this table. Other general chemistry parameters were added as a measure of general water quality and to allow waters to be analyzed according to geochemical techniques.

The parameters in Table 3.4 marked with an asterisk indicate that analyses for these parameters were performed on only a few, special samples. Some of these special parameters were needed to complete the input to the WATEQFC computer model (see section 3.4.3); others were specifically relevant to the UNC tailings spill. Stable isotopes (oxygen-16/18; hydrogen/deuterium) were analyzed at the beginning of the study with the intention of using them as tracers for minewater in the alluvial ground water. The initial data results, however, indicated that the isotopic signatures of mine dewatering effluents were not distinguishable from native ground waters, and thus stable isotope analyses were dropped from the monitoring program.

TABLE 3.4. Water Quality Constituents Analyzed in Surface and Ground Waters.

CLASS	PARAMETER
Radiochemistry	Gross beta (pCi/l) Gross alpha (pCi/l) Radium-226 (pCi/l) *Radium-228 (pCi/l) *Radon-222 (pCi/l) *Polonium-210 (pCi/l) *Lead-210 (pCi/l) *Isotopic Thorium (pCi/l)
Trace Elements	Arsenic (ug/l) Barium (ug/l) Cadmium (ug/l) Lead (ug/l) Molybdenum (ug/l) Selenium (ug/l) Uranium (ug/l) Vanadium (ug/l) Zinc (ug/l) *Aluminum (ug/l) *Cobalt (ug/l) *Iron (ug/l) *Manganese (ug/l)
General Chemistry	pH Temperature (°C) Ammonia (mg/l) Nitrate + nitrite (mg/l) Calcium (mg/l) Magnesium (mg/l) Potassium (mg/l) Sodium (mg/l) Bicarbonate (mg/l) Chloride (mg/l) Sulfate (mg/l) Total filterable residue (TDS) (mg/l) Total nonfilterable residue (TSS)(mg/l) Conductivity at 25°C (umho) *Chemical oxygen demand (mg/l) *Oxygen 18/16 ratio *Hydrogen/Deuterium ratio *Dissolved Oxygen (mg/l) *Phosphates (mg/l)

*Special, limited samplings

Through mid-I979, most analyses were done for the dissolved form of the constituents. In evaluating data from the UNC tailings spill, however, it became evident that interaction of trace elements and radionuclides with sediment was extremely important in the contaminant transport process. Therefore, analyses of surface waters were subsequently done for total as well as dissolved concentrations. ("Total" refers to the quantity of a constituent precipitated and adsorbed to suspended particles in the water, plus the quantity dissolved in the water, whereas "dissolved" refers to the quantity of a constituent in the portion of the sample that passes through a 0.45 micron filter.)

Runoff Samples and Leach Tests.
Samples of runoff were analyzed for radioactive and trace elements, total suspended solids, and other general chemistry parameters when sufficient sample volume was available to do all analyses. Leachates from the waste pile samples were analyzed for arsenic, barium, cadmium, lead, molybdenum, selenium, uranium, vanadium, zinc, gross alpha particle activities and gross beta particle activity.

Analytical Laboratories.
Most of the water quality analyses were performed by the Scientific Laboratory Divison (SLD) of the New Mexico Health and Environment Department, located in Albuquerque, NM. These included all general chemistry, trace element, and most radiochemistry analyses. Additional radiochemistry analyses, performed by Eberline Instrument Corporation, a private firm in Albuquerque, included all analyses for thorium-230, polonium-210, and lead-210, as well as some analyses for gross alpha and beta particle activities and radium-226. Stable isotope analyses were done by the University of Arizona Laboratory of Isotope Geochemistry in Tucson, AZ.

3.3.3. Analytical Methods

Tables 3.5 and 3.6 list the techniques used for analysis of each parameter. All procedures followed the specifications of the American Public Health Association et al. (1980) and of the U.S. EPA (1979).

Leach tests on mine waste were performed according to the EPA EP toxicity test procedure (40 CFR 261, Appendix II), with a slight modification. The procedure requires that the pH of the leach mixture be kept below 5 by addition of acetic acid if necessary. Samples from the Hyde mine, the first analyzed, were leached accordingly. However, due to the common presence of alkaline soils and the alkaline condition of runoff, it was judged that Grants Mineral Belt conditions would be more accurately reflected if the pH of the mixture were above 7.5, and the procedure was accordingly modified. Most samples yielded pH above 7.5 upon mixing with deionized water. Those that were below 7.5 were adjusted to pH 7.5 with 0.5 N sodium hydroxide.

3.4 DATA REDUCTION

3.4.1. Statistics

The data were usually characterized by standard statistical techniques. Means, standard deviations, and time trends were generated by the EPA computerized STORET data base in which the raw data are stored. Correlation and regression analyses were performed in accordance with Draper and Smith (1966) on a programmable calculator.

TABLE 3.5. Analytical Techniques Used By the New Mexico Scientific Laboratory Division.

DATA	TECHNIQUE
TSS	gravimetric (used filter minus new filter)
TDS	evaporation plus gravimetric
Cond	conductivity meter plus temperature correction
pH	pH meter
As	atomic absorption spectrophotometric (AA)
Ba	AA
Se	AA with nickel-nitrate addition
Mo	AA
NH_3-N	colorimetric-Technicon Autoanalyzer
Na	flame emission spectrophotometric
Cl	colorimetric-Technicon Autoanalyzer
SO_4	colorimetric-Technicon Autoanalyzer
Ca	EDTA titration
K	flame emission spectrophotometric
HCO_3/CO_3	potentiometric titration
Cd	AA
NO_3/NO_2-N	colorimetric-Technicon Autoanalyzer (cadmium reduction)
Mg	EDTA titration
Pb	AA
V	AA
Zn	AA
Al	AA
U	fluorescence, sodium fusion
Ra-226	collection by carrying on barium sulfate and radon emanation
Gross alpha	evaporation and alpha count with correction for absorption
Gross beta	evaporation and beta count with correction for absorption

TABLE 3.6. Analytical Techniques Used by Eberline Instrument Corporation

PARAMETER	TECHNIQUE
Ra-226	radon emanation
Gross alpha	evaporation and alpha count with correction for absorption
Gross beta	evaporation and beta count with correction for absorption
Isotopic Thorium	separation by ion-exchange methods followed by electro-plating and alpha spectroscopy
Po-210	electroplating on nickel foil and alpha counting
Pb-210	chemical separation followed by ingrowth and alpha counting of the daughter product bismuth-210

In addition to these standard techniques, a probability methodology was used to analyze water quality data.

Sinclair Probability Plots.

The method of Sinclair (1976) was develped to enable identification of unique populations within a large number of samples. It is based on the fact that many consitutents have log-normal probability distributions in the natural environment. The method is applied to one constituent at a time. Cumulative probabilities for values of the constituent are plotted on probability paper (arithmetic or logarithmic). For example, suppose sample X has a sulfate value of 56 mg/l, and that 27 percent of the samples had sulfate concentrations less than or equal to this value. The plotting position for sample X is (27,56). Usually, a sample population plotted by this method will give a straight line (if the log-normal assumption is correct). There may be, however, breaks in the slope of the line (inflection points). These breaks may indicate two or more distinct populations within the plotted data. Sinclair also described partitioning techniques that can be used to identify and characterize the different populations. Sinclair's technique was utilized in this study to identify concentrations of uranium in ground water which were above natural levels, and to distinguish between waters impacted by uranium minewaters and those impacted by the UNC spill.

3.4.2. Piper Diagrams.

Several methods are available to transform data values for major anions and cations into a "picture". By comparing the "pictures" of several samples, similarities and trends in quality may become evident. Various such methods were employed in this study, including development of cluster analysis dendograms and plotting data using techniques by those of Schoeller (1962) and Stiff (1951). The most useful technique proved to be that of Piper (1953).

A Piper diagram is a means of expressing water composition in terms of major cationic and major anionic species (Figure 3.6). A point, for example, on the left trilinear represents the relative percentages of calcium, magnesium, and sodium lumped with potassium (that is, the major cationic species) in a water sample. In a similar way, a corresponding point on the right trilinear represents the relative percentages of carbonate-bicarbonate, chloride, and sulfate (that is, the major anionic species) in the water sample. Relative percentages are determined from ionic concentrations in milliequivalents per liter. As indicated on Figure 3.7, the water can be typified according to the area of each trilinear plot in which it falls. For example, on Figure 3.6, Sample A (indicated on the figure by a circle) is a sodium bicarbonate water, whereas Sample B (indicated by a triangle) is a calcium-magnesium sulfate water.

The upper part of the Piper diagram is a diamond-shaped field. The points in the trilinear plots are projected into the diamond as indicated. The position at which a water plots on the diamond is very sensitive to changes in water quality in both time and space; changes in water quality will show up on the Piper diagram as a clear trend in the plotted positions. A mixture of water A and water B will plot on a line which connects points A and B (unless substantial ion-exchange with soil occurs). Thus, Piper diagrams can be useful for tracing movement and mixing of a given water and historical changes in water quality. On the other hand, the technique deals only with major ions, and provides no direct information on the dynamics of many constituents of concern in this study, such as trace e·ements and radionuclides.

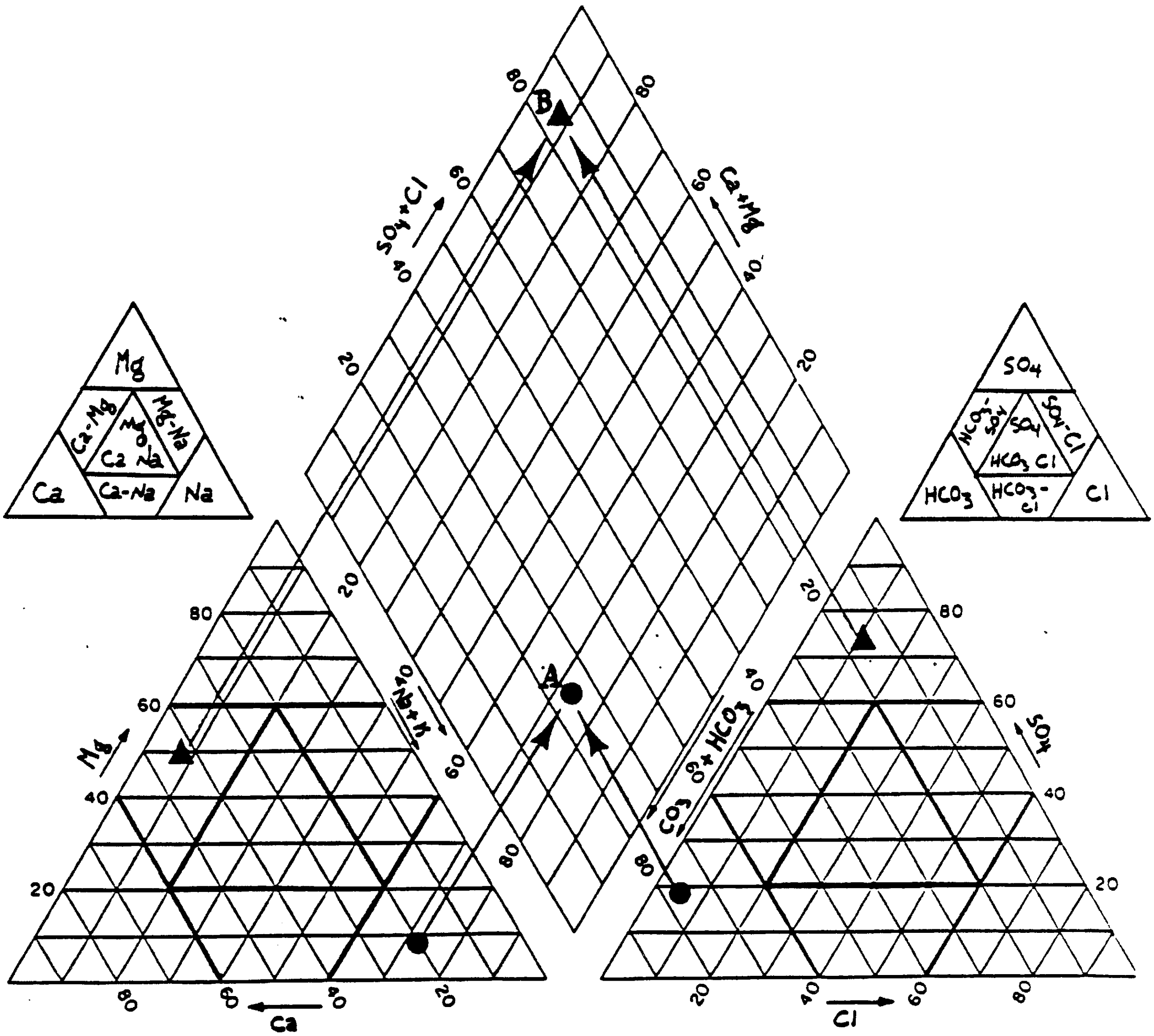


FIGURE 3.6 Chemical analyses of water represented as percentages of total equivalents per liter on the diagram developed by Piper (1944).

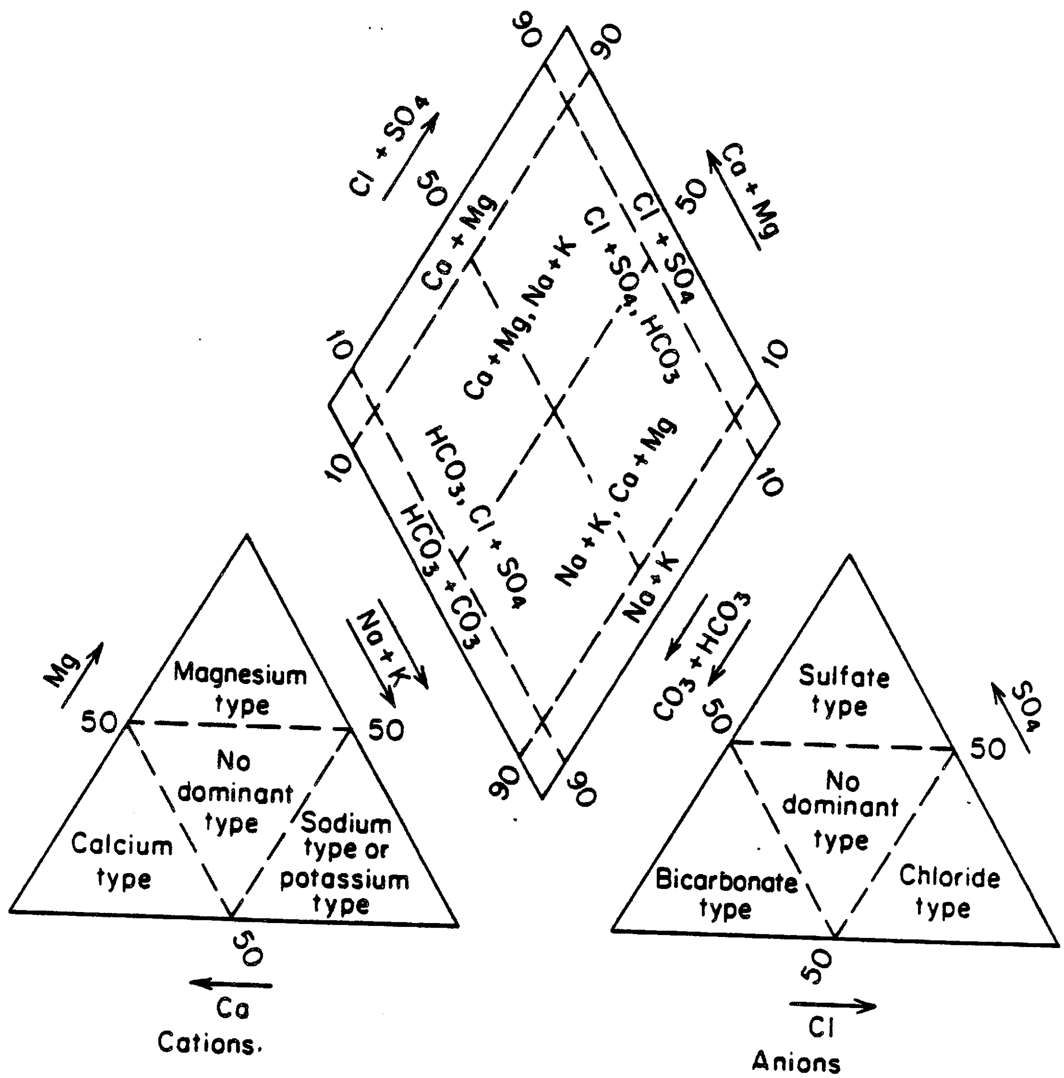


FIGURE 3.7 Classification diagram for anion and cation facies in terms of major-ion percentages. Water types are designated according to the domain in which they occur on the diagram segments.

WATEQFC is a computer program modified by Runnells and Lindberg (1981) to study geochemical dynamics in ground water systems. It models aqueous speciation and calculates the state of chemical saturation of a water with respect to 47 chemical elements. These elements are represented by approximately 650 aqueous species in equilibrium with 540 minerals and compounds. The model output indicates propensities for aqueous species to precipitate or for solid phases to dissolve. Thus, contaminant concentration changes due to equilibrium controls can be predicted. Model runs were performed separately for natural ground waters in the Grants Mineral Belt, for ground water recharged by mine dewatering effluent, for ground water showing tailings spill impact, and for ground water having both minewater and spill impacts.

The extent to which a particular solution is supersaturated or unsaturated with respect to a particular mineral is expressed by the logarithmic ratio of the ion activity product (IAP) to the equilibrium solubility product (KT) of the mineral. This ratio is the saturation index. According to thermodynamic theory, if log IAP/KT >0 the solution is supersaturated and precipitation of the species in question should occur. On the other hand, if log IAP/KT <0 the solution is undersaturated and the particular species in question will remain in solution.

The value of the ratio quantitatively reflects the degree of saturation. To illustrate, a value of -2.0 indicates that the solution is undersaturated by two orders of magnitude (10^2), or one hundred times; a value of + 1.0 indicates that the solution is supersaturated by one order of magnitude (10^1), or ten times.

IV. NATURAL SURFACE WATER QUALITY IN THE GRANTS MINERAL BELT

EID sampling programs have provided quantification of the quality of natural surface waters that have been unaffected by uranium mining within the Grants Mineral Belt. These natural waters serve as a baseline against which the impact of uranium industry effluents can be evaluated. Since 1978, the EID has systematically sampled the few naturally perennial waters in the region. These data were augmented in 1982, when samples of snowmelt and thunderstorm runoff from ephemeral watercourses were collected. All natural surface water sampling sites were located upstream from uranium mining activities.

Three aspects of natural water quality are specifically addressed in this chapter. The first is the chemical quality of sediment-free water; that is, the concentrations of dissolved salts, trace elements, and radioactivity. The second aspect is the high sediment load that is typically carried by ephemeral streams in the Grants Mineral Belt during runoff events. Finally, the chemical and radiological quality of raw, unfiltered runoff is discussed. Sediment-laden runoff characteristically has large concentrations of trace elements and radionuclides.

4.1 PERENNIAL STREAMS

Under natural conditions, most watercourses in the Grants Mineral Belt flow only when sustained by snowmelt or storm runoff. Nonetheless, there are a few perennial watercourses in the three mining districts investigated in this regional assessment. Perennial waters in the Church Rock district are limited to a few small springs along the Puerco River. In the Ambrosia Lake district, San Mateo Creek has flowed continuously in the vicinity of the community of San Mateo since the construction of San Mateo Reservoir upstream. Both the Rio Paguate and the Rio Moquino, which originate on the well-vegetated northeast slope of Mount Taylor, are perennial. These streams flow into the Jackpile-Laguna district, converge, and as the Rio Paguate, complete the traverse of the district.

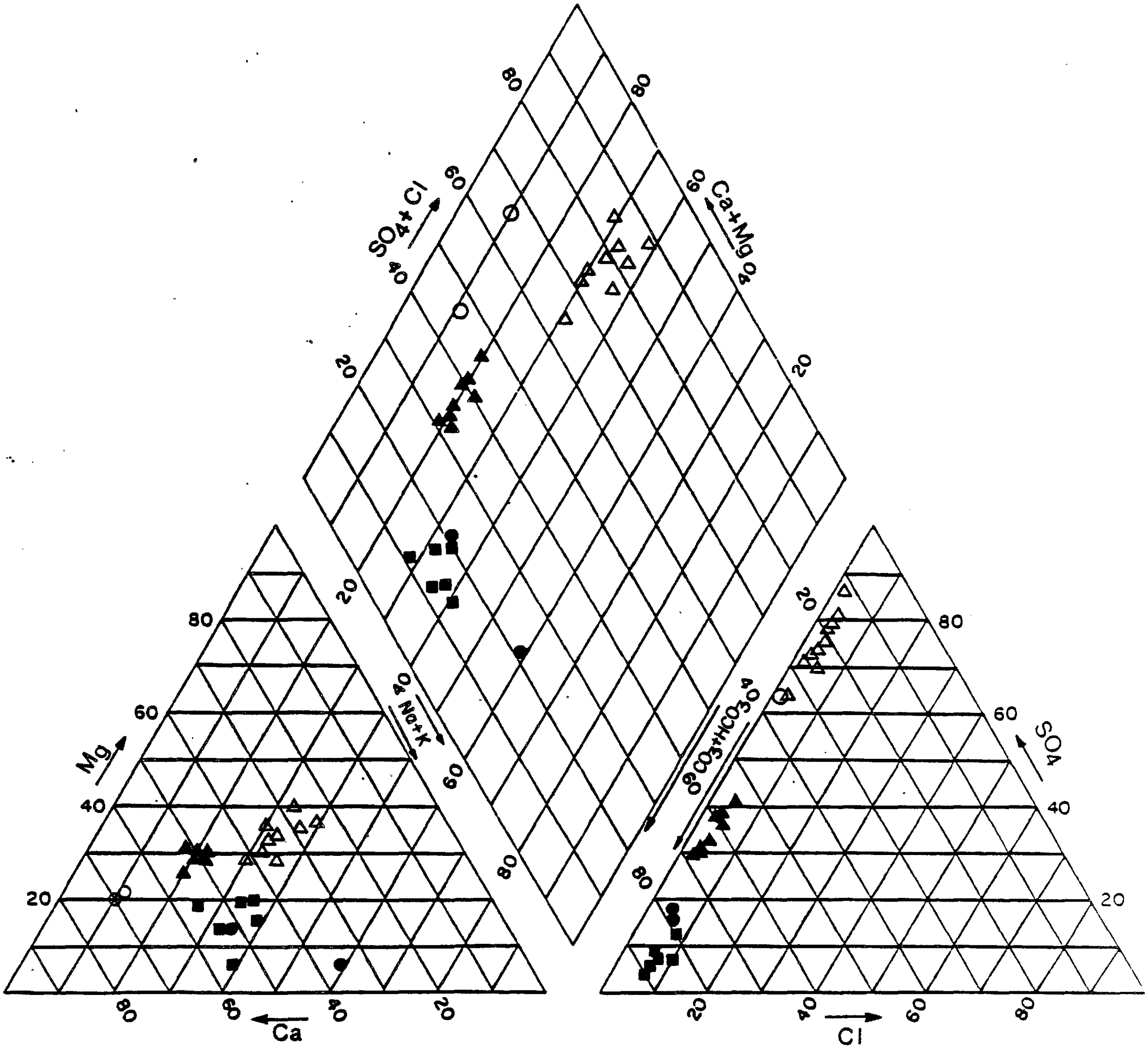
4.2 DISSOLVED SUBSTANCES

Dissolved salts in surface waters of the Grant Mineral Belt originate chiefly from weathered rocks and residues from evapotranspiration. Shale and limestone units are the primary geologic sources of dissolved solids in the region.

4.2.1. General Chemistry

Evaluation of sampling data shows that natural concentrations of the total dissolved solids in streams in the Grants Mineral Belt vary from less than 200 mg/l to over 1500 mg/l. The least saline waters are perennial San Mateo Creek and ephemeral flows in the South Fork of the Puerco River. The most saline water is found in the perennial Rio Moquino. The Mancos Shale, from which the Rio Moquino valley was excavated, has been shown to be one of the largest sources of salinity in the entire Colorado River Basin (Jackson and Julander, 1982).

A Piper diagram graphically illustrates the geochemical composition of different surface waters in the Grants Mineral Belt (Figure 4.1). Natural waters from the Rio



NATURAL SURFACE WATERS	TDS
● Puerco River South Fork at 566 bridge (ephemeral flow)	300
○ Puerco River North Fork at BLM (ephemeral flow)	580
■ San Mateo Creek at San Mateo (perennial stream)	180
▲ Rio Paguate above Jackpile (perennial stream)	490
△ Rio Moquino above Jackpile (perennial stream)	1530

FIGURE 4.1 Geochemical composition of natural surface waters, Grants Mineral Belt. Ions are expressed percentages of total equivalents per liter.

Moquino and ephemeral flows in the North Fork of the Puerco River are dominated by dissolved calcium and sulfate, which are abundant in the Mancos Shale. In contrast, South Fork of Puerco River and San Mateo Creek flow chiefly in limestone terrain and are enriched with bicarbonate ions. The perennial Rio Paguate has waters of chemical composition intermediate between these two types.

4.2.2. Trace Elements and Radioactivity

Dissolved trace element and radionuclide concentrations are very low in perennial streams in the Grants Mineral Belt. Dissolved concentrations in ephemeral flows are similarly very low, but may be slightly higher in line with the increased sediment loads (Table 4.1). Owing to the uniformly low concentrations found, the data are combined in Table 4.1 rather than presented by separate drainages or mining districts.

Dissolved concentrations of trace elements are usually quite low because existing natural compounds have low solubility under the neutral or slightly alkaline pH conditions common in the region and because the majority of dissolved trace elements in surface water become attached to sediment grains or form precipitates (Popp and Lacquer, 1980). Like the trace elements, most naturally occurring radionuclides are relatively insoluble.

4.3. SUSPENDED SEDIMENT

Suspended sediment levels in surface waters of the Grants Mineral Belt span a wide range of concentrations (Table 4.2). The few naturally perennial streams, such as Rio Moquino, Rio Paguate, and, locally, San Mateo Creek, are virtually sediment free, but most of the region is drained by dry arroyos that carry turbid flash floods after summer thunderstorm activity. The tremendous sediment concentrations of regional arroyos are among the world's highest (Gregory and Walling, 1973).

The majority of streamflows in watercourses in the Grants Mineral Belt are of the short-lived, turbid type. Maximum suspended sediment concentrations in these arroyos are many hundreds of thousands of milligrams per liter (mg/l) (Busby, 1979). The Puerco River exemplifies this type of stream. The name "puerco", which means "murky", has been applied to several regional streams that are "too thick to drink, to thin to plow."

The high suspended sediment concentrations are attributable to three major environmental factors. First, several geological strata in the region weather to silt and clay-sized particles that are easily carried in suspension by flowing water Important sediment-producing rock units are shales, including the Mancos Shale of the Puerco River Valley (Dane and Bachman, 1965; Jackson and Julander, 1982). Second, the semiarid climate prevents establishment of protective vegetative cover on the soil. In lowland areas the soil is sparsely vegetated with drought-resistant plants, including shrubs and bunch grasses. Overgrazing by livestock has rendered the ground surface even more vulnerable to erosion. Third, the late summer (July-September) rainy season brings intense thunderstorms that rapidly generate large volumes of runoff. Whether overland or in a channel, these flows readily entrain exposed sediment grains.

TABLE 4.1 Median Dissolved Concentrations of Trace Elements and Radioactivity in Natural Surface Waters. Number of samples given in parentheses.

CONSTITUENT	DISSOLVED CONCENTRATION Perennial Streams		Ephemeral Flows	
	(ug/l)			
As	<5	(39)	<5	(3)
Ba	100	(30)	<100	(3)
Cd	<1	(26)	<1	(3)
Pb	<5	(26)	<5	(3)
Mo	<10	(36)	<10	(8)
Se	<5	(39)	<5	(7)
U-natural	<5	(37)	10	(5)
V	<10	(29)	25	(3)
Zn	<50	(27)	<50	(3)
	(pCi/l)			
Gross alpha	2	(29)	17	(3)
Ra-226	0.1	(36)	1.2	(11)
Pb-210	1	(2)	4.5	(10)
Po-210	--	--	2.3	(7)
Th-238	--	--	0.3	(7)
Th-230	--	--	0.3	(7)
Th-232	--	--	0.2	(7)

TABLE 4.2. Suspended Sediment Concentrations in Natural Surface Waters.

STREAM	SUSPENDED SEDIMENT CONCENTRATION (mg/l) Log Mean	Min.	Max.	No. of Samples
Perennial Streams				
San Mateo Creek at San Mateo Reservoir	10	<1	83	7
Rio Moquino above Jackpile-Paguate Mine	14	<1	73	10
Rio Paguate above Jackpile-Paguate Mine	4	<1	59	12
Ephemeral Flows				
San Mateo Creek Drainage below San Mateo	8,100	940	32,000	4
Puerco River-South Fork Drainage	22,400	5,600	73,000	3
Puerco River-North Fork Drainage	55,700	3,700	561,000	3

4.4. CHEMICAL QUALITY OF TURBID WATERS

Suspended sediment can be a significant transport agent for chemical substances in water. In the ephemeral watercourses of the Grants Mineral Belt, high suspended sediment concentrations account for the major proportion of contaminant transport (see Keith, 1978).

4.4.1. Relation of Chemical Quality to Suspended Sediments

Data presented in Tables 4.3 and 4.4 illustrate the extreme variability in trace element and radionuclide levels in unfiltered waters. Concentrations of those constituents may range from below analytically detectable levels up to 1000 times greater than detectable levels.

Concentrations of most trace elements and radionuclides in turbid runoff demonstrate a strong, statistically significant dependence on the amount of sediment present in the sample. Regression analyses for individual constituents show that, in most cases, the amount of a particular constituent detected in an unfiltered water sample is a positive, linear, first-order function of total suspended sediment; correlation coefficients (r) are often greater than 0.90. In other words, each additional quantity of sediment added to surface water volume usually adds constant proportions of adsorbed or precipitated trace elements and radionuclides. The relation between the concentration of a particular constituent and the sediment concentration (i.e., the slope of a regression line) varies between drainages and depends chiefly on the elemental composition of rocks and sediments in the basins.

While data from the Ambrosia Lake mining district are limited, natural runoff in that district appears to be poorer in quality than runoff in the Church Rock district. In particular, the median concentrations of selenium and uranium in Ambrosia Lake runoff are 6 and 3 times greater, respectively, than in Church Rock runoff. These larger values are probably reflective of the abundance of uranium-ore-bearing outcrops in the Ambrosia Lake district (e.g., at the Poison Canyon mine). In contrast to the other trace elements, noteworthy is the virtual absence of molybdenum in runoff in both districts.

4.4.2. Radiological Quality of Turbid Waters

Radioactive substances were present in detectable concentrations in all of the runoff samples analyzed in this study. In the Ambrosia Lake mining district, gross alpha particle activity measurements of 5 samples ranged from 33 picocuries per liter (pCi/l) to 2100 pCi/l with a median concentration of 1200 pCi/l. Gross beta particle activity measurements of 4 samples ranged from 546 pCi/l to 2,000 pCi/l with a median concentration of 1,060 pCi/l. Slightly lower radioactivities were measured in 12 samples collected in the Church Rock mining district.

High radionuclide concentrations may be present in turbid flows throughout northwestern New Mexico, including the Grants Mineral Belt. Ephemeral washes draining northward from the Grants Mineral Belt into the San Juan Basin exhibit similar patterns of radioactivity to those within the drainages sampled. During turbid flow conditions, gross alpha and gross beta activities as high as several thousand pCi/l have been measured by the U.S. Geological Survey in the Chaco Wash

TABLE. 4. Total Trace Element Concentrations in Natur… …unoff, 1982. All concentrations given in milligram… …er liter (mg/l)

CONSTITUENT	AMBROSIA LAKE MINING DISTRICT (Based on 6 Samples)			CHURCH ROCK MINING DISTRICT (Based on 13 Samples)		
	MAX.	MIN.	MEDIAN	MAX.	MIN.	MEDIAN
As	0.26	0.05	0.13	0.30	0.02	0.08
Ba	43.5	1.4	7.7	9.6	0.44	4.8
Cd	0.05	0.003	0.006	0.06	0.001	0.003
Pb	2.0	0.05	0.52	2.0	0.01	0.17
Mo	<0.01	0.005	<0.01	0.02	<0.01	<0.01
Se	0.15	<0.005	0.03	0.03	<0.005	<0.005
U-natural	0.56	0.03	0.10	0.22	0.005	0.03
V	3.2	0.18	0.61	0.92	0.04	0.40
Zn	1.7	0.38	1.5	8.5	<0.05	0.38

TABLE 4.4. Total Radioactivity in Natural Runoff, 1982. All concentrations given in picocuries per liter (pCi/l). Number of samples in parentheses.

CONSTITUENT	AMBROSIA LAKE MINING DISTRICT			CHURCH ROCK MINING DISTRICT		
	MAX.	MIN.	MEDIAN	MAX.	MIN.	MEDIAN
Gross Alpha Activity	2,100	33	1,200 (5)	1,600	7	720 (12)
Gross Beta Activity	2,000	546	1,060 (4)	1,480	135	710 (9)
Pb - 210	720	4	88 (4)	74	0	53 (7)
Po - 210	43	---	--- (1)	450	9	80 (6)
Ra - 226	321	2	15 (4)	47	1	19 (9)
Th - 228	ND	ND	---	43	3	22 (7)
Th - 230	ND	ND	---	42	0	24 (7)
Th - 232	ND	ND	---	43	3	24 (7)

Note: *ND = No data available

drainage basin (see USGS Water Resources Data, New Mexico, Water Reports NM-75-1 through NM-81-1). The USGS, however, has not performed analyses for specific radionuclides.

Samples of unfiltered runoff from three sites were tested for the isotopes lead-210, polonium-210, radium-226, and thorium-228,-230, and-232. Most of these radionuclides are in the uranium-238 decay series (Figure 4.2). While the observed radionuclide concentrations presented in Table 4.4 are weighted toward the Church Rock district, they are thought to be representative of the entire Grants Mineral Belt. The Church Rock, Ambrosia Lake, and Laguna-Paguate mining districts are very similar in terms of sedimentary geology and landform development. Moreover, sediments collected from Ambrosia Lake and Laguna-Paguate mining districts (Popp and others, 1983) contain concentrations of radium-226 and lead-210 similar to these in the Church Rock district (Weimer, andothers, 1981).

The partitioning of different radionuclides between solid and dissolved phases is significant in runoff. Radium-226 and lead-210, the chief radiological concerns in Grants Mineral Belt runoff, tend to adsorb onto suspend sediments rather than to remain dissolved in runoff (Table 4.5). EID data indicate that 85-to-95 percent of the radum-226 and lead-210 detected in a turbid water sample is bound to the sediment.

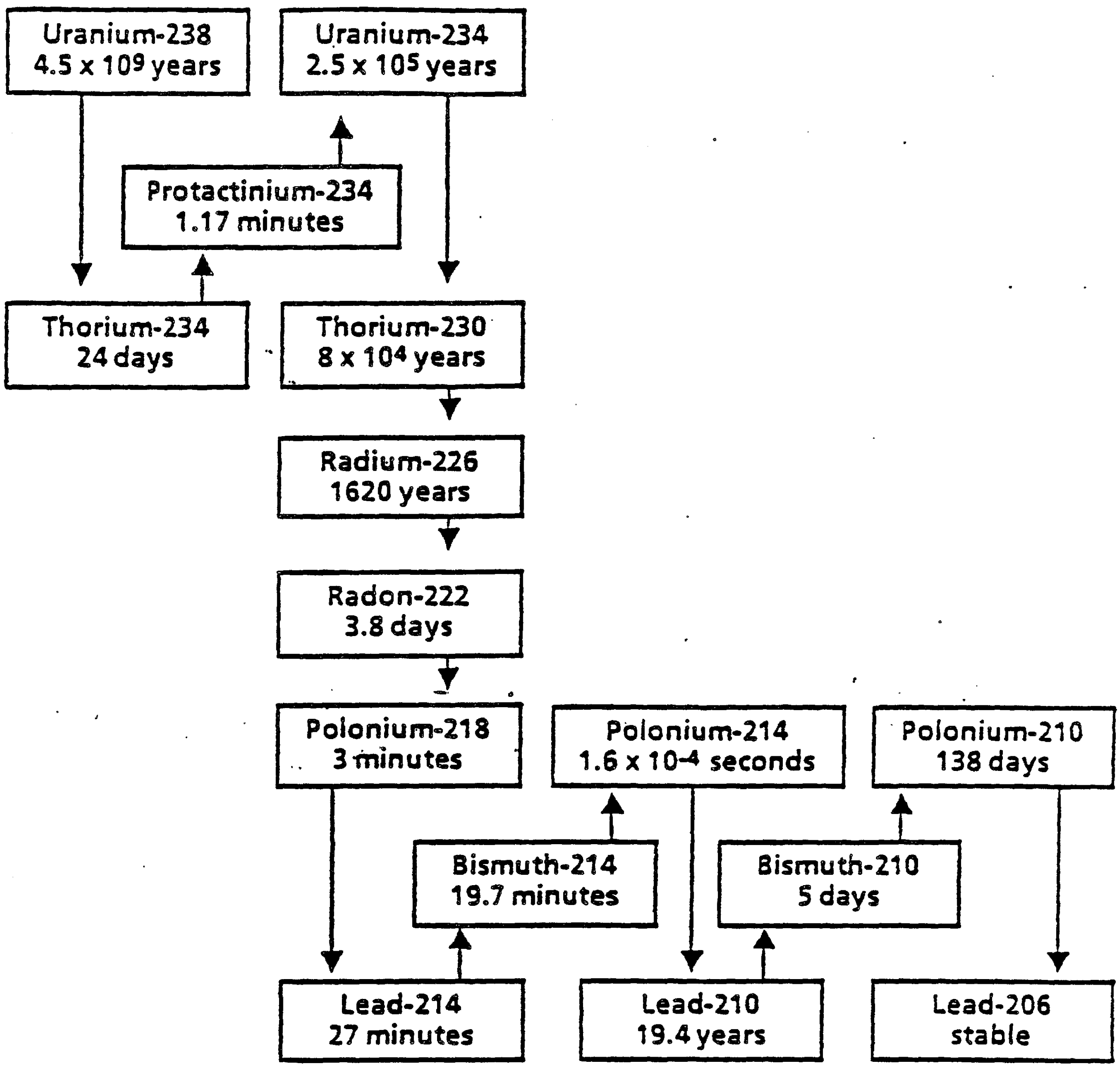


FIGURE 4.2 Principal radionuclides in the uranium-238 decay chain. The half-life of each nuclide is shown. Downward pointing arrows indicate alpha emissions and upward pointing arrows indicate beta and/or gamma emissions.

TABLE 4.5. Partitioning of Radium-226 and Lead-210 between Dissolved and Suspended Fractions of Natural Runoff.

LOCATION	DATE (M-D-Y)	Ra-226 (pCi/l)		Pb-210 (pCi/l)	
		Dissolved	Suspended	Dissolved	Suspended
Puerco River-North Fork BLM cluster	08-04-82	5.8 ± 1.7	41 ± 14	33 ± 5	31 ± 18
	08-24-82	1.3 ± 0.3	2.7 ± 1.1	5 ± 3	6 ± 4
Puerco River-South Fork at Hwy 566 Bridge	08-12-82	0.4 ± 0.1	19 ± 6	2 ± 2	51 ± 17
	08-23-82	1.2 ± 0.4	28 ± 8	6 ± 2	55 ± 21
	08-05-82	3 ± 1	13 ± 15	14 ± 2	21 ± 9
	09-21-82	4 ± 1	19 ± 6	14 ± 2	60 ± 12
Sa.. Mateo Creek at Hwy 53 Bridge	08-03-82	0.7 ± 0.2	22 ± 7	4 ± 2	39 ± 8

V. PRELIMINARY EVALUATION OF THE EFFECTS OF URANIUM MINE WASTE PILES AND OPEN PITS ON NATURAL SURFACE WATER QUALITY

Uranium mine waste piles, both active and abandoned, exert a potentially significant influence on the quality of surface waters in the Grants Mineral Belt. Since the regional onset of uranium mining in the early 1950s, a large area has been explored, prospected, and mined for uranium ore. In a comprehensive survey, Anderson (1980) described 21 abandoned or inactive uranium mine sites in Cibola County and 72 such sites in McKinley County. In addition, Perkins (1979) listed 34 mines that were then active.

In the majority of cases, each mine has associated waste piles. Waste piles may include one or more of the following: barren (non-ore-bearing) overburden, low-grade ore (i.e., are with too low a uranium content to be economically milled), and ore stockpiled for later milling. The EPA (1983) estimated that an average surface mine generates about 6 million metric tons of solid waste per year, while an underground mine generates considerably less - - about 20 thousand metric tons per year. For surface mines waste dumps are larger in proportion to the amount of ore produced, because such dumps are mostly barren overburden. Since the waste varies with respect to ore content, potential impacts on water quality are quite variable. This chapter discusses the impacts of mine waste piles on surface water quality.

The EID investigated the effects of mine waste piles on surface water quality, through runoff sampling and laboratory studies. The sampling program collected water and suspended sediment samples in ephemeral watercourses receiving runoff from mine waste piles. Analysis of runoff samples provided data on concentrations of trace elements and radioactivity in affected arroyos. In conjunction with the runoff sampling, dry samples of mine waste were collected and leached in the laboratory to determine the potential for constituents to leach into surface or ground water.

Open pits created by surface mining have a potential to effect water quality similar to that of waste piles. The exposure of the ore body in open-pit mining subjects it directly to the same runoff factors as waste piles. In addition, as mentioned above, open pits typically have large amounts of waste in the vicinity of the operation. In order to focus on the potential for open pit mining operations to effect water quality, stream sampling was conducted at the largest open pit operation in the Grants Mineral Belt, the Jackpile-Paguate mine. This mining operation is of water quality interest not only because of its size but because of the confluence of two perennial streams within the mining area.

5.1 RESULTS OF RUNOFF SAMPLING

Runoff samples were collected from several sites representing varying degrees of proximity to, and input from, uranium mine waste piles. The data provide information on the water quality impacts of specific piles. The data also help to define generic water quality problems associated with uranium mine waste piles in the region. Throughout the discussion that follows, interpretation of the data is facilitated by frequent reference to natural runoff quality described in Chapter IV. The observations in this section apply directly to the Ambrosia Lake mining district where almost all the samples were collected. Limited sampling results suggest similar sampling results would be obtained in the Church Rock district.

All of the runoff sampling data presented herein reflect instantaneous contaminant concentrations, specific to a particular location and time. Because of the random and short-lived nature of the runoff events, however, the total quantity of mine waste material entering local drainages is unknown. Nonetheless, the mine waste-affected runoff contaminant concentrations exceed natural levels by up to several hundred times, and thus are of concern.

5.1.1. Sediment

Results of runoff sampling suggest that sediment concentrations from uranium mine waste piles in Ambrosia Lake district are comparable to natural sediment concentrations in the district. In 11 samples from drainages with mine waste piles, suspended sediment concentrations ranged from 764 to 75,500 mg/l with a median of about 40,000 mg/l. Three samples from drainages unaffected by waste piles varied from 939 mg/l to 50,000 mg/l with a median of about 32,000 mg/l. The number of samples though is too small to permit definitive statistical analysis.

Cooley (1979) reported that runoff from uranium mine waste piles picks up "clay, silt, and sand, which, depending on the proximity of stream channels, may be transported and deposited downstream." It has been noted that erosion of mine waste piles is accelerated relative to undisturbed soil profiles for a number of reasons, chief of which are lack of topsoil, steep angle of slopes, presence of toxic elements and buildup of salt in the near surface (which inhibit vegetative growth), and poor water retention characteristics (U.S. EPA, 1983).

The U.S. EPA (1983) has stated that most abandoned mines in the region are small surface mines that have little impact on surface waters. Based on recent extensive work by Anderson (1980), we estimate that 10 to 20 percent of all abandoned mines and a few large active mines in the Grants Mineral Belt have waste piles that are directly eroding into local drainage channels.

5.1.2. Trace Elements and Radionuclides

The problem of poor water quality due to high sediment loads is exacerbated when the sediment comes from rock that is geologically enriched in uranium and associated elements, as is the case for mine waste piles. Total contaminant concentrations in drainages affected by uranium mine waste piles are positively correlated with suspended sediment concentrations, just as they are under natural conditions (see Section 4.4) except that waste-affected runoff has proportionally higher contaminant concentrations per quantity of sediment. Therefore, an effective means of evaluating the degree of contamination is comparison of the amount of contaminant per gram of sediment rather than per liter of water. While samples collected at the base of a waste pile reflect uranium mine waste contaminant concentrations, other samples collected far downsteam (up to 5 miles) from any source of contaminants, reflect dilution processes which make them indistinguishable from natural conditions.

Trace Elements

Table 5.1 compares ranges and median of contaminant concentrations found in unfiltered runoff from uranium mine waste piles with those of unfiltered natural runoff. In runoff from these waste piles, uranium and molybdenum maxima exceed maxima in natural runoff by over two orders of magnitude. Maximum arsenic, selenium, and vanadium concentrations exceed maximum natural runoff levels by six to eight times. Other elements (i.e., barium, cadmium, lead, and zinc) are not appreciably above background concentrations. These results indicate that uranium mine waste piles are potential major sources of uranium and molybdenum and perhaps of arsenic,

TABLE 5.1. Total Contaminant Concentrations in Ambrosia Lake Waste Pile Runoff Compared with Natural Runoff. Number of samples in parentheses.

CONSTITUENT	MINE WASTE PILE RUNOFF Range	MINE WASTE PILE RUNOFF Median	NATURAL RUNOFF Range	NATURAL RUNOFF Median
		(mg/l)		
As	<0.005-1.5	0.21 (15)	0.05 - 0.26	0.13 (6)
Ba	0.18 - 37.5	5.9 (15)	1.4 - 43.5	7.7 (6)
Cd	<0.001-0.02	0.006 (15)	0.003 - 0.05	0.006 (6)
Pb	0.02 - 2.5	0.56 (15)	0.05 - 2.0	0.52 (6)
Mo	<0.001 - 3.2	0.02 (15)	0.005 - <0.01	<0.01 (6)
Se	<0.005 - 0.85	0.03 (15)	<0.005 - 0.15	0.03 (6)
U-natural	0.04 - 62.6	0.58 (15)	0.03 - 0.56	0.10 (6)
V	0.04 - 24.8	1.1 (15)	0.18 - 3.2	0.61 (6)
Zn	<0.05 - 4.4	1.7 (15)	0.38 - 1.7	1.5 (6)
		(pCi/l)		
Gross Alpha	300 - 420,000	10,800 (15)	33 - 2,100	1,200 (5)
Gross Beta	177 - 168,000	6,700 (15)	546 - 2,000	1,060 (5)
Pb - 210	29 - 30,050	1,000 (6)	4 - 720	88 (4)
Ra-226	1 - 34,900	650 (6)	2 - 321	15 (4)

selenium, and vanadium in surface waters. These findings are in general agreement with EPA data (U.S. EPA, 1983).

Radionuclides

Radionuclides in unfiltered waste pile runoff are also elevated with respect to levels in natural runoff (Table 5.1). The data also are graphically depicted in a "box and whisker" plots in Figure 5.1. The lower and upper ends of the box represent the 25th and 75th percentile values, respectively; the vertical line within the box is the median value; and the lower and upper extent of the lines (whiskers) are the minimum and maximum values of the data set (McLeod, Hipel, and Comancho, 1983). Maximum gross alpha particle activity exceeds maximum natural runoff activity by 200 times. Maximum levels of two major alpha emitters, natural uranium and radium-226, exceed natural maximum runoff levels by over 100 times. Gross beta particle activity and its chief contributor, lead-210, are also far in excess of natural runoff levels. Natural runoff and waste pile levels of thorium-230 and polonium-210 cannot be compared because of lack of data.

The Old San Mateo Mine illustrates specific impacts of a large waste pile on nearby surface water drainage system, San Mateo Creek (Figure 5.2). Three nearby stations uncontaminated by mine wastes were used to define trace element and radionuclide levels in natural sediments in the area. In contrast, with natural sediment, the waste materials (sediments from the waste pile) contained elevated levels of gross alpha and gross beta particle activities, radium-226, natural uranium , arsenic, lead, molybdenum, selenium, and vanadium. Contaminant concentrations in stream bottom sediments decreased ultimately to natural levels with distance from the waste pile as other sediments carried along the watercourse become mixed with the mine waste material. Contaminated sediments from Old San Mateo Mine are in evidence at least 550 meters downstream from the mine waste pile. Nonetheless, even natural levels, of trace elements and radionuclides in bottom sediment are relatively high. Bottom sediments can under go a continuing cycle of resuspension in runoff and deposition further downstream.

5.2 MINE WASTE LEACHING TESTS

Thirty seven composite mine waste samples were leached with acetic acid and deionized water in the slightly modified EPA EP toxicity test procedure described in section 3.3.3. Acetic acid (pH <5) simulated the leaching effects of natural rainfall, which is similarily acidic, and deionized water (pH >7.5), the leaching effects of rainfall after contacting the alkaline rich soils common to the Grants Mineral Belt. Leachates were analyzed for arsenic, barium, cadmium, lead, molybdenum, selenium, vanadium, zinc, and gross alpha and gross beta particle activities. By definition, a material exhibits the characteristic of EP toxicity if any of the contaminant concentrations in the leachate exceed federal safe drinking water standards by 100 times or more (40 CFR 261, Appendix II).

Table 5.2 presents average leachate concentrations obtained from tests of mine wastes. None of the samples subjected to this test exhibited the characteristic of EP toxicity. No EP toxicity limits have been established for those constituents found in the highest concentrations, natural uranium and gross alpha activity. The uranium concentrations account for most of the alpha activity (for natural uranium, 1.0 mg/l is equivalent to 677 pCi/l of alpha activity, at secular equilibrium). These results suggest that in a neutral or slightly acidic environment, contaminants in uranium mine wastes have a relatively low potential for leaching or for significantly degrading ground water quality.

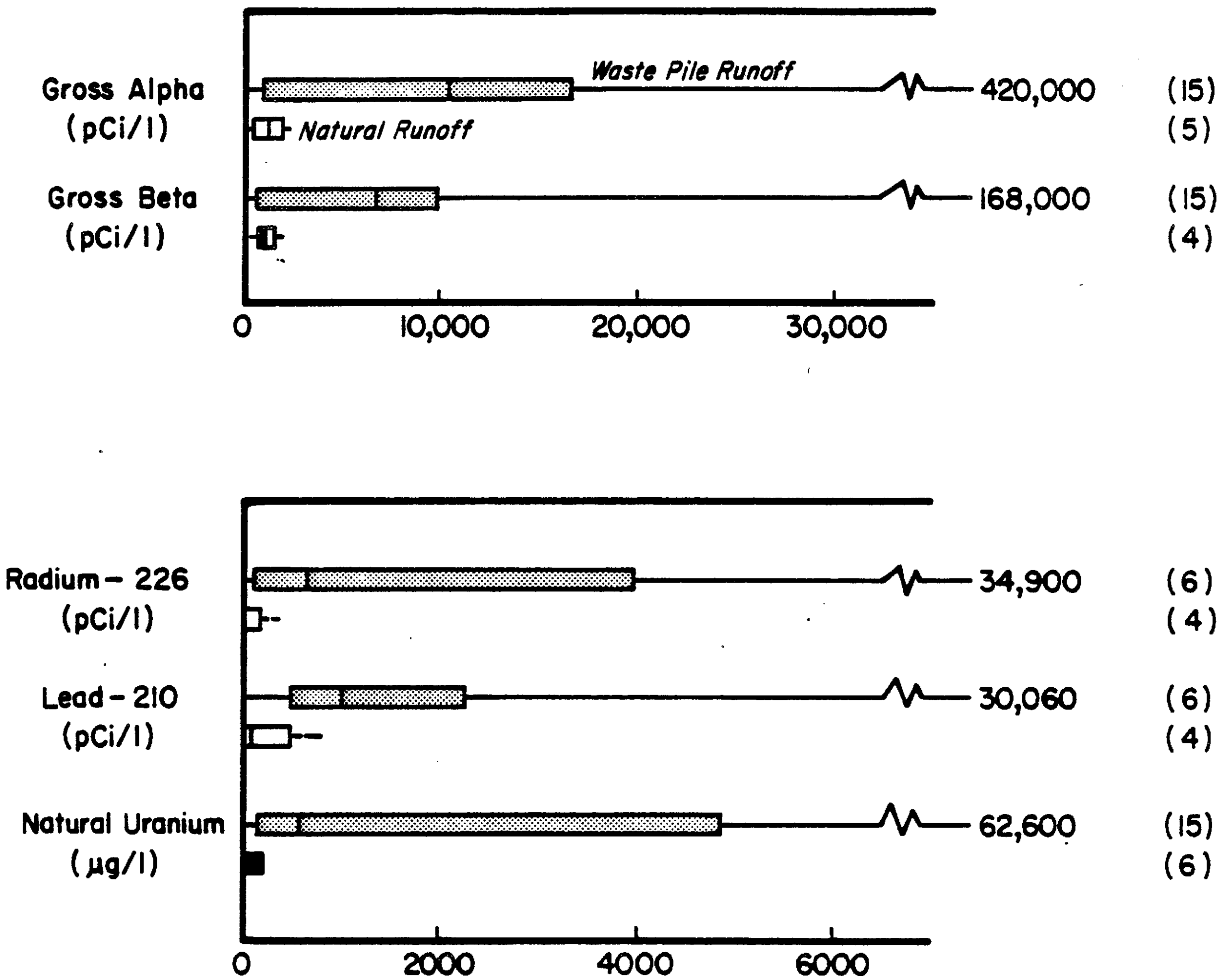


FIGURE 5.1 Total radioactivity and uranium concentrations in uranium mine spoils piles runoff, Grants Mineral Belt.

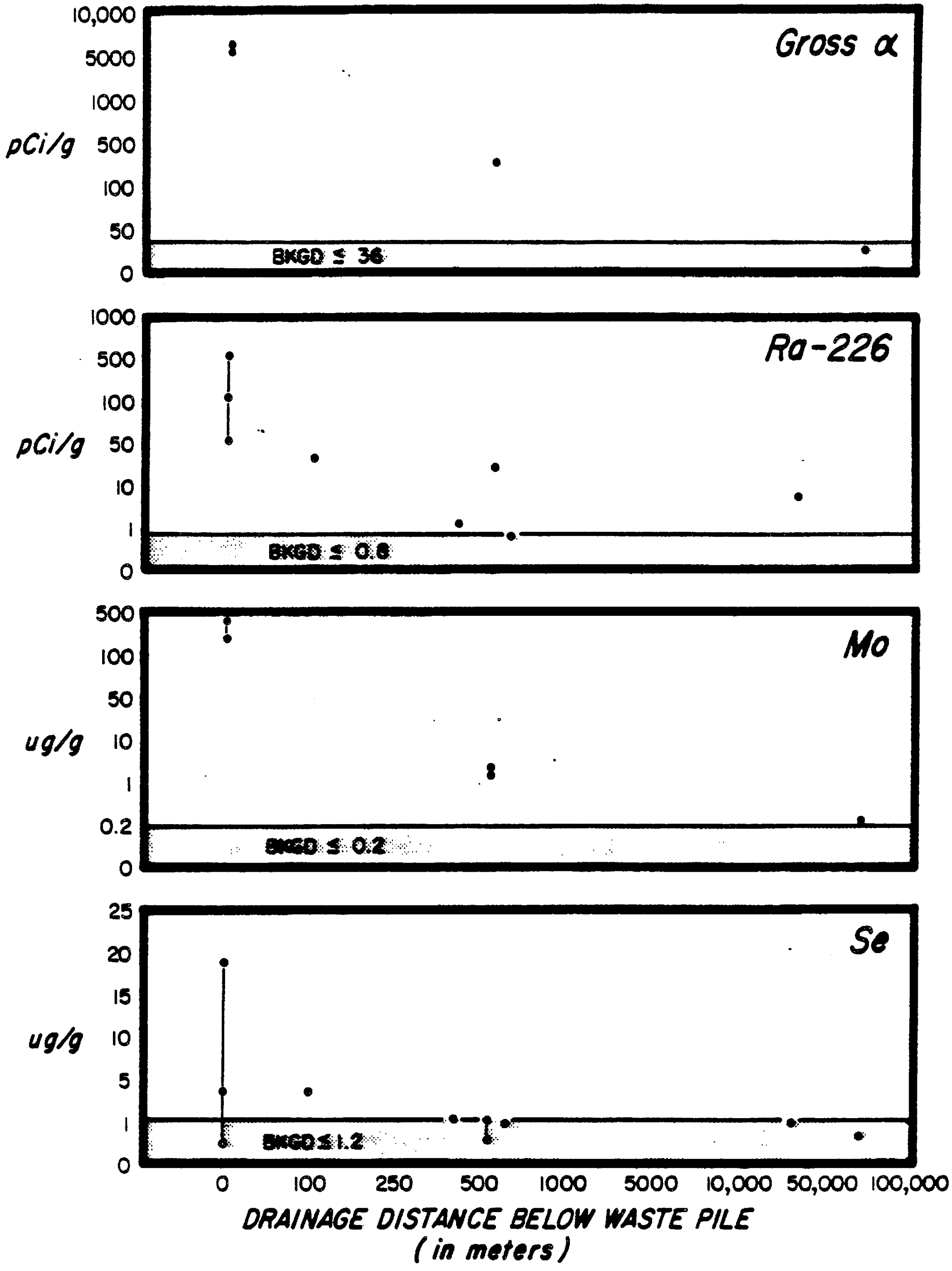


FIGURE 5.2 Persistence/attenuation of selected contaminants in sediments within the drainage system below the Old San Mateo Mine waste pile. Each analysis is represented by dot; some stations have multiple analyses. Three nearby stations were used to define natural background levels.

TABLE 5.2 Results of Mine Waste Leaching Tests (EP Toxicity 'Vater Extract)

AVERAGE CONCENTRATIONS (mg/l)

MINE	As	Ba	Cd	Pb	Mo	Se	U-natural	V	Zn	Gross Alpha*	Gro Bet
UNC-NE Church Rock (4 composite samples)	.005	.145	<.001	<.005	<.01	.026	.910	.029	<.05	706	250
KM-1 Church Rock (4 composite samples)	.006	.142	<.001	<.005	.132	.097	1.09	.015	<.05	663	282
Hyde** (6 composite samples)	<.005	<.10	.001	.006	<.01	.015	.231	.01	.139	240	143
Vallejo (7 composite samples)	.006	.102	<.001	.005	<.01	.006	.136	.011	<.05	93	28
Poison Canyon (8 composite samples)	.010	.176	.01	<.005	.021	.007	.056	.080	<.05	51	7
Old San Mateo (8 composite samples)	.029	.162	.003	<.005	.955	.069	1.42	.011	<.05	1030	164
RCRA ALLOWABLE LIMITS	5	100	1.0	5	NL***	NL***	NL***	NL***	NL***	NL***	NL*

*Concentration in pCi/l
** Acetic Acid Extract
*** No established limit.

5.3 PERENNIAL FLOW THROUGH AN OPEN PIT MINE

The water quality impacts of an open pit uranium mine on perennial streams were studied at the Jackpile-Paguate mine on the Pueblo of Laguna east of Grants. This mine, covering more than 2700 acres of disturbed land, is by far the largest open pit uranium mine in the Grants Mineral Belt. In its twenty-five years of operation, this mine has excavated almost 200 million tons of overburden and mine waste. This is stored in 28 dump sites spread over more than 1100 acres. The pit itself encompasses about 1,000 acres and, in places, approaches 400 feet in depth (U.S. Department of the Interior, 1980).

Two of the several natural perennial streams which descend the northeast flank of Mt. Taylor, the Rio Paguate and the Rio Moquino, converge within the mine; the Rio Paguate continues through the open pit area and eventually flows into the Paguate Reservoir. Water released from the reservoir flows into the Rio San Jose near the town of Laguna. Figure 5.3 shows these features.

A reconnaissance of the Jackpile-Paguate mine area performed by Cooley (1979) provided visual evidence of uranium mine waste piles affecting surface waters. He reported that mine waste had been dumped along the margins of Rio Paguate and that:

> During large flows the river cuts laterally into debris piles. Corrosion of the unconsolidated debris adds considerable bedload and suspended sediment to the river.

Data presented in a recent study by Popp and others (1983) demonstrate that mining activities at the Jackpile-Paguate mine have caused a significant increase in the naturally occurring radioactivity in that drainage system. Detailed chemical and radiological analyses were performed on the sediment which has accumulated in Paguate Reservoir downstream from t' mine. The data clearly show elevated levels of uranium-238 decay products in sediments date after the mid-1950s. Additionally, lead-210 concentrations in sediments increased from pre-mining levels of approximately 2 pCi/g to average post-mining concentrations of approximately 10 pCi/g.

The perennial waters that traverse the mine area have been studied by the EID for uranium-industry impacts since 1978. Surface water samples were collected quarterly at two background sites (Rio Paguate and Rio Moquino upstream from the mine) and one impacted site (Rio Paguate below the mine). Figure 5.3 shows the sampling locations.

As a result of the typically low sediment concentrations in the Rio Paguate, the concentrations of suspended (total minus dissolved) radioactive substances are usually negligible relative to those of the dissolved fraction (Table 5.3). During periods of runoff, however, total radioactivity would be expected to increase because of greater sediment concentrations.

Water quality data from the three sites sampled by the EID demonstrate that the dissolved concentrations of several constituents increase in the streams flowing through the mine area. Table 5.4 shows that average concentrations of gross alpha emitters, radium-226, arsenic, barium, cadmium, lead, molybdenum, selenium, natural uranium, vanadium, and zinc are quite low in the waters above the mine. In fact, both background streams, dissolved concentrations of arsenic, cadmium, lead, molybdenum, selenium, natural uranium, vanadium, and zinc were below detection limits for at least 67 percent of the samples. Among the trace elements, only barium was detected in more than half of the samples in the two streams.

By the time the Rio Paguate exits the Jackpile-Paguate mine, several dissolved constituents are elevated above background levels (Table 5.4). Radioactive parameters experience the largest dissolved concentrations increases; gross alpha particle activity, radium-226, and natural

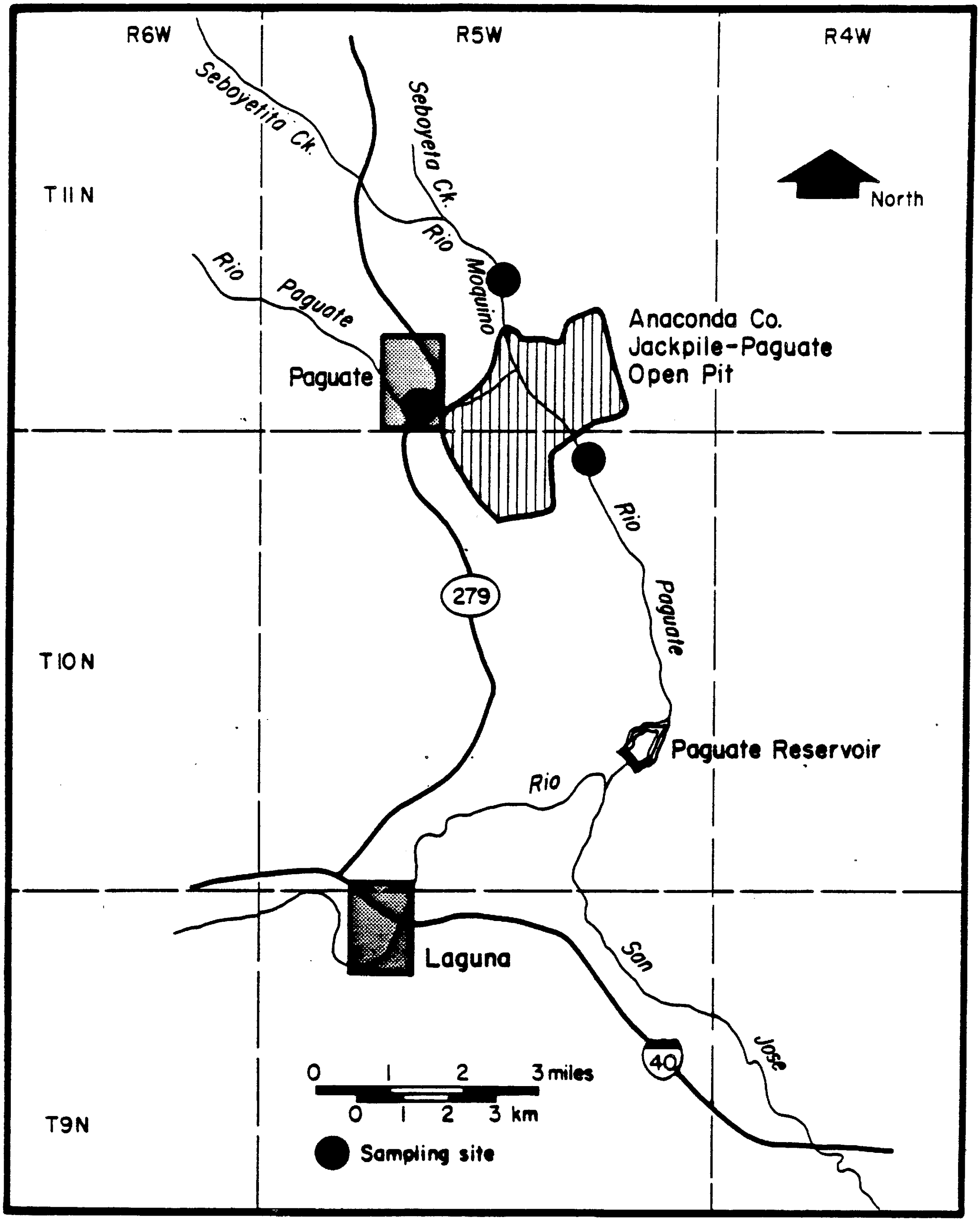


FIGURE 5.3 Major features of the Laguna-Paguate mining district

TABLE 5.3. Radioactivity and Suspended Solids Concentrations in Rio Paguate below the Jackpile - Paguate Mine.

SAMPLE DATE	GROSS ALPHA ACTIVITY (pCi/l)		RADIUM-226 (pCi/l)		TOTAL SUSPENDED SOLIDS (mg/l)
	Dissolved	Total	Dissolved	Total	
6-09-80	78 ± 6*	79 ± 6	3.6 ± 0.1	4.1 ± 0.2	36
12-08-80	71 ± 10	68 ± 10	1.0 ± 0.03	1.1 ± 0.1	27
6-24-81	155 ± 22	153 ± 15	1.4 ± 0.04	1.7 ± 0.1	5

* Picocuries per liter ± one sigma counting error.

TABLE 5.4. Average Surface Water Quality Above and Below the Jackpile-Paguate Mine. Averages based on a minimum of 7 samples.

DISSOLVED CONSTITUENT (ug/l unless noted)	RIO MOQUINO ABOVE JACKPILE MINE	RIO PAGUATE ABOVE JACKPILE MINE	RIO PAGUATE BELOW JACKPILE MINE
TDS (mg/l)	1540	525	1705
SO_4 (mg/l)	825	155	960
pH (s.u.)	8.2	8.0	8.2
As	<5	6	6
Ba	145	130	145
Cd	2	<1	2
Pb	<5	<5	<5
Mo	7	7	7
Se	5	5	6
U-natural	6	6	120
V	10	9	10
Zn	<250	<250	<250
Gross alpha (pCi/l)	3.7	1.0	79
Gross beta (pCi/l)	9.6	4.2	48
Ra-226 (pCi/l)	0.48	0.19	3.7

* For locations, are given on Figure 5.3

uranium all increase by factors of 10 or more. Aside from uranium, there are no statistically significant increases in dissolved trace elements concentrations.

VI. HYDROLOGIC EFFECTS OF MINE DEWATERING EFFLUENTS

Disposal of uranium mine dewatering effluents in the normally dry arroyos of the Grants Mineral Belt has had a significant impact on regional surface waters and ground waters. Where dewatering occurs, ephemeral streams are transformed into perennial streams. The artifically supplied perennial streams have dramatically increased the volume of water that recharges underlying alluvial aquifers. The added recharge has raised water tables and increased the amount of ground water that can be easily obtained from shallow wells. As a result, more near-surface ground waters and surface waters are available.

6.1. HISTORY

The history of uranium mine dewatering has been summarized by Perkins and Goad (1980). In general, dewatering has been performed continuously in the region since at least 1956. The Church Rock and Ambrosia Lake mining districts have witnessed the largest volume of mine dewatering. Water production from mines in the Ambrosia Lake district has been continuous since 1956, with peak production in the early 1960s. Significant dewatering in the Church Rock area began in 1967 and peaked about 1980. Decline of the industry since 1980 has caused several mines to close and the flow of dewatering effluents to diminish in both the Ambrosia Lake and Church Rock districts. Some mines which are not extracting ore, however, have been placed on "stand-by status" and continue dewatering operations. Figure 6.1 illustrates the history of minewater production in the Grants Mineral Belt through 1982.

6.2. HYDROLOGIC IMPACTS ON REGIONAL SURFACE WATERS

6.2.1. General Characteristics of Flow Before and During Mine Dewatering

Prior to dewatering of underground uranium mines in the 1950s and 1960s, the regional drainages were ephemeral. These streams experienced an wide range of discharges, from zero flow to large flash floods (e.g., Busby, 1979). Maximum discharges of flash floods often reach several thousand cubic feet per second (cfs) (Thomas and Dunne, 1981). The only significant perennial waters in the region are a few small springs along the Puerco River, and perennial streams draining the north and east flanks of Mt. Taylor.

Discharges of uranium mine dewatering effluents have transformed several ephemeral streams to perennial streams flowing for many miles. Minewaters have provided perennial baseflow for Pipeline Arroyo and the Puerco River in the Church Rock mining district, and Arroyo del Puerto and San Mateo Creek in the Ambrosia Lake mining district. Other newly created perennial streams occur in other regional mining districts not covered by this report. Table 6.1 presents approximate average distances that perennial flow conditions are sustained by various mine discharges during 1979-1981. The greater distances occur along river reaches where stream bottom leakage rates are relatively low.

Before mine dewatering, flow in the Puerco River, for example, was distinctly seasonal (Figure 6.2). One season of flow was late winter (February through April) a time of gentle frontal precipitation and melting snow. May and June were months of little or no precipitation and low stream flow in the Puerco River. The second season of flow was middle-to-late summer (July through October). Summers in the region are usually characterized by frequent, intense, and isolated thunderstorms that can produce large

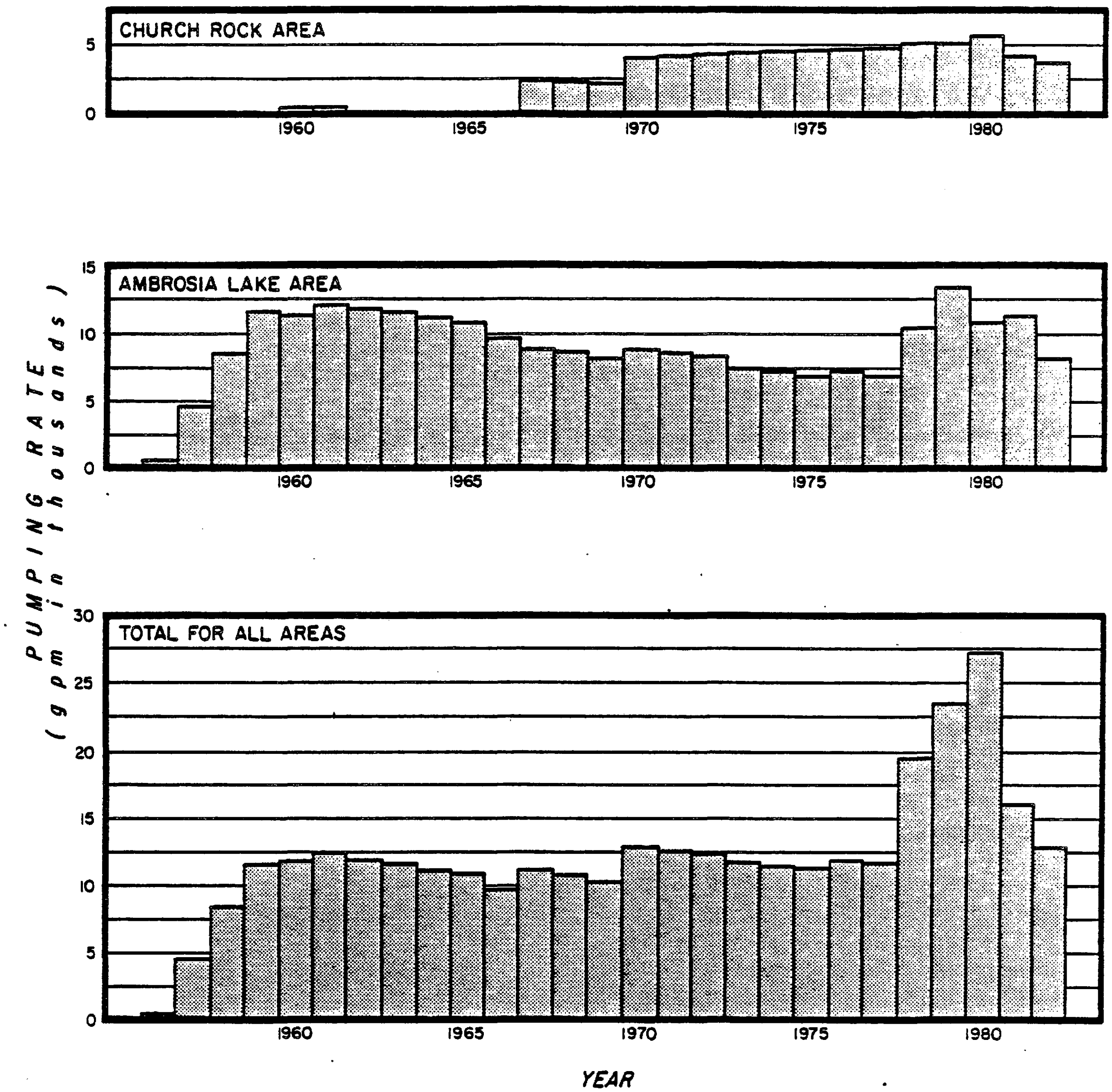


FIGURE 6.1 Water production by uranium mines, Grants Mineral Belt.

TABLE 6.1 Approximate Average Distances of Constant Flow below Mine Discharges, 1979-1981. Location of mining districts shown on Figure 2.1.

DRAINAGE CHANNEL	VOLUME OF DISCHARGE (gallons per minute)	APPROXIMATE DISTANCE OF FLOW* (miles)
	Church Rock Mining District	
Puerco River	5000	50
	Ambrosia Lake Mining District	
Arroyo del Puerto	2300	5
San Mateo Creek	1500	3
	Mt. Taylor Mining District	
San Lucas/Arroyo Chico	4000	40
	Crownpoint Mining District	
Kim-me-ni-oli Wash	3400	20
	Marquez Mining Area	
Rio Marquez	1000	15
Rio Salado	1000	10

*Distances are based on the authors' observations, review of EID files, and U.S. Geological Survey annual water data reports.

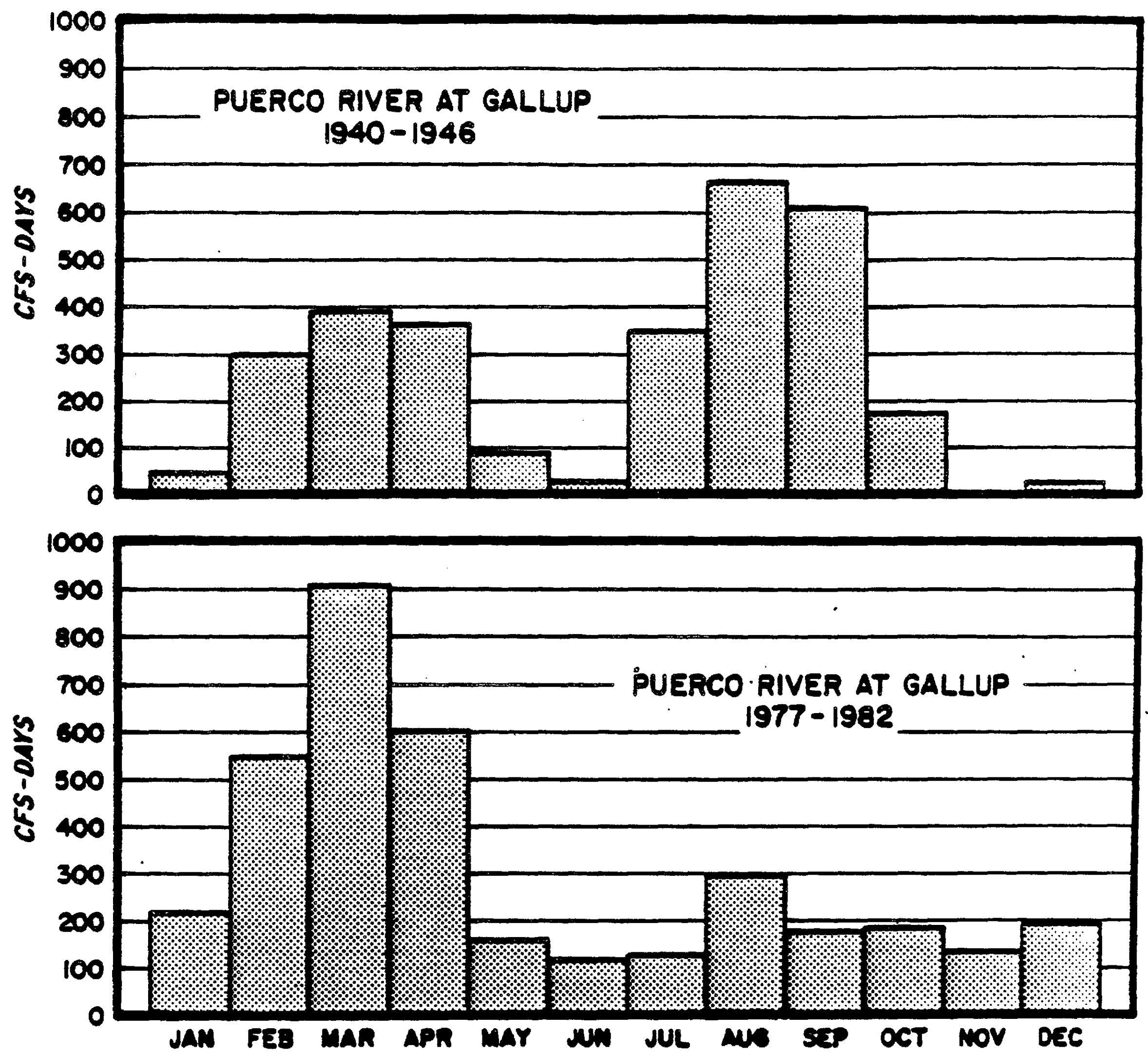


FIGURE 6.2 Monthly flow in the Puerco River at Gallup before mine-dewatering and with flow augmented by mine dewatering

flash floods. Autumn months of November through January were once again dry, in terms of both precipitation and stream flow.

With ongoing mine dewatering, flow in the Puerco River become continuous. Figure 6.2 shows that climatic dry seasons (May through June and November through January) are no longer times of no flow in the Puerco. Whereas during these months in the 1940s the Puerco River was often without flow, between 1977 and 1982 the river was never dry and flow at all months averaged at least 120 cfs-days.

Figure 6.2 depicts augmented late winter stream flows, but few high flows in middle-to-late summer. The dearth of summer high flows in recent years reflects the failure of significant summer thunderstorms to materialize over the basin from 1978 to 1981. These storms returned in 1982 and 1983. A longer period of record would probably show the continued presence of the two high flow seasons that typified the pre-mining era.

6.2.2. Characteristics of Low Flows

Flow duration curves constructed for daily discharges in the Puerco River for the periods 1940 to 1946 and 1977 to 1982 further demonstrate the change in low flow conditions attributable to the continuous discharges of uranium mine dewatering effluents (Figure 6.3). Prior to mine dewatering, streamflow in the Puerco River at Gallup was greater than 1 cfs only 20 percent of the time (Curve A). In fact, the stream was normally dry. Since mine dewatering, however, the Puerco River has been perennial. The median discharge (that flow that has been equalled or exceeded 50 percent of the time) is now about 5 cfs at Gallup (Curve B) under the new artificial flow regime.

The Pipeline Arroyo/Puerco River system is now perennial from the Church Rock mines to as far as Arizona, a distance of about 50 river miles. Eventually, unless naturally augmented, all surface flow is lost to infiltration, evaporation, and transpiration. Comparison of median flow at Church Rock (Curve C) and Gallup (Curve B) suggests that about 2.5 cfs of flow is lost between these two gages. As the Puerco River continues into Arizona, its flow eventually becomes intermittent and then ephemeral.

6.2.3. Annual Water Yield

Annual water yield, or the yearly volume of surface flow, in the Puerco River at Gallup has increased substantially because of mine dewatering (Table 6.2). The logarithmic mean annual water yield at Gallup was about 1900 cfs-days in the 1940s. This is assumed to be representative of pre-mining conditions. The years 1977-1982 exhibit a logarithmic mean annual water yield of about 3400 cfs-days. These years, therefore, exhibit a 78 percent increase in water yield over pre-mining conditions.

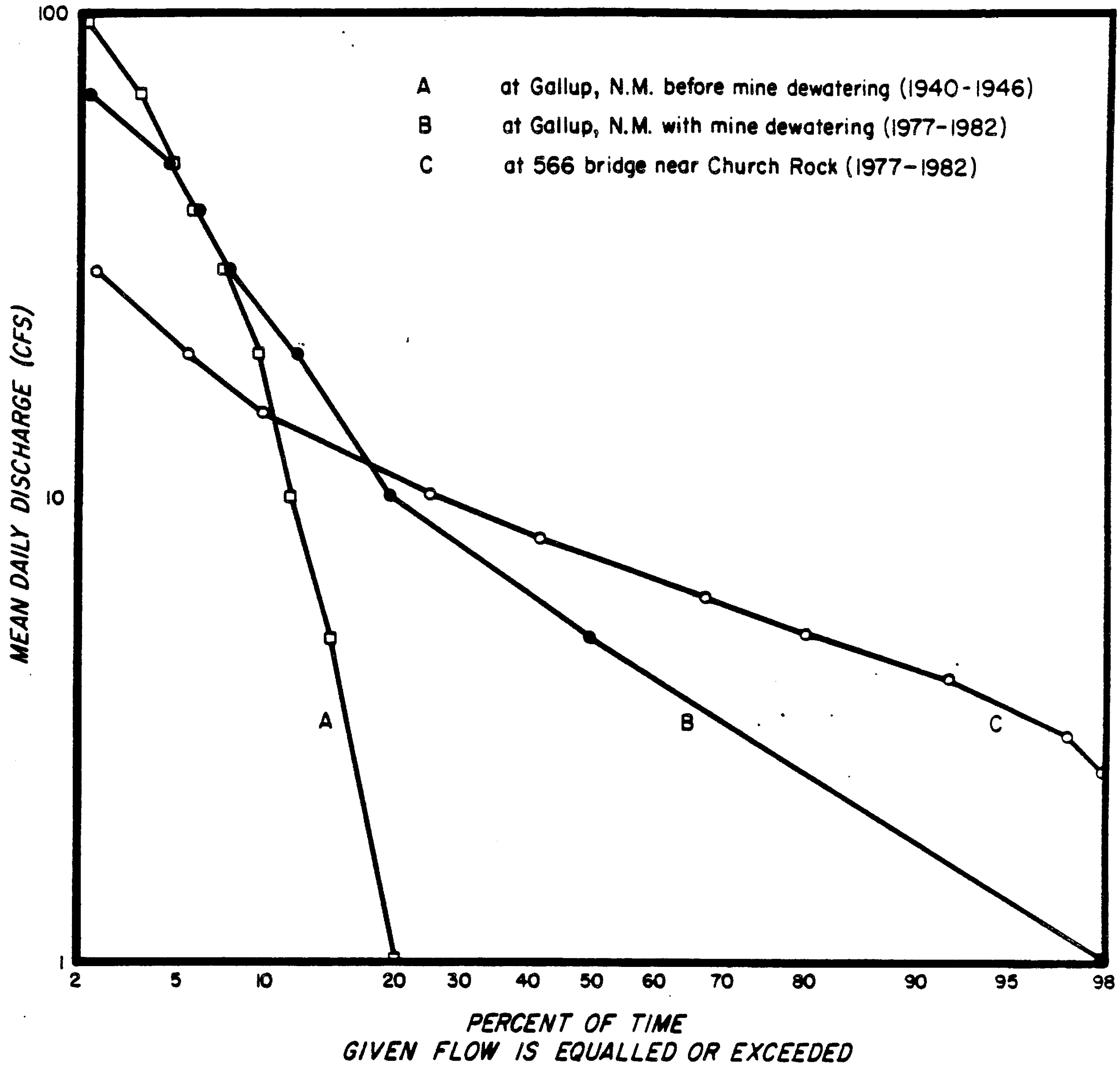


FIGURE 6.3 Flow duration curves for the Puerco River before mine dewatering and with mine dewatering

TABLE 6.2 Annual discharge for the Puerco River at Gallup before Mine Dewatering and with Flow Augmented by Mine Dewatering in cfs-days. Source: USGS.

BEFORE MINE DEWATERING		WITH MINE DEWATERING	
Water Year	Annual Discharge	Water Year	Annual Discharge
1940	7,283	1978	1,502
1941	1,459	1979	5,656
1942	2,893	1980	5,463
1943	741	1981	2,702
1944	3,264	1982	3,446
1945	645		
Log Mean	1,906		3,366

Although no stream flow data exist for San Mateo Creek before mine dewatering, flow records for 1977 through 1982 include periods both of active discharge to San Mateo Creek and of no discharge. Dewatering was ongoing in 1977, when flow measurement in San Mateo Creek began. At that time, about 2900 gallons per minute of dewatering effluents were released to San Mateo Creek (Perkins and Goad, 1980). Beginning in spring 1978, however, virtually all effluents were diverted for irrigation and to an adjacent drainage basin and did not reach San Mateo Creek. The impact of this diversion on flow in the stream can be seen in Figure 6.4. It is clear that the dewatering effluents maintained a small perennial stream at the gage site. Without the minewaters, flow in San Mateo Creek at the gage site is much reduced and ephemeral.

6.3 HYDROLOGIC IMPACTS ON REGIONAL GROUND WATERS

Streams created by the discharge of dewatering effluents are, with the possible exception of a few reaches, losing flow to the subsurface. While some surface flow is evaporated or transpired, a large volume infiltrates into the arroyo beds, and thereby recharges the shallow alluvial aquifers of the Puerco River, Arroyo del Puerto, and San Mateo Creek, among others.

Rates of infiltration were probably greater at the onset of mine dewatering than they are today because of a gradual "filling" of available storage in the alluvium. Infiltration rates along Arroyo del Puerto and San Mateo Creek are rapid Relative to the Puerco River, due to an abundance of sandy material in San Mateo Creek and because of influences of underlying dewatered bedrock aquifers. Gaging data indicate average stream bed losses along the San Mateo Creek of approximately 0.72 m^3/min/km, as compared with bed losses along the Puerco River of about 0.24 m^3/min/km (EPA 1983).

Infiltration has been estimated to range from at least 90 percent to perhaps 99 percent of mine discharge (EPA, 1983). A review of flow records from the Church Rock mining district showed seepage losses of 7.5 m^3/min in October 1975, and 7.25 m^3/min in July

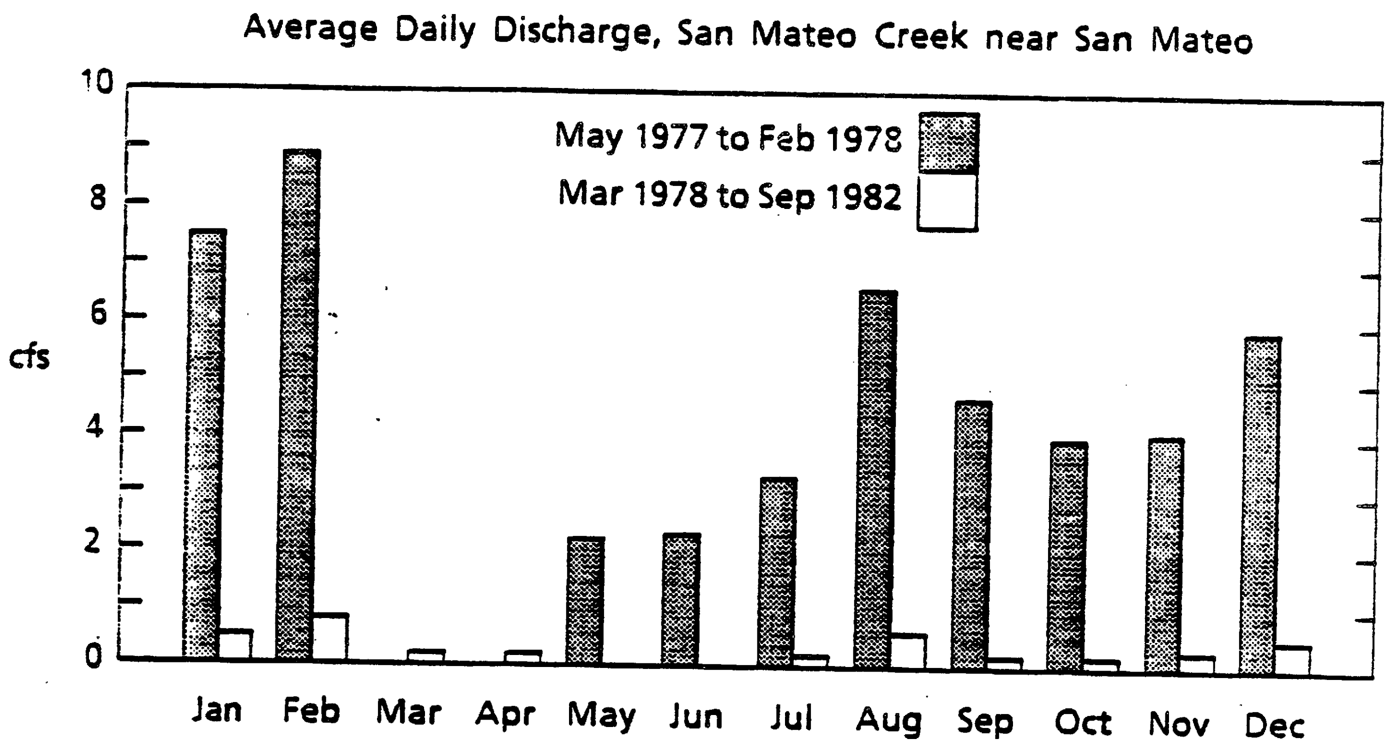


FIGURE 6.4 Average daily discharge for San Mateo Creek near San Mateo before and after diversion of mine dewatering effluents

1977 and May 1978. In the Ambrosia Lake mining district, infiltration was calculated at 7.54 m^3/min.

The overall hydrologic impact of mine dewatering on bedrock aquifers has been a region-wide acceleration of drawdown in these aquifers. In a limited number of stream reaches, however, the hydraulic connection between the alluvial aquifer and underlying bedrock allows some recharge of deeper sandstone aquifers (Lyford, 1979), i.e., water pumped from the mines is returned to the sandstone aquifers via recharge.

6.3.1. Hydraulic Connection Between Surface Waters and Shallow Ground Waters

While recharge generally is a continuous process along the minewater-dominated streams, it is intermittent under natural conditions. The intermittency of natural recharge largely minimizes the potential for dilution of contaminant concentrations in minewater affected ground water. Under natural conditions, ground-water levels most clearly demonstrate a response to surface flows in late winter and early spring. This period, usually February to April, is one of warming weather, melting snows, and gentle frontal rains. Stream flows during this period are usually increased above low winter flows. Moreover, these higher flows tend to be of long duration, often lasting several weeks. These flows, even though not of the magnitude of summer flash floods, provide a prolonged period of heightened flows that enhance infiltration to the underlying alluvium.

Figures 6.5 and 6.6 illustrate the intermittency of recharge from natural runoff along a reach of San Mateo Creek. In March and early April of 1980, a time when mine dewatering discharges to the channel were insignificant, occasional flows of less than 1 cfs, recharged the alluvium and caused the water table to rise slowly (Figure 6.5). In late April, however, stream flow increased to as great as 3 cfs. The period of increased flow was almost two weeks long, ending on April 29, 1980. Ground water response to the elevated flows was rapid: the water table began to rise within one week and peaked in mid-May, more than one foot higher than in mid-April.

In general, shallow ground water levels are much less responsive to summer flash floods. Such floods exhibit peak discharges often as great as several thousand cfs, but their potential for recharging ground water is offset by their brevity. The large volumes of thunderstorm runoff usually traverse miles of arroyo bed in a matter of hours. While most of the water eventually does infiltrate, it may penetrate only a short distance into the alluvium. Very little water reaches the water table; most is ultimately evaporated or transpired.

The relationship between surface flows and ground water levels in summer is illustrated in Figure 6.6. After receiving significant recharge in late April 1980, the alluvial aquifer underlying San Mateo Creek experienced a declining water table through the summer. Brief runoff events generated by thunderstorms during August had an insignificant impact on the declining levels. Even the high flows of September, which had an instantaneous peak discharge of 16 cfs (U.S. Geological Survey, 1980), failed to percolate to the underlying alluvial aquifer in noticeable quantities. While summer flash floods resulting from thunderstorms are probably too short-lived to significantly recharge alluvial aquifers, San Mateo Creek and other alluvial systems in the region do demonstrate a close hydraulic connection that is most responsive to late winter and spring stream flow.

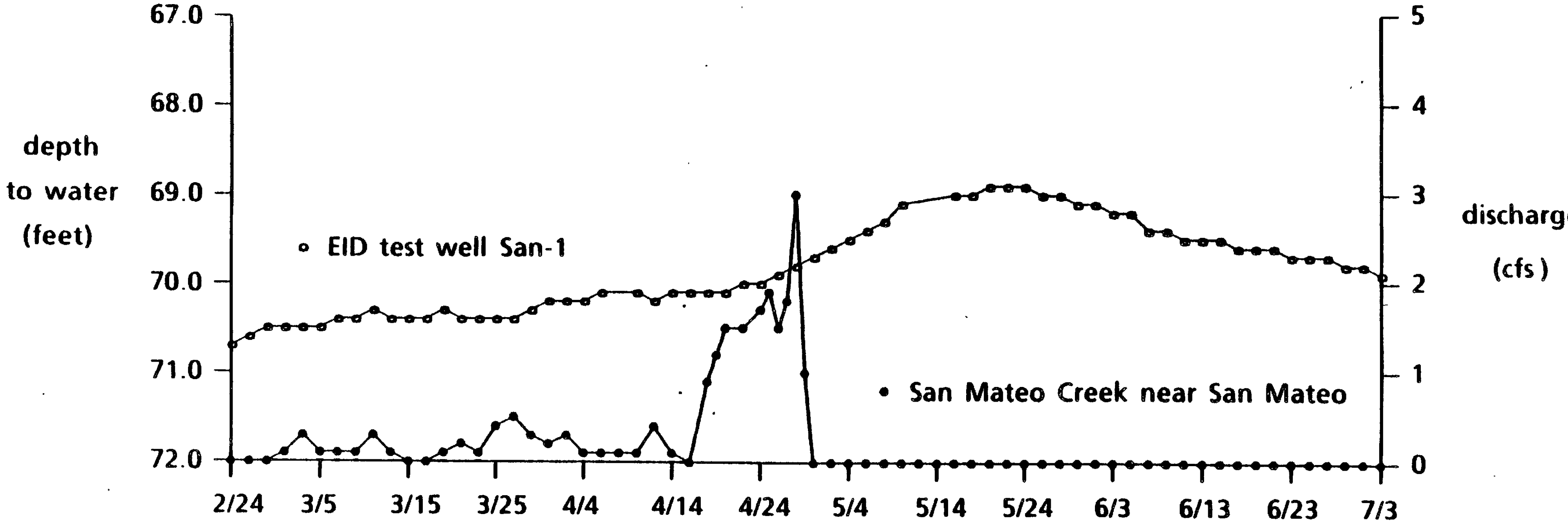


FIGURE 6.5 Streamflow and ground-water levels at the San Mateo Creek near San Mateo gaging site, February-July, 1980

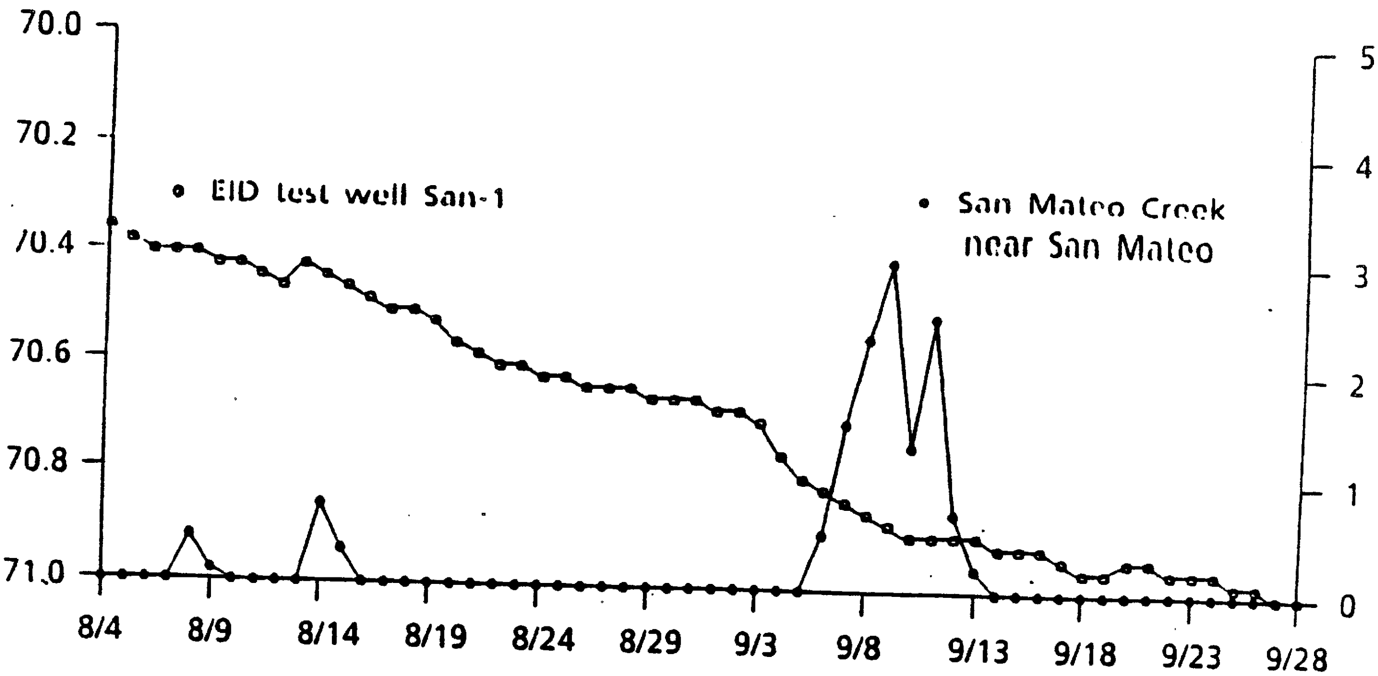


FIGURE 6.6 Streamflow and ground-water levels at the San Mateo Creek near San Mateo gaging site, August-September, 1980

6.3.2. Storage of Water in Alluvial Aquifers

Much of the water resulting from the dewatering of uranium mines has gone into storage in valley fill aquifers. Indeed, in the Ambrosia Lake district, water tables in affected aquifers may have risen as much as 50 feet between the onset of mine dewatering in the 1950s and the late 1970s (Kerr McGee Nuclear Corp.,1981).

Minewater production has been greatly reduced in the Ambrosia Lake district in recent years. Major minewater producers of the 1960s and 1970s (Kerr-McGee and Ranchers Exploration, for example) have drastically curtailed or completely ceased their discharges of dewatering effluents into San Mateo Creek and Arroyo del Puerto. Cessation of minewater discharges in this drainage basin has resulted in a diminished volume of water recharging the alluvium. Water levels in well OTE-1, below the confluence of Arroyo del Puerto and San Mateo Creek, showed continuous decline from March 1978 to March 1982 (Figure 6.7). During this time the water table at this site fell a total of eight feet, a rate of 2.0 feet per year. Alluvial water levels subsequent to the cessation of mine dewatering now appear to be returning to their natural conditions.

6.3.3. Bedrock Aquifers

For the most part, ground water recharge by dewatering effluents is limited to the shallow alluvial aquifers. There are a few stream reaches, however, in which the saturated valley fill overlies permeable bedrock with a downward hydraulic gradient. These places are recharge zones for northward dipping bedrock aquifers such as the Morrison Formation. At these localities, dewatering effluents are drawn by the downward gradients into the alluvium and eventually into the underlying sandstone.

Recharge of bedrock units by minewaters is seen to occur at varying degrees in virtually all of the mining districts where minewaters flow across bedrock subcrops or outcrops (Figure 6.8). This recharge mechanism has been noted in the Church Rock area by Raymondi and Conrad (1983) and Gallaher and Cary (1986); at Ambrosia Lake by Kaufmann, Eadie, and Russell (1976), Brod and Stone (1981), and Stephens (1983), and near San Mateo by Gulf Minerals Resource Co. (1979).

The total volume of minewater which enters the bedrock units probably represents only a small fraction of that which infiltrates to the shallow alluvial aquifers. Nevertheless, in the Ambrosia Lake district, effluents discharged to the Arroyo del Puerto and to the San Mateo Creek constitute a significant proportion of the locally derived recharge in the Dakota and Morrison Formations.

Recharge of the Morrison Formation by minewaters within the drainages is encouraged by regional dewatering of the unit by the mines. Despite some return flow of formation waters, local water level declines in excess of 500 feet have resulted from the dewatering (Lyford and others, 1980).

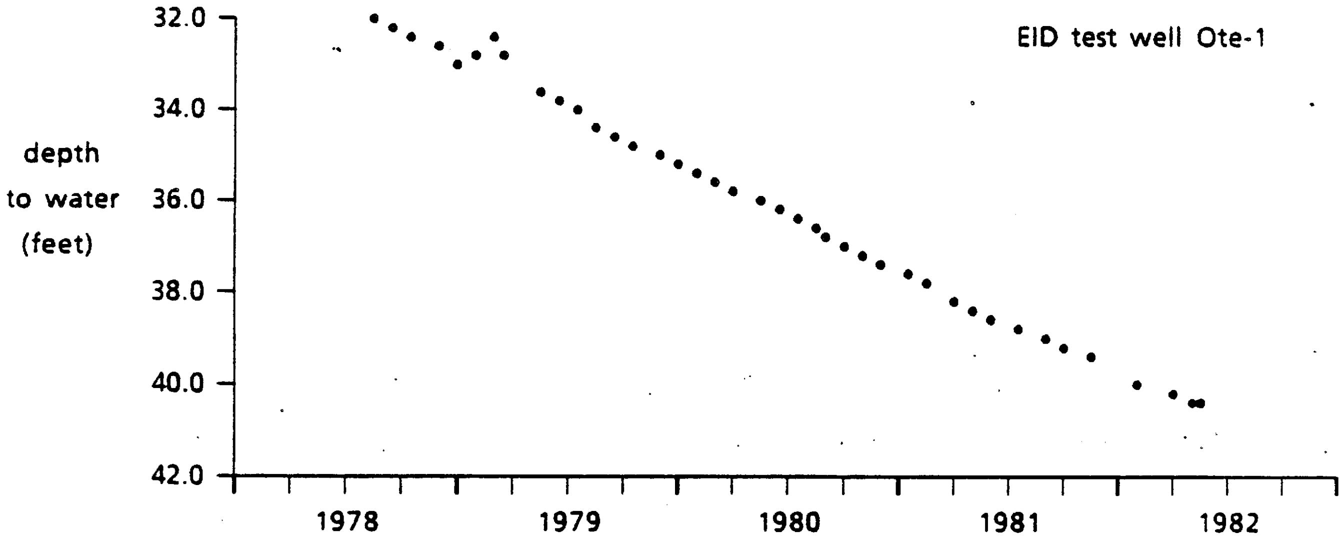


FIGURE 6.7 Ground water levels at EID test well OTE-1, 1978-1982

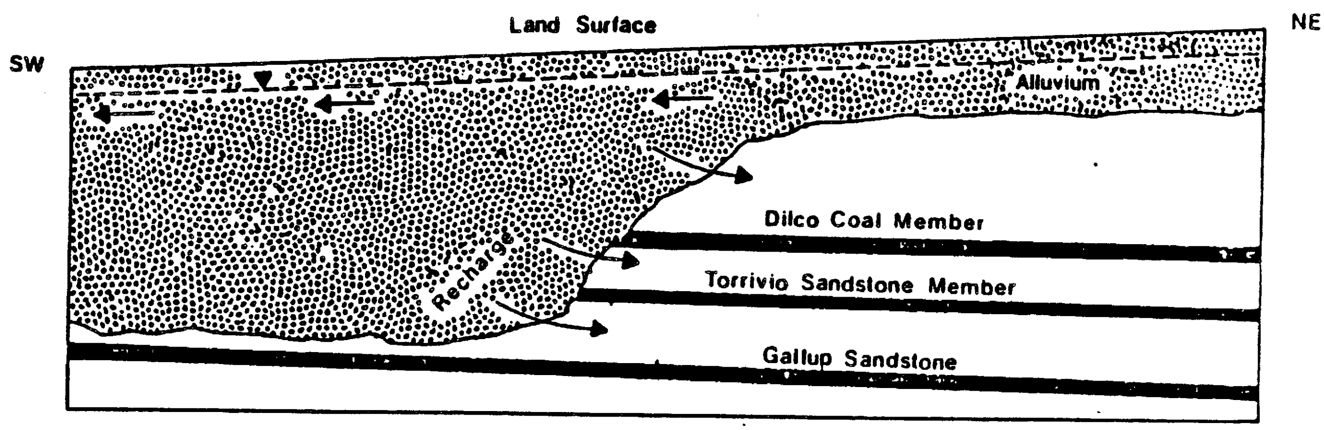


FIGURE 6.8 Conceptual diagram illustrating alluvial aquifer ground water recharge to underlying bedrock aquifers (after Raymondi and Conrad, 1983).

VII. IMPACTS OF MINE DEWATERING EFFLUENTS ON SURFACE WATER QUALITY

This chapter documents the chemical influences that mine dewatering effluents have had on the natural surface water environment. The chemical quality of treated minewaters differs in several important ways from the chemical quality of receiving surface waters. Dewatering effluents are most often different with respect to amounts of total dissolved solids and suspended sediments, general ionic composition, and concentrations of trace elements and radionuclides associated with uranium ore deposits.

In most affected drainages, dewatering effluents constitute a substantial portion of the total amount of water. Therefore, water quality characteristics of receiving streams frequently have been altered to reflect the chemical character of minewater rather than their natural quality. A comparison of the quality of effluent streams with regulatory standards is presented in Chapter IX.

7.1 RAW MINEWATERS

A review of the literature indicates that various trace elements, radionuclides, and dissolved salts can be found in raw (i.e. untreated) uranium mine dewatering effluents (Clark, 1974; U.S. EPA, 1975; Perkins and Goad, 1980). In raw minewaters in the Grants Mineral Belt (Table 7.1), the constituents present at elevated concentrations are 1) gross alpha and beta particle activities and the radionuclides radium-226, lead-210, and natural uranium; 2) the trace elements molybdenum and selenium and; 3) dissolved solids, particularly sulfate. Occasionally, barium, arsenic, and vanadium are detected at elevated concentrations in raw minewaters.

It was only in the past decade that mine dewatering effluents received any noteworthy treatment before their release into Grants Mineral Belt drainages. Until that time thousands of gallons per minute of raw minewaters were discharged to Arroyo del Puerto and the Puerco River. As suggested by Table 7.1, these waters often contained high levels of uranium, radium-226, and gross alpha particle activity.

7.2 TREATED MINEWATERS

Beginning in the mid-1970's, the quality of minewaters discharged to watercourses began to improve, because many mine operators adopted minewater treatment systems. The basic treatment strategy is outlined by Perkins and Goad (1980):

> Once the water pumped from a mine reaches the surface it usually goes through one or more mine water settling ponds. At most facilities a flocculant is added to promote settling. Barium chloride is usually added to the liquid after it has gone through one or more suspended solids settling ponds. Further settling and precipitation of radium as a barium sulfate salt then occurs as the liquid moves through additional settling pond(s). Where uranium levels are high enough to justify it, the liquid is usually run through an ion exchange (IX) plant for recovery of uranium contained in the mine water. The IX plant may either precede or follow barium chloride treatment.

As a result of treatment, minewater concentrations of radium-226, lead-210, polonium-210, natural uranium, and gross alpha activity are considerably reduced. Concentrations of most other minewater constituents, though, are not greatly influenced by these treatments. As

TABLE. 7.1. Quality of Raw Minewater at Active Mines, 1980 - 1982. All data reflect total concentration in grab samples collected by EID personnel.

CONSTITUENT	AMBROSIA LAKE MINING DISTRICT				CHURCH ROCK MINING DISTRICT			
	MAX.	MIN.	MEDIAN	SAMPLE SIZE	MAX.	MIN.	MEDIAN	SAMPLE SIZE
	(mg/l)							
TDS	1,800	740	1,235	10	960	434	525	9
SO_4	1,030	310	715	10	458	126	156	9
	(mg/l)							
As	0.08	0.008	0.021	8	0.40	0.005	0.008	6
Mo	5.30	<0.01	1.19	10	0.791	0.008	0.030	6
Se	1.22	0.014	0.075	10	0.071	0.011		6
U-natural	20.0	1.56	3.82	10	27.30	2.100	4.3460	6
	(pCi/l ± one sigma standard error of counting)							
Gross alpha	11,900 ± 1,400	490 ± 50	3,050 ± 300	14	24,000 ± 1000	460 ± 30	3,205 ± 150	10
Gross beta	6,550 ± 590	30 ± 16	280 ± 7	14	6,440 ± 550	530 ± 100	1,320 ± 200	6
Pb - 210	1,300 ± 100	15 ± 4	690 ± 52	4	1,200 ± 100	44 ± 4	--	2
Po - 210	14 ± 2	0.95 ± 0.35	4 ± 0.5	4	10 ± 1	3.4 ± 0.4	--	2
Ra - 226	1,650 ± 50	30 ± 9	280 ± 7	14	2,500 ± 800	7.0 ± 0.2	295 ± 5	10
Th - 228	0.6 ± 0.3	-0.1 ± 0.1	0.0 ± 0.1	5	0.1 ± 0.1	-0.2 ± 0.2	--	2
Th - 230	1,400 ± 100	0.2 ± 0.1	3.3 ± 0.5	5	210 ± 10	0.1 ± 0.1	--	2
Th - 232	4.0 ± 0.2	0.0 ± 0.1	0.0 ± 0.1	5	0.1 ± 0.1	0.0 ± 0.1	--	2

demonstrated in Table 7.2, a seven-fold reduction in average radium-226 and natural uranium concentrations in treated minewaters is found when 1975 data are compared with 1981-82 data.

TABLE 7.2 Comparison of 1975 Mine Dewatering Effluent Quality with 1981-82 Quality. Number of samples in parentheses.

Constituent	Flow-Weighted Means	
	1975*	1981-82**
Total Radium-226 (pCi/l)	71.2 (23)	10.5 (15)
Total Uranium-natural (mg/l)	7.25 (23)	1.0 (14)

* Calculated from data in U.S. EPA (1975).
** Calculated from data in EID files.

The quality of treated mine effluents during the period 1978 through 1982 is summarized for key constituents in Table 7.3. It is readily evident that substantial variability in water quality exists between the two major mining districts, as well as within each mining district. Most striking in this regard are the concentrations of total dissolved solids, sulfate, molybdenum, selenium, and radium-226.

The wide range in radium-226 concentrations reflects occasional poor operation of the radium treatment systems. Thomson and Matthews (1981) attribute these "upsets" to incomplete mixing of the mine waters with barium chloride and to poor settling of the barium-radium sulfate precipitates. Variability in molybdenum, selenium, sulfate, and total dissolved solids, on the other hand, cannot be attributed to ineffectual treatment. This variability instead reflects chemical differences in the ground waters discharged from the mines, as indicated in Table 7.1.

As would be expected, sludges which accumulate in the minewater treatment pond bottoms as a result of settling, floculation, and precipitation are highly concentrated in radium-226 and other radionuclides. Analyses presented by Perkins and Goad (1980) and additional data in EID files indicate that the radium-226 concentrations in the accumulated sludges probably average more than 200 pCi/gram. Under standards proposed by EPA (1976), uranium mine wastes with a radium-226 concentration in excess of 5 pCi/gram would be treated as hazardous materials and subject to special handling and disposal procedures.

7.3 EFFECTS OF MINE DEWATERING EFFLUENTS ON SURFACE-WATER QUALITY

The previous chapter discussed the significant effects that discharge of minewater effluents has had on the hydrology of watercourse in the Grants Mineral Belt. Effects on water quality have been similarly significant. This section discusses how the quality of these effluents differs from the quality of runoff that constitutes the natural water quality of the stream and how the quality of these artifically maintained streams changes as the waters flow downstream.

7.3.1. Comparison of the Quality of Mine Dewatering Effluents with Natural Runoff Quality

Under natural, pre-mining conditions, watercourses receiving mine dewatering effluents, such as San Mateo Creek and the Puerco River, often have low flows or are even dry. When flow occurs in these watercourses, it is the result either of storm runoff or of runoff from snow melt. Therefore, comparison of the quality of mine dewatering effluents with natural storm runoff

TABLE. 7.3 Quality of Treated Minewater at Active Mines, 1977-1982. All data reflect total concentrations in grab samples collected by EID personnel. Number of samples in parentheses.

CONSTITUENT	AMBROSIA LAKE MINING DISTRICT				CHURCH ROCK MINING DISTRICT			
	MAX.	MIN.	MEDIAN	AVG.	MAX.	MIN.	MEDIAN	AVG.
	mg/l							
TDS	2,615	510	1,610	1440 (26)	1,190	360	452	580 (16)
SO_4	1,370	185	755	655 (22)	600	60	136	210 (17)
As	0.20	<0.005	0.011	0.02 (26)	0.02	<0.005	<0.005	0.007 (16)
Ba	1.7	0.1	0.21	0.24	2.1	0.10	0.413	0.5 (15)
Mo	3.2	0.03	0.80	1.0 (27)	0.6	0.01	0.01	0.2 (15)
Se	1.0	0.01	0.09	0.24 (27)	0.3	0.01	0.04	0.07 (15)
U natural	3.0	0.2	1.56	1.5 (26)	1.8	0.6	1.07	1.0 (14)
V	0.29	<0.01	0.029	0.08 (21)	0.07	0.01	0.012	0.02 (13)
	pCi/l ± SE*							
Gross alpha	1,760 ± 100	54 ± 14	635 ± 70	780 (14)	1,200 ± 100	280 ± 30	440 ± 40	600 (11)
Gross beta	945 ± 225	84 ± 16	377 ± 125	435 (6)	663 ± 125	322 ± 30	460 ± 74	480 (6)
Pb - 210	33 ± 6	6.9 ± 2.6	14 ± 5	15 (9)	10 ± 2	4.5 ± 2.3	--	-- (2)
Po - 210	14 ± 2	0.95 ± 0.35	1.1 ± 0.4	6 (4)	15 ± 5	3.4 ± 0.4	9.8 ± 7.4	10 (13)
Ra - 226	200 ± 10	0.12 ± 0.04	6.4 ± 1.2	27 (28)	89 ± 5	0.67 ± 0.2	2.0 ± 0.2	10 (13)
Ra - 228	0 ± 2	0 ± 2	0 ± 2	0 (5)	<0.2	<0.2	--	-- (2)
Th - 228	<0.3	<0.1	<0.1	0.2 (3)	0 ± 2	0 ± 2	--	-- (2)
Th - 230	4.0 ± 0.5	<0.3	0.7 ± 0.2	1.7 (3)	3.9 ± 0.5	<0.2	--	-- (2)
Th - 232	<0.1	<0.1	<0.1	<0.1 (3)	<0.2	<0.2	--	-- (2)

*SE = Standard Error of Measurement (one sigma) quality provides an indication of how the change from ephemeral to artificially-maintained perennial watercourses has affected chemical quality.

Suspended Sediment

In all effluent-dominated watercourses, suspended sediment concentrations under minewater baseflow conditions are smaller than the concentrations borne by thunderstorm runoff (see Chapter IV). EID and uranium industry self-monitoring data indicate that these simple treatment measures, used to remove radium-226 before discharge to watercourses usually reduce suspended sediment concentrations from more than 100 mg/l in the untreated minewater to less than 10 mg/l in the final effluent. Runoff has average suspended sediment concentrations greater than 30,000 mg/l.

Although treated minewaters are relatively free of sediment when they are discharged, they eventually become burdened with suspended silts and clays. Stream channels in the Grants Mineral Belt which receive mine dewatering effluents are relatively free of suspended sediments just below the point of minewater discharge. Silt and clay particles are entrained from the channel bed as flow continues downstream. On November 13, 1980, for example, suspended sediment concentration increased from 52 mg/l below the Kerr-McGee Church Rock I mine outfall in Pipeline Arroyo to 3500 mg/l in the Puerco River in Gallup approximately 19 miles downstream. Similar trends were evident on other days as well.

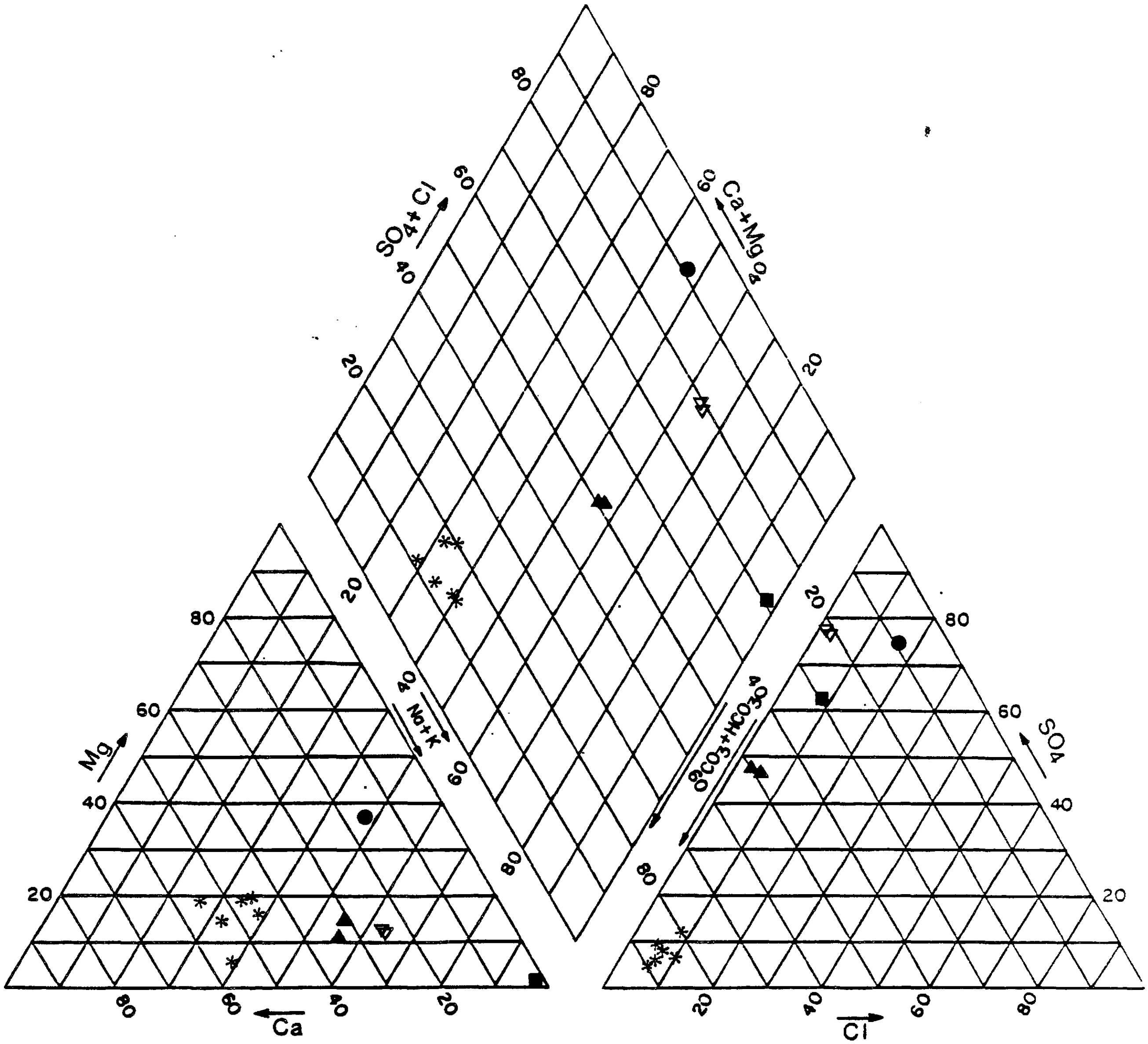
San Mateo Creek in the Ambrosia Lake district also entrains sediment. The prevalence of sand over fine-grained sediments in the San Mateo Creek alluvium, however, causes suspended sediment concentrations, typically less than 400 mg/l, to be lower than in the Puerco River system.

Dissolved Solids

Concentrations of total dissolved solids (TDS) in minewaters are variable in the Grants Mineral Belt. In the western portions of the Ambrosia Lake mining district, mines produce waters with 1200 to 1800 mg/l TDS (Perkins and Goad, 1980). These concentrations are reflected in Arroyo del Puerto, where TDS concentrations are often 1500 to 2,000 mg/l. Mixing of mine dewatering effluents with natural waters resulting from runoff occasionally dilutes TDS levels in this watercourse to less than 1,000 mg/l. Minewaters discharged to Arroyo del Puerto thus bear about twice the concentration of dissolved solids of that in natural runoff in the area, which is typically below 1,000 mg/l TDS.

In contrast, minewaters produced in the Church Rock and the eastern portion of the Ambrosia Lake districts usually contain only a few hundred mg/l TDS. Data presented by Perkins and Goad (1980) demonstrate that effluents discharged to Pipeline Canyon and San Mateo Creek contain only 300 to 600 mg/l TDS. TDS values in natural runoff are quite similar. In the these areas, therefore, minewaters have not influenced the TDS concentrations of receiving streams. It is noteworthy that the TDS concentrations are only one-fourth of those found in western portion of the Ambrosia Lake minewaters despite the fact that all minewaters are produced largely from the Morrison Formation. High TDS concentrations in the western portion of the Ambrosia Lake district have been attributed to greater mineralization of the host rock and to dewatering-induced leakage of more saline ground water into the mines from the overlying Dakota Formation (Brod, 1979; Kelley and others, 1980).

The relative concentrations of specific ions in minewaters appear to differ from concentrations found in natural runoff. Analysis of Figures 7.1 and 7.2 indicates that minewaters generally have proportionally more sodium and sulfate than natural runoff.



* Natural runoff

MINES

● Homestake IX

▽ Kerr-McGee Sec. 35 & 36

▲ Ranchers' Johnny M

■ Gulf Mt. Taylor

FIGURE 7.1 Comparison of the ionic composition of mine dewatering effluents and natural runoff, Ambrosia Lake mining district. Ions are expressed as percentage of total equivalents per liter.

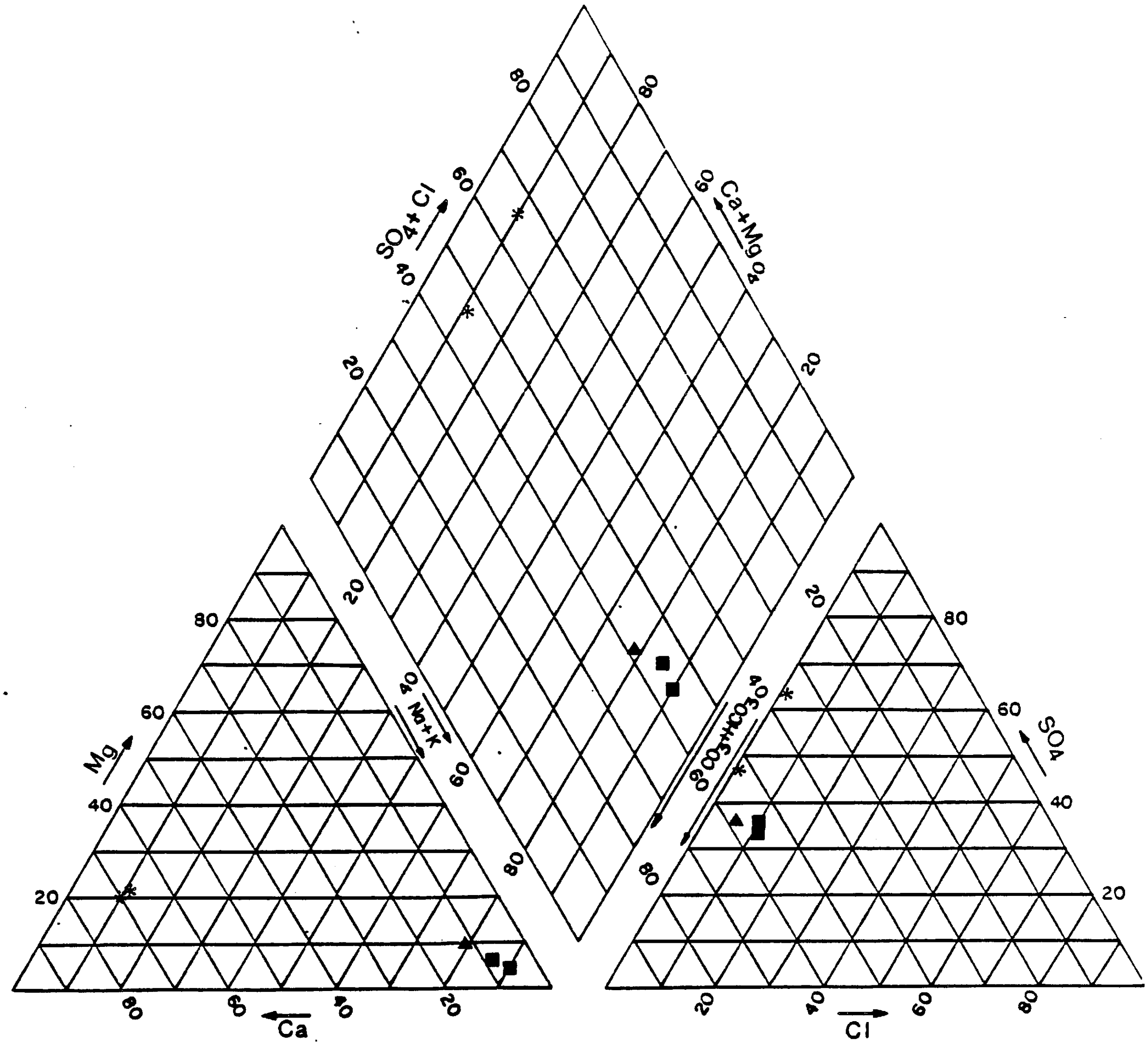


FIGURE 7.2 Comparison of the ionic composition of mine dewatering effluents and natural runoff, Church Rock mining district. Ions are expressed as percentage of total equivalents per liter.

Total versus Dissolved Concentrations

In contrast to natural runoff in which contaminants are largely associated with suspended sediment and precipitates, trace elements and radionuclides in treated minewaters are generally present in the dissolved form. The proportions of minewater contaminants in the dissolved phase are highly variable, but typically the dissolved fraction of a contaminant constitutes more than 50 percent of the total concentration (Table 7.4). Usually, more than 85 percent of the total concentration of gross alpha activity, molybdenum, selenium, and natural uranium in minewaters is in the dissolved fraction. Dissolved radium-226 proportions average about 30 percent of the total concentration.

The following discussion of trace elements and radionuclides focuses on comparison of total constituent concentrations in treated minewaters with total concentrations in natural runoff. Direct comparisons of dissolved concentrations are limited by the amount of available data. Nonetheless, based on information in Table 7.4, it can be assumed for many contaminants that even if minewaters and runoff have nearly equivalent total contaminant concentrations, then the dissolved concentrations in minewaters are probably significantly greater than in natural runoff, particularly for gross alpha particle activity, molybdenum, selenium, and natural uranium.

Trace Elements

Of the nine trace elements routinely analyzed in treated minewaters, only the concentrations of molybdenum, selenium, and uranium are consistently higher than in natural runoff (Figure 7.3). Since these trace elements are known to be naturally associated with uranium ores, their presence in surface watercourses suggests that the watercourse is receiving mine dewatering effluents. Arsenic, vanadium, and barium are occasionally detected in significant concentrations in minewaters, the latter because it is added in the treatment process to remove radium-226. Cadmium, lead, and zinc are usually below detectable levels in dewatering effluents and are therefore judged not to be of concern in these waters.

Uranium is the trace element with the highest concentrations in mine effluents throughout the Grants Mineral Belt. The median concentrations of total uranium in Ambrosia Lake and Church Rock effluents of 1.6 and 1.1 mg/l, respectively, are over 16 and 37 times greater than the median concentrations of natural runoff in the districts.

Molybdenum levels in minewaters vary from extremely low levels to more than 3 mg/l. Discharges in the Ambrosia Lake district have median total molybdenum concentrations of 0.80 mg/l. In comparison, only a small fraction of the natural runoff samples collected during this study contained detectable concentrations (> 0.01 mg/l) of total molybdenum. Lower concentrations are found in the Church Rock district, where the median total molybdenum concentration in effluents is 0.01 mg/l.

The third element that is consistently higher in mine dewatering effluents than in natural runoff is selenium. Treated effluent normally contains less than 0.04 to 0.09 mg/l selenium, but a few Ambrosia Lake mines discharge effluent with selenium concentrations approaching 1.0 mg/l. In contrast, data indicate median total selenium levels in natural runoff of 0.03 mg/l in Ambrosia Lake district and <0.005 mg/l in the Church Rock district.

Two other metals that occasionally appear in dewatering effluents are arsenic and vanadium. Elevated levels of arsenic and vanadium appear to be restricted to one facility in the region. The discharge from the Homestake ion exchange facility in Ambrosia Lake contains average total arsenic and vanadium concentrations of 0.05 and 0.17 mg/l, respectively.

TABLE 7.4 Percentage of Total Constituent Concentrations in the Dissolved Phase of Treated Minewaters, Ambrosia Lake and Church Rock Mining Districts, 1980.

CONSTITUENT	NO. OF SAMPLES	PERCENT IN DISSOLVED PHASE	
		RANGE	MEAN
As	3	12 - 90	57
Ba	5	<35 - 100	<71
Mo	6	88 - 100	95
Se	5	83 - 100	93
U-natural	5	68 - 100	89
V	5	20 - 100	61
Gross alpha	6	82 - 100	94
Gross beta	5	72 - 100	93
Ra-226	6	2 - 71	32

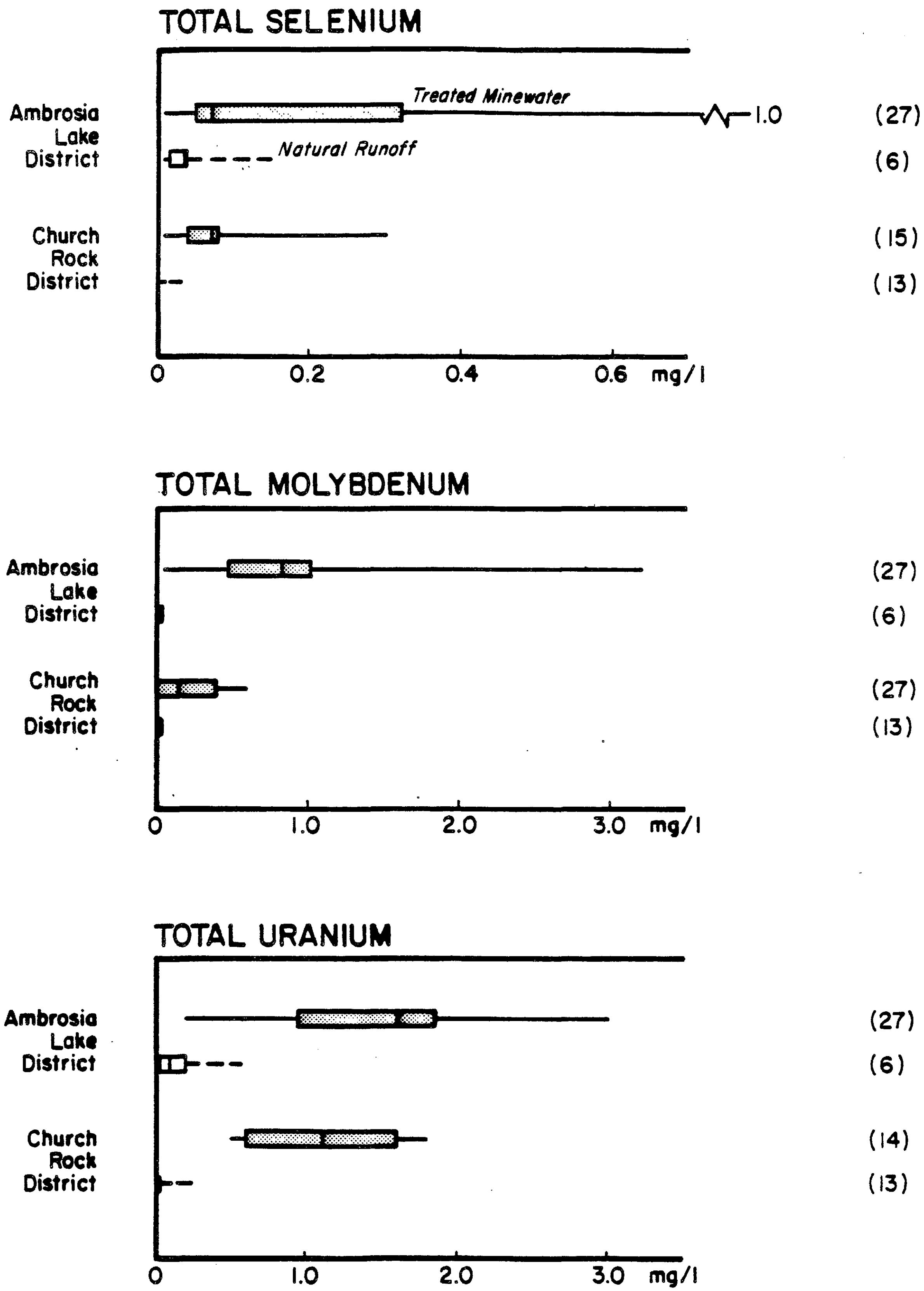


FIGURE 7.3 Comparison of selected total trace element concentrations in treated minewaters and natural runoff

Barium is of potential interest because it is added as barium chloride to co-precipitate radium-226 from minewaters before their discharge to watercourses. Median total barium concentrations in natural runoff in Ambrosia Lake and Church Rock districts are 7.7 and 4.8 mg/l, respectively. These are many times greater than the concentrations of 0.212 and 0.413 in treated minewaters from these districts.

Radionuclides

With the exception discussed above of natural uranium, median total concentrations of radionuclides in treated minewaters are less than those measured for natural runoff (Figure 7.4). Compared to natural runoff, however, minewaters have a higher, usually considerably higher, percentage of total radionuclide concentrations associated with the dissolved phase. EID data indicate that as much as 99 percent of the gross alpha and gross beta particle activities of natural runoff are associated with precipitates and suspended sediment. In contrast, over 90 percent of this radioactivity in treated minewaters is normally associated with the dissolved fraction (see Table 7.4). Total suspended sediments in dewatering effluents are quite low (averaging about 5 mg/l).

The total gross alpha particle activity of dewatering effluents is comparable to natural runoff levels. Dissolved gross alpha levels of several hundred to over 1,000 pCi/l in dewatering effluents, on the other hand, are ten to one hundred times greater than dissolved gross alpha levels in natural runoff (normally less than 20 pCi/l). On average, dissolved uranium accounts for more than 80 percent of the observed total gross alpha activity. Other alpha-emitters in the uranium-238 decay series (chiefly, thorium-230, radium-226, and polonium-210) are present in small concentrations in the effluents relative to uranium (see Table 7.3).

Median total gross alpha and beta concentrations are roughly equivalent in Ambrosia Lake and Church Rock mine effluents. Maximum concentrations of these constituents in Ambrosia Lake discharges, though, are about 40 percent greater than in the Church Rock discharges. The differences are most likely due to more effective ion-exchange treatment of the minewaters in the Church Rock district.

Despite high concentrations of radium-226 in raw minewaters, most mines discharge minewaters with 6 pCi/l or less of total radium-226 (Figure 7.4). While an average, of about 30 percent of the radium in these effluents may be in the dissolved form, natural runoff often exceeds 15 pCi/l in total radium-226, but is quite low in dissolved radium-226, usually less than 2 pCi/l. Three facilities, evidently sampled during "upset" conditions, discharged effluent containing 75, 89, and 200 pCi/l total radium-226, concentrations similar to concentrations in untreated minewater. Large influxes of dissolved radium-226 may be introduced to receiving watercourses from any mine with ineffective radium-removal processes.

None of the thorium isotopes or radium-228 are normally present in detectable levels in minewaters. Treated minewaters have exhibited up to 33 pCi/l of total lead-210 and up to 15 pCi/l of total polonium-210. Greater concentrations (several hundred pCi/l) may ocur during periods of ineffective minewater treatment. Although the data are limited, there does not appear to be significant differences between the Ambrosia Lake concentrations and those presented for the Church Rock district. Natural runoff, in comparison, typically contains between 40 to 90 pCi/l each of total lead-210 and polonium-210.

7.3.2. Fates of Minewater Constituents in Surface Drainage Channels

Of the trace elements and radionuclides identified earlier as being elevated above levels in natural runoff, only radium-226 and lead-210 are known to undergo significant partitioning

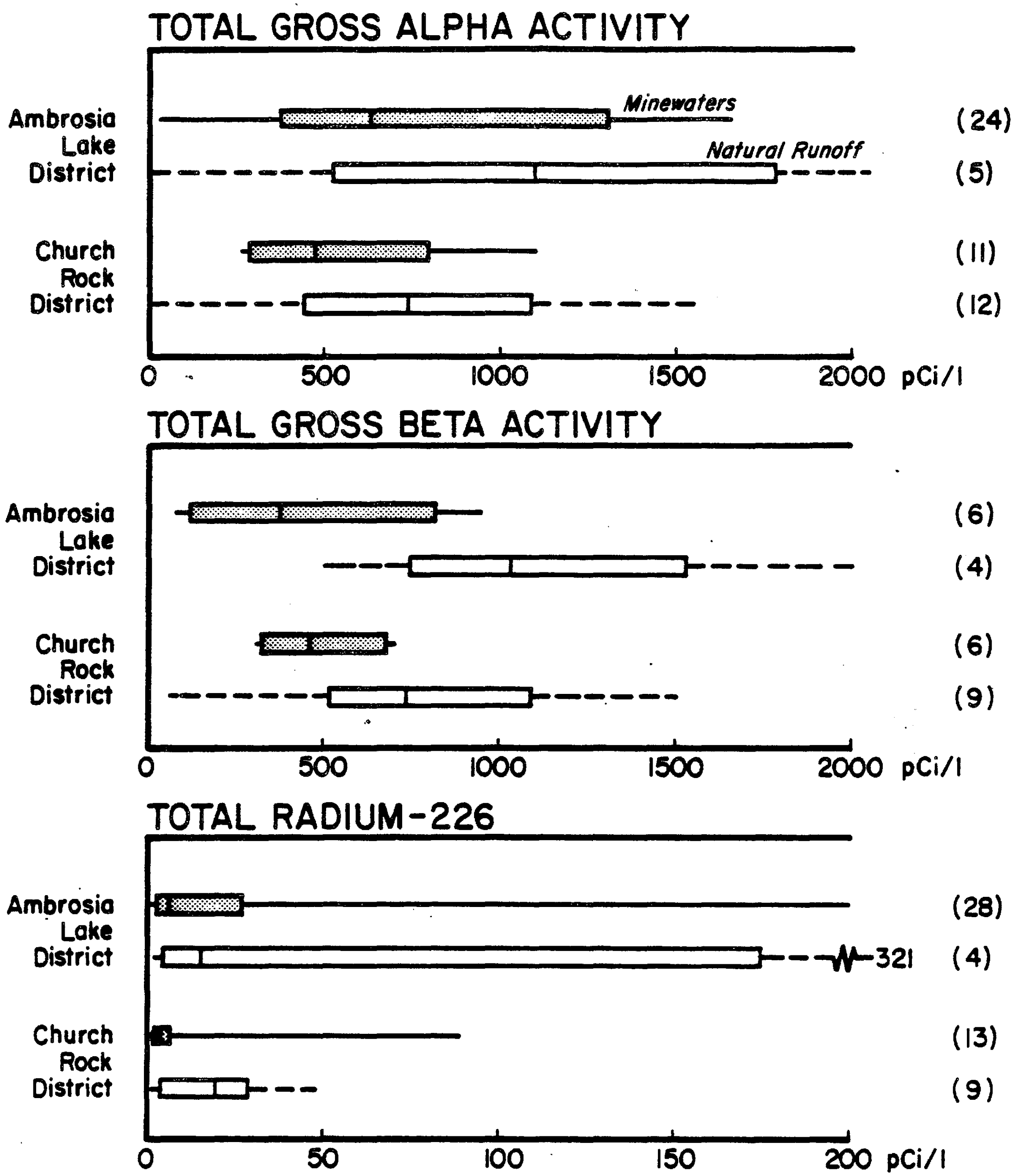


FIGURE 7.4 Comparison of total radioactivity in mine dewatering effluents and natural runoff

changes between dissolved and suspended phases as they travel downstream. These radionuclides are usually lost from solution shortly after their release to regional arroyos. Investigation of both dissolved and suspended phases revealed that precipitates and sediments suspended in the water account for virtually all these constituents. As shown in Table 7.5, a significant proportion of radium-226 is discharged to the Puerco River in dissolved form, but by the time radium-226 has travelled a few miles almost none remain in solution.

Once precipitated or bound to the stream sediments, minewater contaminants are subject to being moved downstream during normal artificially-maintained flows or, more significantly, during natural runoff events. During major streamflows, minewater-affected sediments are scoured from the stream bottoms, mixed with other sediments carried by the streamflows, and redeposited variable distances downstream. In drainages with sediment-rich streamflows, minewater-affected sediments generally become indistinguishable from other sediments carried along the watercourse and deposited on the stream bottom due to the large dilution factors involved and to the elevated levels of natural radioactivity in regional soils. Popp and others (1983) confirmed this along various drainages within the Rio Puerco watershed.

While dissolved radium-226 and lead-210 usually precipitate or are adsorbed by stream sediments, these radionuclides appear to stay in solution in stream channels that are relatively sediment free. Dissolved radium-226 concentrations along the Arroyo del Puerto, for example, consistently range between 3 and 6 pCi/l.

Unlike radium-226 and lead-210, the trace elements uranium, molybdenum, and selenium, and the major dissolved solids generally are not rapidly attenuated in the channels of receiving waters. These constituents generally remain in solution and move downstream with the minewater. Figure 7.5 shows downstream changes in water quality along the Puerco River on October 6, 1976 as an example (U.S. Geological Survey, 1977). The data show that constituents not precipitating or interacting rapidly with sediment decline gradually in concentration downstream, but still may be found in significant levels 50 miles from the mines. The declines in selenium and gross alpha concentrations are most likely related to decreasing pH levels downstream. While the initial dissolved radium-226 concentration is significantly elevated in contrast with the radium-226 levels measured during this study, concentrations nevertheless decline rapidly downstream. Similar responses have been found by the U.S. Geological Survey and the EID at more typical concentrations.

Table 7.5 Comparison of dissolved versus suspended concentrations of radium-226 at sites along the Puerco River. Data represent average concentrations. Number of samples in parentheses.

Site	Dissolved Ra-226 (pCi/l)	Total Ra-226 (pCi/l)	Suspended* Ra-226 (pCi/l)	River Miles From Mines
Church Rock Mines	3.2**(13)	9.98(13)	6.78	----
Puerco R. at NM 566	0.22 (14)	8.06 (13)	7.84	5.1
Puerco R. at Gallup	0.11 (12)	7.93 (12)	7.82	18.5

*Determined by subtraction.
**Estimate based on data in Table 7.4.

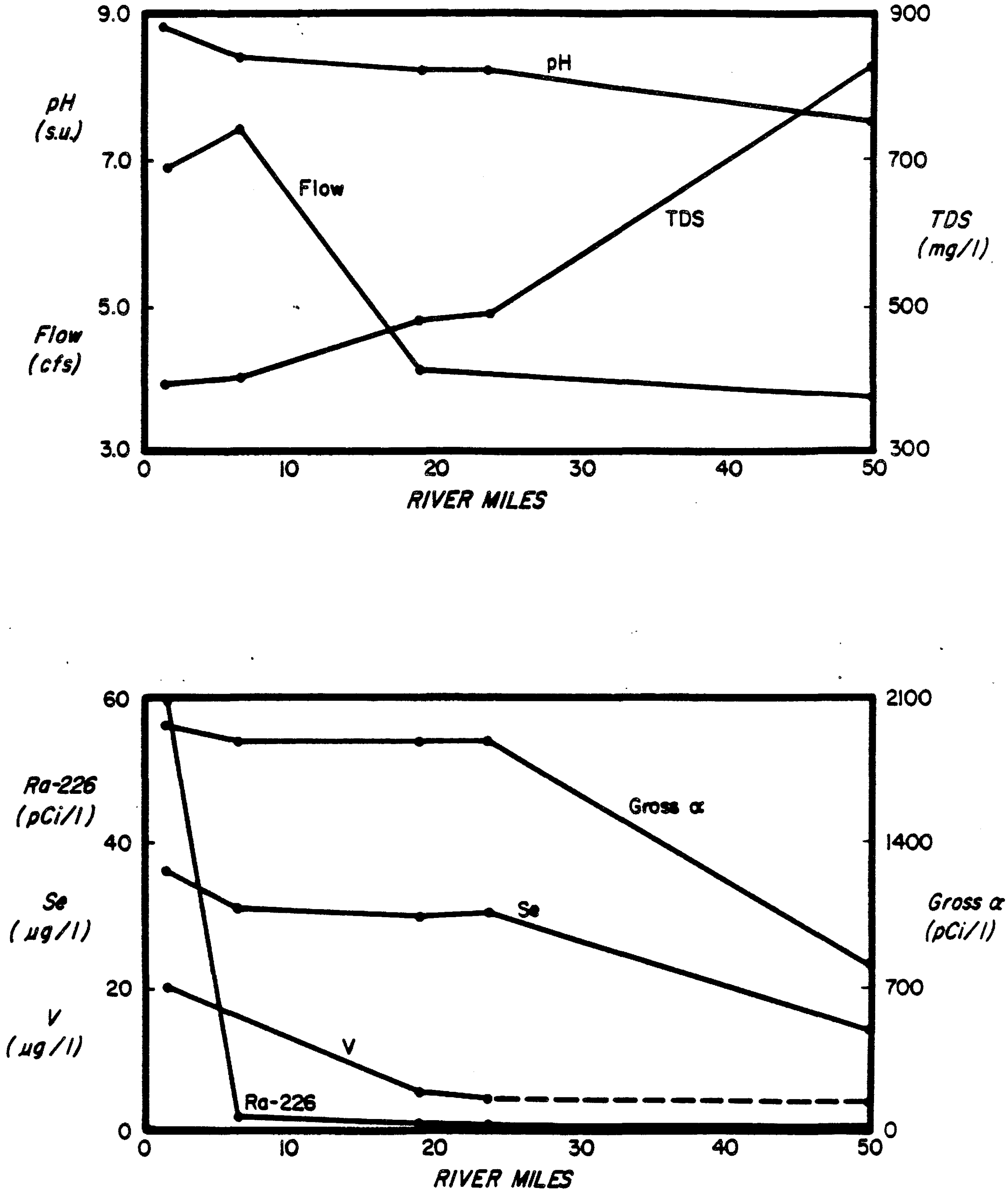


FIGURE 7.5 Water quality and flow along the Puerco River from the Church Rock mines to the New Mexico-Arizona border, October 6, 1976 (source: U.S. Geological Survey).

VIII. MINEWATER IMPACTS ON THE QUALITY OF SHALLOW GROUND WATERS

Release of dewatering effluents to Grants Mineral Belt arroyos greatly increased the volume of water infiltrating to shallow alluvial aquifers. This infiltration has been accompanied by a gradual change in the overall chemistry of these ground waters. In certain locations along San Mateo Creek and the Puerco River, the alluvial ground waters now bear a stronger chemical resemblance to minewaters than to natural waters. This condition is most pronounced in areas where stream-bottom leakage is high. Evaluation of this apparent change is somewhat hampered, however, by the lack of pre-mining ground water quality data.

Many of the impacts realized by surface waters are not experienced by underlying ground waters. Minewater constituents that adsorb to sediments or form insoluble precipitates do not usually reach ground waters. Chief among such constituents is radium-226. As shown previously, radium-226 quickly leaves solution in most Grants Mineral Belt streams, either by adsorbing to sediments or by forming insoluble precipitates, and thus is not found in significant concentration in alluvial ground water. On the other hand, chemical constituents that do not readily interact with earth materials or form insoluble precipitates, such as uranium, selenium or molybdenum, may be found in ground waters in concentrations approaching those in undiluted minewater and suggest ground water degradation from mine dewatering effluents.

Within the drainages studied effluent-dominated surface flows more closely approximate the infiltration capacity of the stream channel bottoms than those associated with natural runoff. The factor that most controls recharge volumes at any given location within these drainages, therefore, is duration of surface flow rather than flow rate or volume. Because of their perennial nature, effluents potentially may affect ground-water quality to a greater extent than would be projected from a comparison of volume of effluent-to-volume of natural runoff.

Variation of effluent seepage will cause fluctuations in ground water quality in the alluvium. For example, during spring runoff more dilution (mixing) of effluent with surface water takes place. This commingled water then may gradually with ground water in the alluvium. Under this condition, ground water quality is probably only locally affected. Conversely, under low-flow conditions and with the same amount of effluent discharged, ground water contamination may become more significant. Factors contributing to degradation of ground water quality include effluent quality and quantity, the amount of mixing of surface and ground water, permeability of the aquifer, surface and ground water quality, dispersion, advection, and the biological and geochemical processes taking place in the subsurface.

8.1 ESTIMATION OF NATURAL GROUND-WATER QUALITY

While the available data are limited, natural, alluvial ground-water quality can be generally described for some constituents. Pre-mining analyses in the Ambrosia Lake and Church Rock mining districts are limited in quantity and scope. Due to the rural nature of San Mateo Creek and the North Fork of the Puerco River, minimal testing of wells was performed before 1974. Most of the pre-mining data are limited to one-time samplings of a few isolated windmills for general chemical characteristics, e.g., sulfate and total dissolved solids, and there are no pre-mining trace element or radionuclide data available for either drainage. The following analysis of natural ground water quality in these drainages uses pre-mining data from stock wells 16-K-336 and 16-K-340 located along the

Puerco River 8.1?

San Mateo Creek (Figure 8.2). There are no pre-mining data available for alluvial waters along the Arroyo del Puerto.

The most useful information for describing natural alluvial ground-water quality comes from wells drilled for and sampled during this assessment. In particular, data obtained from wells located upstream of uranium industry activities reflect the equivalent of pre-mining conditions at those locations. These wells include the BLM wells along the Puerco River (Figure 8.1) and the Lee wells along the San Mateo Creek in the Ambrosia Lake district in the Church Rock district (Figure 8.2)

8.1.1. General Chemistry

Superimposed on any local variabilities in alluvial ground water quality along the North Fork of the Puerco River are regional-scale quality changes. The available records suggest that natural alluvial ground water trends from a calcium sulfate water at the BLM cluster near Pinedale Bridge to a sodium sulfate water at well 16-K-340, and subsequently to a sodium bicarbonate water near Church Rock at well 16-K-336. The ionic composition are presented in Figure 8.3. The calcium-rich water is reflective of gypsum ($CaSO_4$) and lime (CaOH) abundant in the soils near Pinedale. The proportion of sodium increases downstream after soils derived from rocks of Jurassic age are encountered (see Figure 2.5). All of these regional changes appear to be gradual trends in response to changes in the parent rocks.

Along the North Fork of the Puerco River, water quality is highly variable with respect to total dissolved solids (TDS) concentrations. TDS concentrations range from less than 200 to over 1500 mg/l and generally increase with increasing distance from the river channel. The relative proportions of principal cations and anions, however, do not appear to change appreciably with increasing distance from the channel.

Natural alluvial ground waters along the San Mateo Creek trend from a sodium bicarbonate water at the Lee wells to a sodium-sulfate-bicarbonate water at the Sandoval Ranch (Figure 8.4). The bicarbonate is reflective of limestone rocks near the village of San Mateo.

Natural TDS concentrations in San Mateo Creek ground waters range from 500 to 1,000 mg/l (Brod and Stone, 1981). Along the six-mile distance from the Lee wells near San Mateo downstream to the Sandoval Ranch windmill, TDS concentrations do not significantly change; the increase is from 540 to 650 mg/l.

There are no data to describe natural TDS concentrations downstream for the Sandoval Ranch, but concentrations are not expected to increase dramatically in the three-mile distance to the Otero well cluster location (see Figure 8.2). While San Mateo Creek alluvial waters downstream of the Sandoval Ranch could be affected by the inflow of Arroyo del Puerto alluvial ground waters, available data suggest that there was minimal alluvial water along the Arroyo del Puerto under pre-mining conditions (Kerr-McGee Nuclear Corp., 1981).

8.1.2. Molybdenum

Under natural conditions concentrations of molybdenum in alluvial ground waters along the North Fork of the Puerco River and San Mateo Creek are expected to be low. Molybdenum concentrations in ground waters produced from all BLM and Lee wells are very low, consistently less than detection limit of 0.010 mg/l. While there are no other ground water data available for estimating natural molybdenum concentrations, analyses

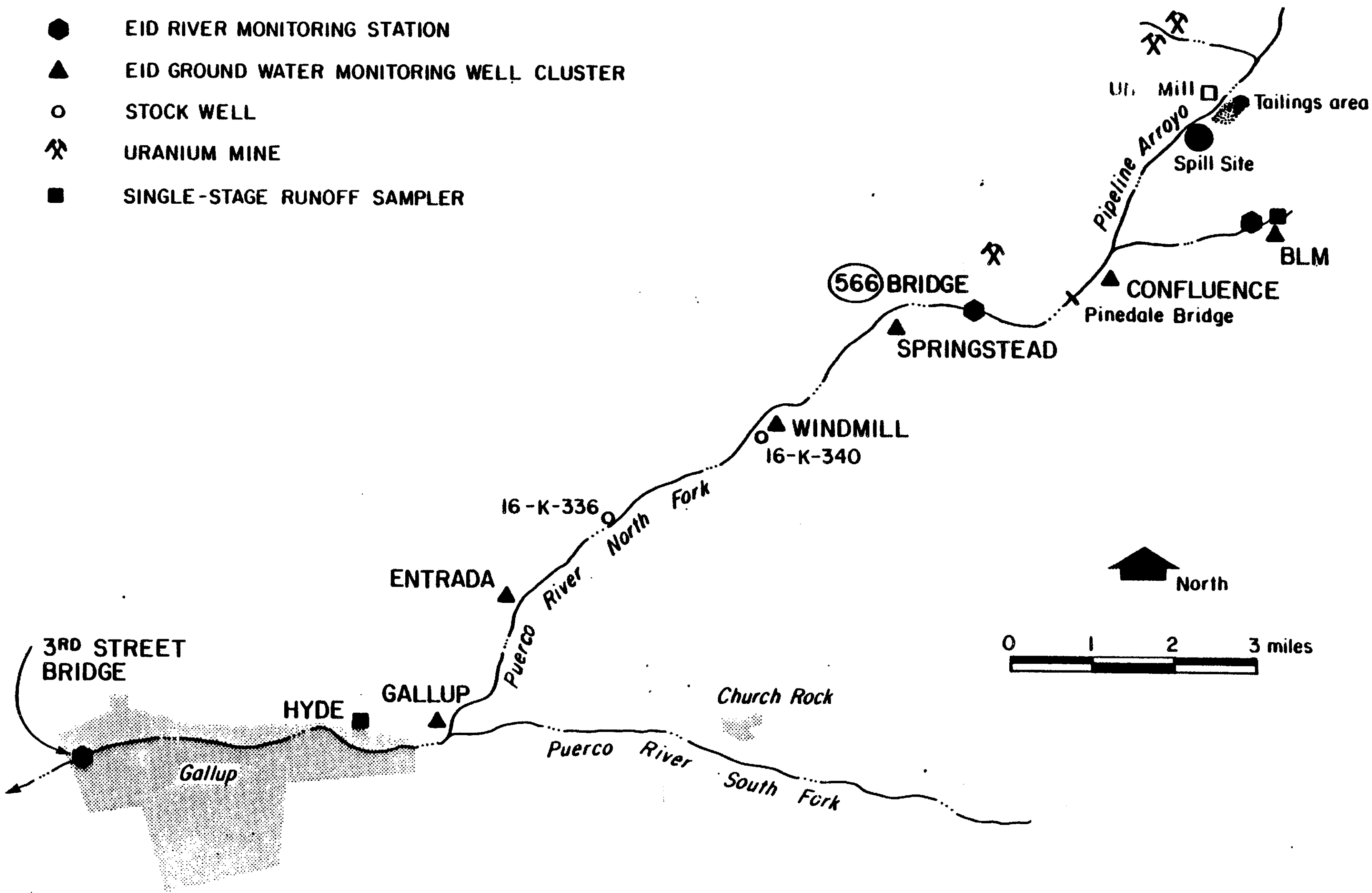


FIGURE 8.1 Well locations in the Church Rock mining district and along the Puerco River

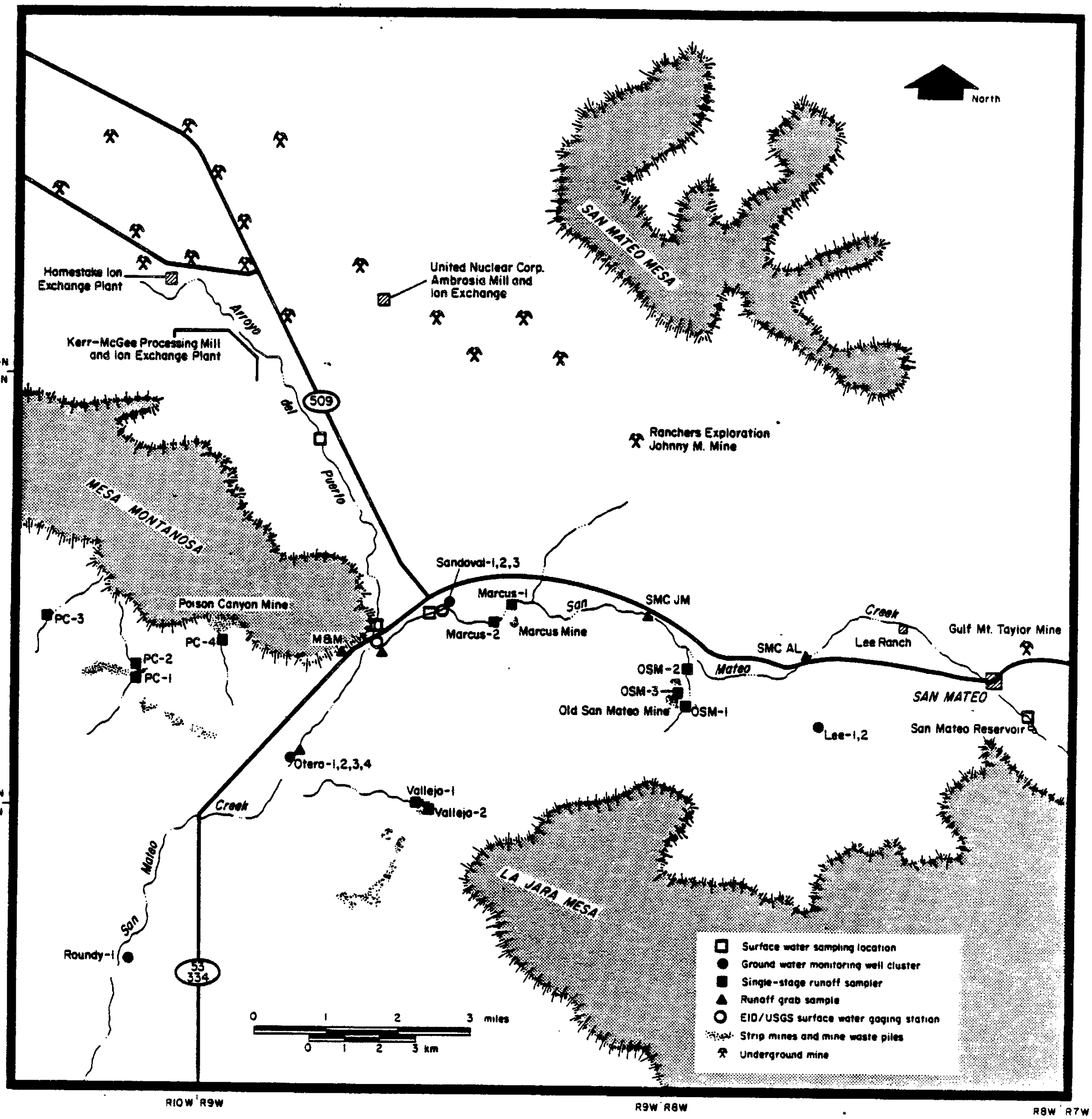


FIGURE 8.2 Well locations in the Ambrosia Lake mining district

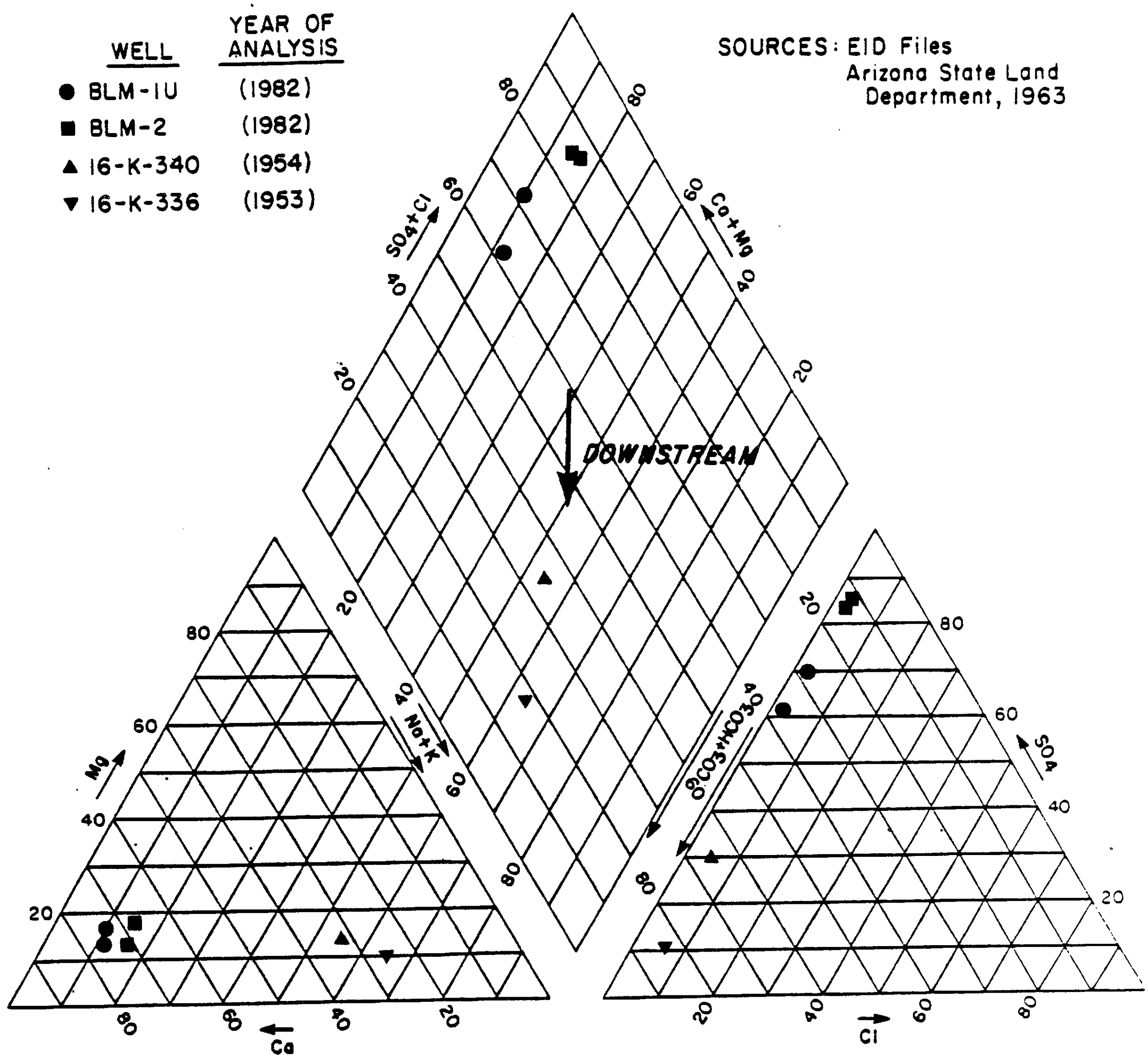


FIGURE 8.3 Natural alluvial ground water quality along the North Fork of the Puerco River

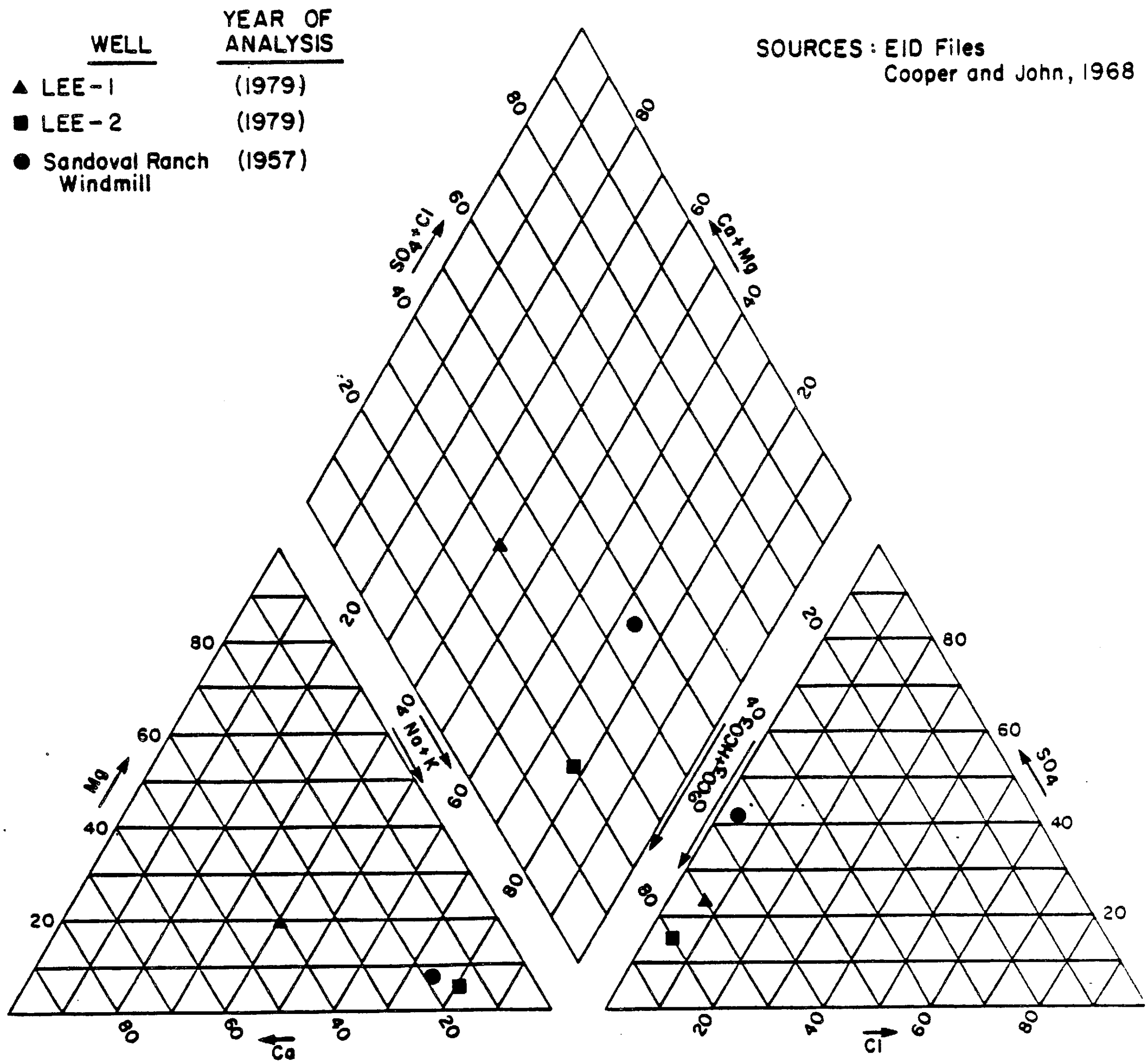


FIGURE 8.4 Natural alluvial ground water quality along San Mateo Creek

of unfiltered natural runoff indicate the virtual absence of molybdenum in sediments and natural waters in these drainages (see Table 4.3).

8.1.3. Uranium-natural

Statistical analyses have been performed on data from the North Fork of the Puerco River in attempt to estimate naturally occurring uranium concentrations in alluvial ground waters within that drainage (see Sinclair Probability Plots, section 3.4.1). These analyses allow differientation of natural ground waters from those influenced by uranium industry wastewaters (i.e., minewaters and the United Nuclear Corporation uranium mill tailings spill). Details of these analyses are given fully elsewhere (Gallaher and Cary, 1986) and are only summarized here.

Results of the analyses suggest that natural uranium concentrations for the North Fork of the Puerco River average approximately 0.02 mg/l and rarely exceed 0.06 mg/l. The estimated average natural concentration is identical to that suggested by U.S. EPA (1975). Average uranium concentrations at the BLM cluster range from 0.014 to 0.048 mg/l.

Natural uranium concentrations in alluvial waters along San Mateo Creek potentially may be higher than along the Puerco River. The abundant natural uranium ore outcrops in the San Mateo Creek drainage (for example, at Marcus and Poison Canyon mines; see Figure 8.2) probably contribute sediments enriched in uranium to the alluvium and these, in turn, contribute uranium to ground waters flowing in the alluvium. That natural runoff in the Ambrosia Lake mining district typically contains total uranium concentrations about three times higher than in the Church Rock mining district is indirect evidence for this mechanism (see Table 4.3).

While uranium concentrations at the Lee wells are consistently below the limit of detection (0.010 mg/l), the Lee wells are completed in alluvium largely derived from non-ore bearing rock material. As ground water flows downvalley from the Lee well cluster, natural uranium concentrations are anticipated to increase gradually as ground water flows through a more uranium-enriched alluvium. Pre-mining uranium concentrations at the Sandoval Ranch are estimated to have been less than 0.030 mg/l, based on interpretation of gross alpha activity concentrations obtained from a 1975 sampling of an alluvial windmill at the ranch (U.S. EPA, 1975). Natural uranium concentrations may increase further downstream. U.S. EPA (1975) estimated that background concentrations may approach 0.1 mg/l within the Ambrosia Lake mining district.

8.1.4. Selenium

Under natural conditions selenium concentrations in alluvial ground water along the North Fork of the Puerco River are expected to be uniformily low, that is, less than 0.01 mg/l. Average concentrations in the two BLM wells are <0.005 and <0.007 mg/l. Further, analyses of unfiltered natural runoff indicates the virtual absence of selenium in sediments and natural waters in this drainage (see Table 4.3).

In contrast, along San Mateo Creek, natural selenium levels may be significantly elevated. Selenium is known to be locally enriched in soils and plants in the Poison Canyon area (Cannon, 1953; Rapaport, 1963). It is noteworthy that median total selenium concentrations in natural runoff are over six times greater in the Ambrosia Lake mining district than in the Church Rock mining district (see Table 4.3).

Selenium concentrations in the Lee wells are generally undetectable (<0.005 mg/l). A 1980 EID analysis of the downstream Sandoval Ranch windmill showed selenium concentrations of 0.018 mg/l (EID files). Although minewaters have been discharged to the San Mateo Creek above this well since 1976, the depth of the well (130 feet) moderates the impacts of the mine discharges and, as a worst case, the 1980 selenium concentration represents an upper limit estimate of the pre-mining concentration. Natural selenium concentrations in ground water may increase downstream from the Sandoval Ranch because of the probable contribution of selenium-enriched Poison Canyon sediments to the San Mateo Creek alluvium.

8.2 IDENTIFICATION OF IMPACTS ATTRIBUTABLE TO MINE DEWATERING EFFLUENTS

Due to the lack of pre-mining data, comprehensive descriptions of the impacts of mine dewatering can not be made for all locations. At many locations, however, minewater impacts can be indirectly estimated after joint consideration of several pieces of hydrogeochemical evidence. The principal indicators that suggest if ground water has been impacted at a given location include the following:

1. Molybdenum concentrations in alluvial ground water greater than 0.03 mg/l. Mine dewatering effluents are the principal sources of dissolved molybdenum in the Puerco River and San Mateo Creek channels. Runoff from uranium mine waste piles may contain detectable levels of dissolved molybdenum, but due to the infrequency of runoff events and dominantly sediment-bound nature of the waste pile contaminants, significant impacts to ground water, if any, should be restricted to the immediate vicinity of the waste pile. The presence of molybdenum in concentrations greater than 0.03 mg/l in alluvial wells along these channels is indicative of the presence of mine dewatering effluents. The absence of molybdenum in these wells, on the other hand, does not mean that minewater impacts are not evident because not all effluents contain elevated levels of molybdenum (see Table 7.3).

2. Uranium concentrations greater than 0.06 mg/l in alluvial ground water along the North Fork of the Puerco River, and greater than 0.03 mg/l upstream and 0.1 mg/l downstream of the confluence of San Mateo Creek with Arroyo del Puerto. The values constitute the estimated upper limit concentrations found in these ground waters under natural conditions.

3. Selenium concentrations greater than 0.01 mg/l along the North Fork of the Puerco River, and greater than 0.15 mg/l along the San Mateo Creek upstream of its confluence with Arroyo del Puerto. Natural selenium concentrations along these river reaches are expected to be relatively low. Natural conditions below the San Mateo Creek-Arroyo del Puerto confluence cannot be projected because of the uncertainty regarding the added influence of selenium-enriched Poison Canyon sediment on ground water quality.

4. Major changes in total dissolved solids concentrations and in general ground water chemistry composition within a distance less than 3 miles. Natural changes in TDS concentrations and in composition are expected to be gradual; rapid changes in both are indicative of minewater effects.

5. Significant decline in molybdenum, uranium, or selenium concentrations with increasing depth in the upper portion of an alluvial aquifer. Contaminants contributed to the aquifer through stream bottom recharge (as is the case with minewaters) are expected to be more concentrated in the upper portion of the aquifer than contaminants naturally occurring in the ground water.

8.3 CHANGES IN IONIC CHEMISTRY

Alluvial ground waters that are recharged primarily by dewatering effluents have been found to assume the ionic composition of the minewaters. Such water-quality changes are seen in areas of ground-water recharge along the Puerco River and San Mateo Creek. Pronounced changes in ionic composition of alluvial ground waters, for example, are seen at the Confluence test well cluster along the Puerco River. This well cluster is located about one mile below the confluence of Pipeline Arroyo, the channel receiving most of the Church Rock mine discharges, and the Puerco River. It is therefore immediately downgradient from the point where native ground waters are potentially affected by minewaters (see Figure 8.1).

Figure 8.5 shows that ground waters produced from wells CON-IL and CON-3 have ionic compositions similar to dewatering effluent and unlike natural waters, as represented by the BLM well cluster. Wells CON-IU and CON-2, on the other hand, produce waters more similar to natural waters. Ground water in well CON-3, which chemically most resembles the minewaters, also has a total dissolved solids concentration similar to minewaters (500 mg/l versus greater than 1000 mg/l at the BLM cluster). It is apparent that some water in the alluvial aquifer at that well cluster has been transformed from the strongly calcium-magnesium sulfate type to an intermediate type that tends toward sodium bicarbonate. Other test wells along the Puerco River that produce ground waters with ionic signatures similar to that for CON-3 are SPR-1, SPR-3U, GAL-1, GAL-2, and GAL-4. Because of the lack of pre-dewatering ground water quality data, it can not be definitely stated that all of these wells have been affected by the dewatering effluents.

The water quality of shallow ground waters in the San Mateo Creek-Arroyo del Puerto drainage has also been transformed by dewatering effluents. This change in major chemistry is most evident near the confluence of San Mateo Creek and Arroyo del Puerto (see Figure 8.2). One mile upstream along San Mateo Creek, alluvial ground waters at the Sandoval monitoring well cluster are of the sodium-sulfate-bicarbonate water chemistry type with a total dissolved solids concentration of about 650 mg/l (Figure 8.6). Although minewater from Ranchers Johnny M. Mine enters San Mateo Creek about 3 miles above the well cluster, no significant changes in ionic composition are evident in the test wells because of the close chemical similarity between minewaters and natural ground water at the site (see Sandoval Ranch windmill analysis, Figure 8.4).

In contrast, downstream from the confluence EID test wells on the San Mateo Creek produce alluvial ground water that bears a strong ionic resemblance to Ambrosia Lake minewaters. Figure 8.6 shows that ground waters at OTE-2, OTE-4, and RDY-1 now are all of the calcium-magnesium sulfate type, as are the minewaters introduced via Arroyo del Puerto. Corresponding to the shift in San Mateo Creek's alluvial ground water chemistry, total dissolved solids concentrations increased from about 650 mg/l at the Sandoval well cluster to over 2100 mg/l at the Otero well cluster, located three miles downstream.

8.4 TRACE ELEMENTS AND RADIONUCLIDES IN GROUND WATER

In addition to altering the dominant water chemistry and total dissolved solids concentrations of ground waters, infiltration of minewaters has elevated the concentrations of trace elements and gross radioactivity. Specifically, in test wells determined to have been affected by minewaters, the concentrations of uranium, molybdenum, selenium, and gross alpha particle activity are elevated above natural levels by 10 to 40 times. Evidence suggests that infiltration of mine effluents has caused similar responses elsewhere in the region beneath zones of significant stream bottom leakage

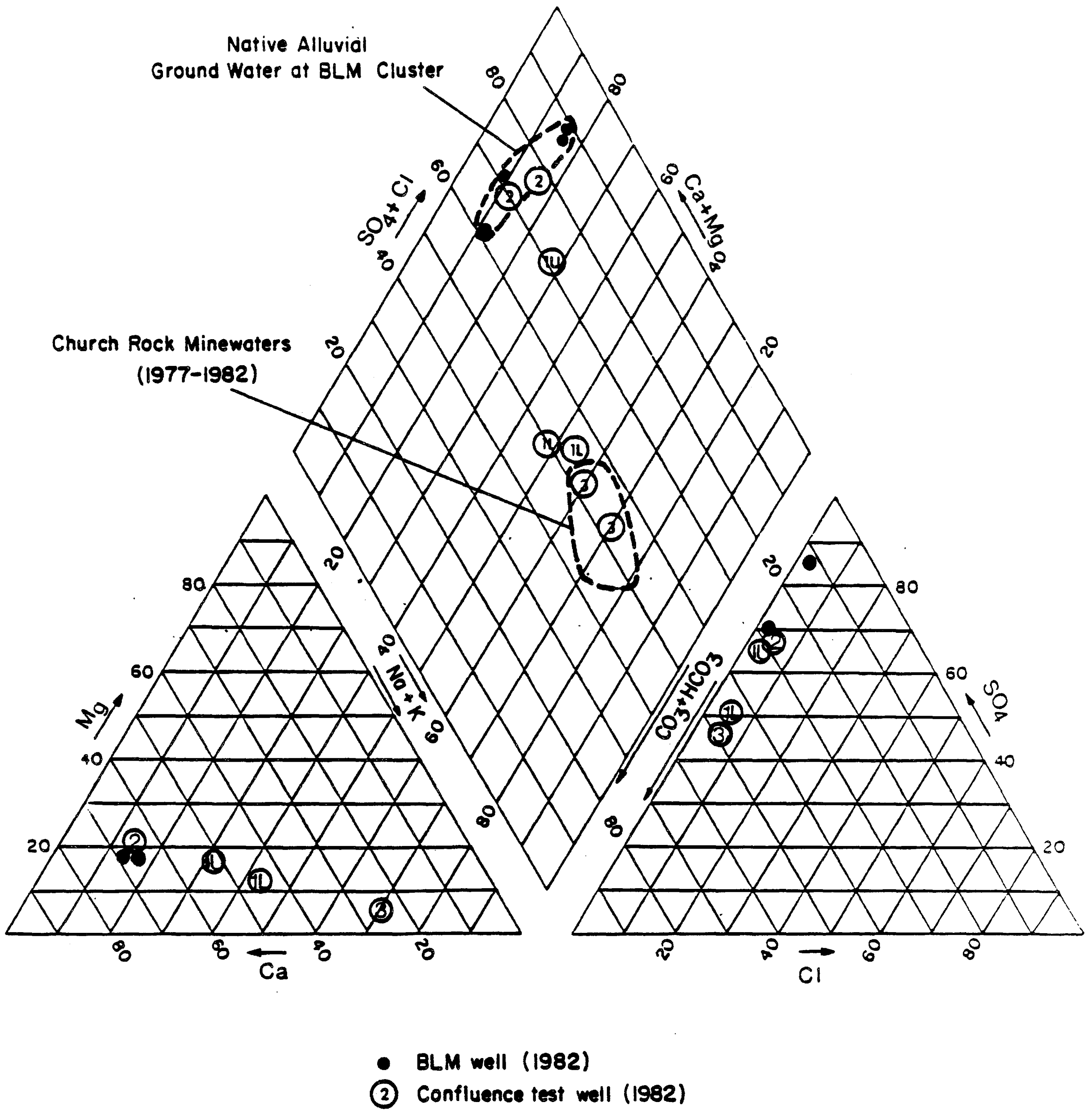


FIGURE 8.5 Ground water quality along the Puerco River near the BLM and Confluence well clusters.

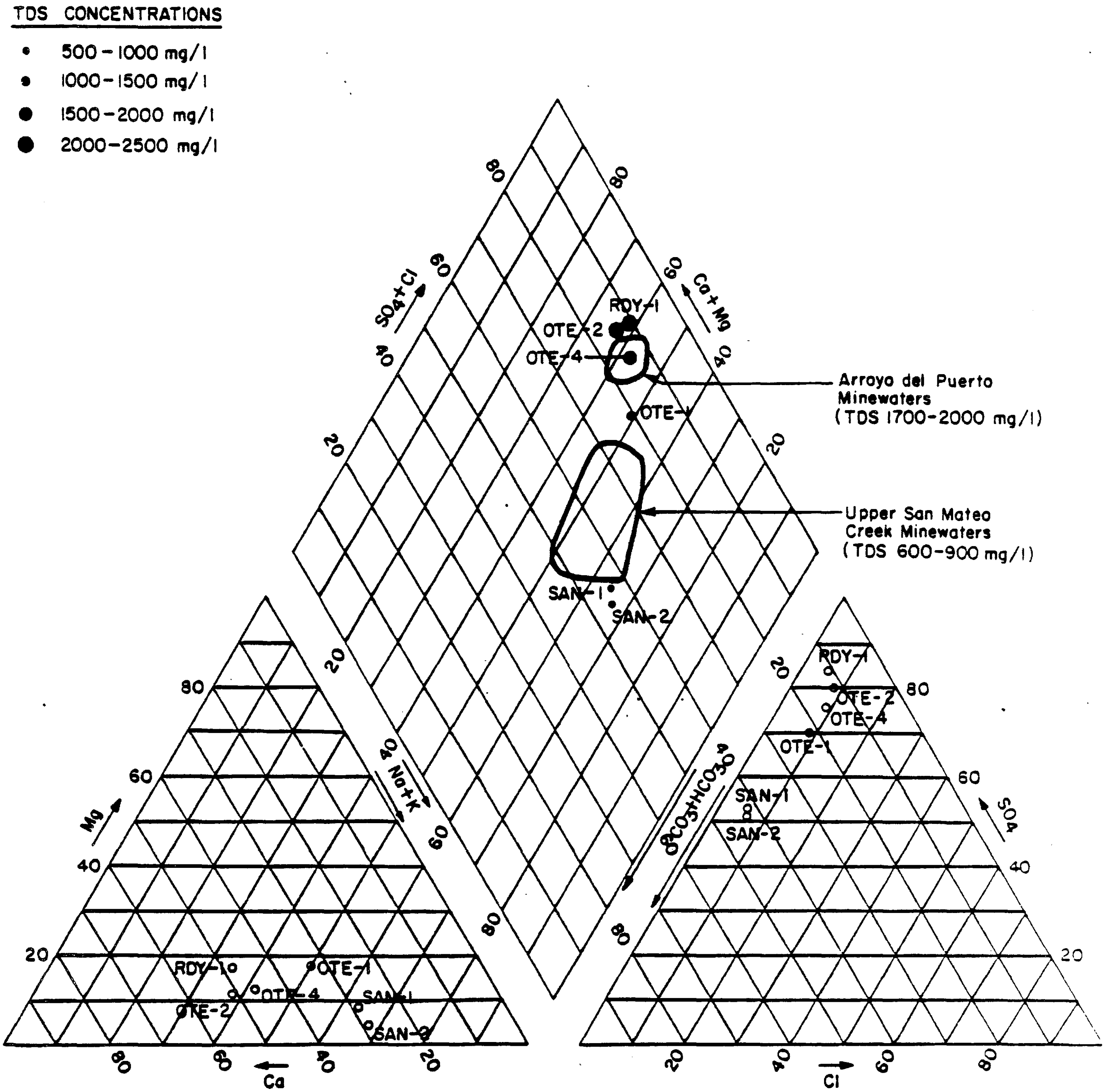


FIGURE 8.6 Ground water quality along San Mateo Creek

Degradation of ground water quality is most pronounced in the Ambrosia Lake mining district. This is to be expected for the following reasons: 1) approximately two-thirds of the historical minewater production from New Mexico uranium mining areas has been in this district (see Figure 6.1); 2) the quality of the discharged water overall is poorer than that in the Church Rock mining district (see Table 7.3); and 3) hydrogeologic conditions along Ambrosia Lake drainages result in relatively rapid infiltration of the wastewaters.

Table 8.1 shows mean contaminant concentrations detected in EID test wells along San Mateo Creek, the principal drainage of the Ambrosia Lake mining district. Uranium, molybdenum, and selenium concentrations at the Lee wells are below detectable levels of 0.005 to 0.01 mg/l. Uranium and molybdenum levels at the Sandoval well cluster are 10 to 20 times detectable limits due to infiltration of dewatering effluents. Other trace elements did not exhibit concentrations elevated above those found at the Lee wells.

Down valley below the confluence with the Arroyo del Puerto, uranium, molybdenum, and selenium concentrations are found to be approximately three times greater than at the Sandoval well cluster. Uranium and molybdenum concentrations in the Otero wells are as much 7 times greater than natural levels projected for this portion of the San Mateo Creek (see section 8.1) and therefore indicate that ground water at that location has been substantially degraded by minewaters. Moreover, both uranium and molybdenum significantly decline in concentration with increasing depth. (For example, molybdenum concentrations decline from 0.38 and 0.28 mg/l in the shallower wells OTE-1 and OTE-2 (54 and 57 feet total depth, respectively) to < 0.01 mg/l in well OTE-4, a deeper well (72 feet total depth) in the same cluster.) Selenium is elevated in all the Otero wells, but is known to be naturally enriched in the area and can not be exclusively attributed to mine dewatering effluents. Generally, the pattern of trace element concentrations in the Otero wells coincides with that of the Sandoval wells (uranium > molybdenum > selenium)..

As with uranium, gross alpha particle activity concentrations are also significantly elevated along the San Mateo Creek below the Lee wells. These concentrations almost exclusively reflect the alpha radiation of uranium. Gross beta particle activities along the San mateo Creek are found in concentrations as much as 100 times those detected at the Lee wells. It is unknown which radionuclide(s) contribute principally to the gross beta concentrations.

Radium-226 concentrations may also increase due to minewater impacts, but the increases can not be verified due to the lack of pre-mining data. Table 8.1 shows radium-226 concentrations of about 0.05 pCi/l for the Lee wells. All but one of the other test wells along San Mateo Creek produce water containing more than 0.10 pCi/l of radium-226, on the average. Student-t and Mann-Whitney statistical tests show that the mean values for radium-226 in all the minewater-affected wells are significantly greater (95% confidence) than levels at the Lee wells. Despite the suggestion that minewaters have elevated radium-226 levels in alluvial ground waters, this increase is small and of little practical significance. A measureable amount of radium-226 may reach ground water, but most of the dissolved radium-226 in surface waters (up to 4 pCi/l) clearly does not.

Due to lack of pre-mining data, definitive statements can not be made regarding the influence of mine dewatering effluents at the Roundy well location, the most downstream well on the San Mateo Creek drainage The average uranium concentration of 0.13 mg/l is slightly above the EPA-estimated maximum natural level of 0.1 mg/l. In contrast, however, molybdenum is below analytically detectable levels. Selenium levels are greatly elevated, but because ground water quality is potentially influenced by Poison Canyon, where sediments are enriched in selenium, these levels can not be exclusively attributed to minewaters.

TABLE 8.1. Mean Trace Element and Radionuclide Concentrations in Wells in the San Mateo Creek Drainage, 1977-1982. Number of samples for each well is shown in parentheses and standard deviations are specified for all means. Well locations are indicated on Figure 8.2.

	WELLS ABOVE URANIUM MINE DISCHARGES		WELLS BELOW URANIUM MINE DISCHARGES					
	LEE-1 (13)	LEE-2 (14)	SAN-1 (13)	SAN-2 (12)	OTE-1 (14)	OTE-2 (15)	OTE-4 (12)	RDY-1 (12)
	ug/l							
As	ND	6.8 ± 1.7	ND	ND	ND	6.8 ± 3.4	ND	5.9 ± 2.4
Ba	133 ± 38	113 ± 18	112 ± 28	108 ± 22	112 ± 33	132 ± 50	124 ± 40	139 ± 38
Cd	ND	ND	ND	ND	ND	ND	ND	ND
Pb	ND	ND	ND	ND	ND	ND	ND	ND
Mo	ND	9.6 ± 3.3	133 ± 60	131 ± 55	381 ± 115	257 ± 145	ND	ND
Se	ND	ND	18.5 ± 7.2	18.0 ± 7.7	80 ± 25	72 ± 25	102 ± 30	273 ± 128
U	ND	ND	222 ± 41	251 ± 79	754 ± 69	668 ± 144	166 ± 23	129 ± 11
V	ND	12 ± 2.7	ND	ND	ND	ND	ND	ND
Zn	ND	ND	ND	ND	ND	ND	ND	ND
	pCi/l							
Ra-226** (pCi/l)	0.05 ± .02	0.04 ± .02	0.15 ± .03	0.09 ± .03	0.11 ± .03	0.15 ± .06	0.13 ± .02	0.15 ± .03
gross alpha	4 ± 2	6.6 ± 1.05	184 ± 38	209 ± 69	496 ± 49	463 ± 49	123 ± 19	92 ± 13
gross beta	3 ± 2	4 ± 2	89 ± 37	96 ± 39	300 ± 93	291 ± 92	72 ± 33	63 ± 19

*ND = not analytically detected
**Radium-226 values reflect samples analyzed by the New Mexico Scientific Laboratory Division (SLD); for uniformity data by Eberline Instrument Corp. were not used in calculation of the mean

The UNC uranium mill tailings spill in July 1979 greatly complicated the task of evaluating minewater impacts on alluvial ground waters in the Puerco River valley. The spill contained large concentrations of many radionuclides and trace elements, including the alpha emitters thorium-230 and uranium and the trace elements molybdenum, vanadium, and selenium. Thus, in all data collected since July 1979 there are always two potential sources for contaminants: the spill and minewaters. There are some pre-spill data for the Gallup cluster, but no pre-spill data exist for the Entrada, Windmill, Springstead, or Confluence well clusters.

Despite this major obstacle, the sources of elevated uranium in Puerco River valley ground waters are indicated through the use of the same probability techniques used to estimate natural uranium levels. These analyses allow differentiation of ground waters influenced by the spill from those influenced by minewaters. Whereas those ground waters that are high in both uranium and sulfate have been affected by the UNC spill, which was enriched in sulfuric acid, those wells that produce high uranium, but low sulfate, have been affected by minewaters, but not the spill. Only these results of these analyses (Gallaher and Cary, 1986) related to wells affected by minewaters are summarized here.

Mine dewatering effluents have degraded Puerco River alluvium with trace elements and radionuclides, although not to the same degree as along San Mateo Creek. Results of the aforementioned probability analysis suggest that fewer than one-third (6 of 21) of the EID wells along the Puerco River have been significantly impacted by uranium industry activities (minewaters and spill waters). Relatively low infiltration rates along this reach of the river effectively moderate the impacts to the underlying ground water.

Two test wells, SPR-1 and CON-3, were found to contain elevated levels of uranium attributable principally to minewaters. Table 8.2 summarizes the trace element and radionuclide concentrations found in these two wells and in BLM wells representative of natural alluvial quality. The data indicate a pattern of minewater effects similar to that documented along San Mateo Creek. Uranium and gross alpha particle activity are clearly elevated above natural levels in the two downstream wells. Molybdenum also shows increases above background although for SPR-1 the increase is negligible as it is the detectable limit. A small increase in selenium concentrations is suggested in CON-3 samples.

While minewater impacts along a given river reach may be relatively limited, they may be more significant further downstream if stream bottom leakage rates increase because of changing hydrogeologic conditions. The resultant ground water quality impacts would be highly site specific, depending on many factors including the infiltration rate, quality of the minewaters, and natural quality of ground water.

In reviewing the data for trace elements and radionuclides, it is clear that dewatering effluents are having similar effects throughout the Grants Mineral Belt. Uranium and gross particle alpha activity concentrations are often elevated in alluvial ground waters downstream from minewater discharges. Molybdenum usually appears elevated although there are exceptions. Selenium also reaches shallow ground water from minewater sources. Selenium, however, can also be locally elevated under natural conditions in Ambrosia Lake. Unless confirmed by evidence of low pre-mining concentrations, the presence of elevated selenium is not alone sufficient to demonstrate contamination by mine dewatering effluents.

TABLE 8.2. Mean Trace Elements and Radionuclides Concentrations of Selected Wells in the Puerco River Valley. Number of samples per well is shown in parentheses.

CONSTITUENT (ug/l)	WELLS ABOVE URANIUM MINE DISCHARGES BLM 1U (2)	BLM-2 (2)	WELLS AFFECTED BY URANIUM MINE DISCHARGES SPR-1 (1)	CON-3 (2)
ug/l				
As	ND*	14	9	6
Ba	100	150	ND	180
Cd	ND	ND	ND	ND
Pb	ND	ND	ND	ND
Mo	ND	ND	10	170
Se	ND	7.5	5	11
U	14	48	145	433
V	ND	ND	ND	ND
Zn	ND	ND	ND	ND
pCi/l				
gross alpha	10 ± 3	28 ± 10	56 ± 15	278 ± 10
gross beta	2.6 ± 2.9	16 ± 4	NA**	118 ± 22
Ra-226	0.13 ± 0.06	0.32 ± 0.10	NA	0.37 ± 0.12

*ND = Not analytically detected
**NA = Data not available; analysis not requested

8.5 GEOCHEMICAL ATTENUATION OF MINEWATER CONSTITUENTS

Ground water quality data collected from EID wells in the Grants Mineral Belt show uranium, radium-226, selenium, and molybdenum concentrations and gross alpha particle activity that are above natural levels, but not as high as in the discharged minewaters. For most of these contaminants, however, ground water concentrations are of the same order of magnitude as in the sources.

Mechanisms which may reduce the contaminant concentrations include dilution surface adsorption, cation exchange, precipitation, hydrodynamic dispersion, and molecular diffusion. Dispersion and dilution may eventually reduce contaminant concentrations, but these processes are slow and may take years or even decades to be effective. Dilution, adsorption, cation exchange and precipitation are more likely mechanisms.

Decreases of uranium, for example, from more than l.0 mg/l in minewaters to 0.5 mg/l in alluvial aquifers can probably be attributed to dilution by native ground waters. Uranium, molybdenum, and selenium all form anions in the geochemical environment of the Grants Mineral Belt and are therefore not greatly affected by some of the most effective attenuation processes, such as surface adsorption and cation exchange. These contaminants are therefore relatively mobile in both surface waters and shallow ground waters.

The tendency for uranium to precipitate from solution in Puerco River alluvium was analyzed using a computer program (WATEQFC) for calculating chemical equilibria of natural waters. Emphasis was placed on assessing the chemical stability of ground waters in EID wells most impacted by minewaters. Calculations were performed separately on natural uncontaminated ground water (BLM-1U) and on ground water dominated by mine dewatering effluents (CON-3). The predominant phase of uranium is calculated by the computer program WATEQFC to be di- oxide species. These complexes are subject to minimal adsorption because of their net negative charge and large molecular radii Tripathi, 1982; Langmuir, 1978) and are therefore very mobile in alkaline aqueous environments. Selected results of the geochemical modeling for the predominant uranium minerals are reported in Table 8.3.

The modeling output that all of the uranium species constituents are undersaturated with respect to their mineral phases by at least one hundred times. It can be inferred that uranium concentrations in the alluvial aquifer cannot be expected to decline solely as a result of long term equilibrium adjustment.

For dissolved radium-226, in contrast to uranium, the alkaline, oxidizing conditions found in the Grants Mineral Belt promote attenuation and discourage mobility. Because of its net positive charge, radium-226 is drawn to cation exchange sites on negatively charged clay minerals, organic matter, and metallic oxide coatings on the surfaces of alluvial materials. For surface and ground waters in the Grants Mineral Belt, only a small fraction of all radium-226 present remains in solution. Most radium-226 is probably immobilized in the stream channels sediments. Attenuation of radium-226 is so effective in Grants Mineral Belt alluvium that apparently minewaters increase the typical dissolved radium-226 concentrations normally carried by regional ground waters by only about 0.l pCi/l.

TABLE 8.3 Selected Mineral Saturation Indices for Uranium in Puerco River Alluvial Ground Water.

Well No.	Sample Date (M-D-Y)	Mineral or Precipitate Phase	Formula	Saturation Index
BLM-1U	01-19-82	Tyuyamunite	$Ca(UO_2)_2(VO_4)_2$	-4.9
CON-3	01-20-82	Tyuyamunite	$Ca(UO_2)_2(VO_4)_2$	-2.7
		Carnotite-A	$K2(UO_2)_2(VO_4)_2 \cdot 3H_20$	-3.3
		Carnotite-B	$K2(UO_2)_2(VO_4)_2 \cdot 3H_20$	-3.5
		Schoepite	$UO_2(OH)_2H_20$	-3.6
		Coffinite	$USi0_4$	-4.4
		Rutherfordine	$U0_2CO_3$	-4.4

Although data are lacking for other uranium-238 decay products, it seems unlikely that any of the major daughter products from uranium mining activities could significantly degrade ground-water quality within the alkaline pH ranges typical of the minewaters. Thorium-230, lead-2l0, and polonium-2l0 all form cations in solution and their attenuation is likely to be as effective as radium-226 attenuation. Overall, the threat to ground water is judged to be small.

IX. EVALUATION OF WATER QUALITY

Earlier chapters have provided an overview of both natural water quality in the Grants Mineral Belt and water quality impacted by uranium mining. In order to evaluate the significance of observed water quality, current and potential uses that are made of the water in this area need to be considered along with relevant aspects of surface and ground water hydrology and the physio-chemical fate of minewater constituents. Furthermore, because of the radioactivity associated with both natural and mining-impacted flows, the quality of these flows needs to be compared with established standards and criteria for public exposure.

All surface waters in the Grants Mineral Belt, whether natural or mining-impacted, are used by livestock for watering. Only artificially maintained perennial streams, however, are used for irrigation or have potential use for domestic water supply. All three uses are made of ground waters. The contaminant and radioactivity levels of surface and ground waters in the Grants Mineral Belth raises concerns about the suitability of natural and mining-impacted surface waters and mining-impacted ground waters for present and potential uses.

9.1 WATER USES

Comparison of water quality with criteria and standards provides a means of evaluating whether water quality in the Grants Mineral Belt is consistent with current use. Livestock watering is the major use of surface waters. Watering from effluent-dominated streams is commonplace. Livestock even use turbid flows that may include both natural runoff and runoff from mine tailings.

Irrigation of gardens is practiced along the Puerco River from the Highway 566 bridge to the City of Gallup. Hoses are used to draw water up from the incised stream to gardens.

Ground waters are used as domestic water supply sources. The authors know of no documented domestic use of surface waters in the Grants Mineral Belt. Nonetheless, the potential for effluent-dominated streams, as modified in chemical quality by physio-chemical processes, to affect the quality ground waters provides sufficient rationale to evaluate such streams as sources of domestic water supply. Moreover, municipalities have considered the possibility of using dewatering effluents to supplement existing water supply sources (Hiss, 1980).

Selected criteria and standards for livestock watering, irrigation, and domestic water supply are given in Table 9.1. The only comprehensive evaluation of water quality necessary to support livestock watering remains that done by the National Academy of Sciences-National Academy of Engineering (NAS/NAE, 1972) for the EPA. The NAS/NAE recommendations are in the form of water quality criteria, that is, concentrations which, if not exceeded, are expected to be suitable to support a specific water use. NAS/NAE (1972) also recommended water quality criteria to support irrigation use. As part of the Molybdenum Project, the relationship between molybdenum levels in irrigation waters and plants was investigated (Vleck and Lindsay, 1977). The New Mexico Ground Water Regulations include standards designed to protect ground water quality for agricultural use (NM WQCC, 1983). These standards are used in this report for comparison purposes only. The regulations should be consulted for information on the applicability of the standards.

TABLE 9.1. Selected Criteria and Standards for Livestock Watering, Irrigation, and Domestic Water Supply.

CONSTITUENT	WATER USE					
	Livestock Watering	Irrigation			Domestic Water Supply	
	NAS/NAE	NAS/NAE	Molybdenum Project	New Mexico Ground Water Regulations	New Mexico Water Supply Regulations	New Mexico Ground Water Regulations
	mg/l					
TDS	3,000			1,000		1,000
SO_4				600		600
As	0.2	0.10		0.1	0.05	0.1
Ba				1.0	1.	1.0
Cd	0.050	0.010		0.1	0.010	0.01
Pb	0.1	5.0		0.05	0.05	0.05
Mo			0.020	1.0		
Se	0.05	0.02		0.05	0.01	0.05
U-natural				5.0		5.0
V	0.1	0.10				
Zn	25	2.0		10.0	5.	10.0
	pCi/l					
Gross Alpha[a]	15				15	
Combined Ra-226 and Ra-228	5	5		30.0	5	30.0

SOURCES: NAS/NAE - NAS/NAE (1972)
Molybdenum Project - Vleck and Lindsay (1977)
New Mexico Water Supply ' ulations - NM EIB (1985)
New Mexico Ground Wate. gulations - NM WQCC (1983)

Two sources of comparison were used to evaluate the quality of water for domestic use. Standards in the New Mexico Water Supply Regulations (NM EIB, 1985) are applicable to water emanating from water supply systems, not to surface and ground waters and are used only for comparison purposes. Similarly, the standards in the New Mexico Ground Water Regulations (NM WQCC, 1983) are not applicable to effluent-dominated streams and are used only for comparison purposes. Both sets of regulations should be consulted for information on their applicability.

As both natural water quality and the quality of waters affected or produced by uranium mining contain radioactivity, standards and criteria in the New Mexico Radiation Protection Regulations (NM EID, 1980) are used as a basis of comparison. The Radiation Protection Regulations are not applicable to natural water quality or uranium mining and the standards and criteria are used only for purposes of comparison. The regulations should be consulted for information on applicability.

9.2 NATURAL SURFACE WATERS

Perennial streams in the Grants Mineral Belt are limited in number, extent, and flow. The other natural source of surface water is runoff associated with storms and snowmelt. Without mine dewatering, runoff would be the surface waters in the Arroyo del Puerto, San Mateo Creek below the community of San Mateo, and the Puerco River. Both natural perennial streams and natural runoff may be used by livestock for watering.

The quality of perennial streams, which normally carry little sediment, is consistent with the livestock watering use. Trace elements and radioactivity concentrations, however, raise concerns about the suitability of natural runoff for this use. Furthermore, levels of radioactivity in natural runoff are sometimes excessive in comparison to health criteria and standards.

9.2.1. Perennial Streams

Dissolved concentrations of trace elements and radionuclides are naturally low in perennial streams in the Grants Mineral Belt. Comparison of natural water quality with livestock watering criteria for six trace elements, gross alpha particle activity, and radium-226 indicates that natural concentrations are normally much less than the criteria (Table 9.2). Similarly, the livestock criteria of 3,000 mg/l total dissolved solids (NAS/NAE, 1972) is almost double the mean natural concentration of 1530 mg/l found in the Rio Moquino at the Jackpile Mine. The Rio Moquino has higher dissolved solids concentrations than the Rio Paguate or San Mateo Creek below San Mateo Reservoir.

9.2.2. Natural Runoff

Trace elements and radionuclides are found to have highly variable levels in natural runoff resulting from storms. These levels are statistically correlated with the amount of suspended sediment carried by the water. Despite the high amounts of sediment that are sometimes carried by natural runoff, livestock may still use these waters. Therefore, natural runoff quality was compared with livestock watering criteria for the same six trace elements used for the comparison with perennial stream quality, but with very different results.

TABLE 9.2. Comparison of Dissolved Concentrations of Trace Elements and Radioactivity in Perennial Natural Waters with Livestock Watering Criteria.

CONSTITUENT	MEDIAN CONCENTRATION	LIVESTOCK WATERING CRITERIA[a]
	mg/l	
As	<0.005	0.2
Cd	<0.001	0.050
Pb	<0.005	0.1
Se	<0.005	0.05
V	<0.010	0.1
Zn	<0.050	25
	pCi/l	
Gross alpha	2	15
Ra-226	0.1	5[b]

[a] The criteria are from NAS/NAE (1972).

[b] The criterion applies to combined radium-226 and radium-228.

Measured total concentrations of trace elements and radioactivity indicate that natural runoff quality may not be consistent with its use for livestock watering (Table 9.3). Lead, vanadium, gross alpha particle activity, and radium-226 are the primary constituents affecting the suitability of natural runoff for livestock watering as median concentrations of all four constituents exceed criteria in both the Ambrosia Lake and the Church Rock mining districts. Even though the gross alpha particle activity criterion excludes alpha activity due to natural uranium, the median gross alpha activities of 1200 and 720 pCi/l in the Ambrosia Lake and the Church Rock mining districts, respectively, far exceed corresponding natural uranium medians of 68 and 20 pCi/l (at equilibrium, 1 mg/l of natural uranium is equivalent to 677 pCi/l).

Of lesser concern are arsenic and selenium in the Ambrosia Lake district and arsenic and cadmium in the Church Rock district because of exceedances of livestock watering criteria by maximum concentrations. The maximum concentration of cadmium measured in the Ambrosia Lake district is at the criterion level.

State limits on allowable concentrations of radionuclides that maybe discharged to unrestricted areas (that is, areas not controlled for the purposes of protecting an individual from exposure to radiation or radioactive materials) provide another means of evaluating the relative importance of radionuclides concentrations. These maximum permissible concentrations (MPCs), however, apply only to state-licensed facilities, not to natural runoff (see NMEID, 1980). Comparison of natural runoff quality with MPCs indicates that radium-226 is of concern in areas unaffected by the uranium industry in the Church Rock mining district and both radium-226 and lead-210 are of concern in similar areas in the Ambrosia Lake district (Table 9.4). Polonium-210 exceeds half its MPC in the Church Rock district; all other radionuclides are present in small amounts compared to MPCs. While these data are limited, it does appear that the radiological quality of natural runoff may be worse in the Ambrosia Lake district than in the Church Rock district.

While radium-226 and lead-210 sometimes exceed MPCs in uncontaminated, natural runoff, natural radiation levels may be a cause for concern even when these radionuclides simply approach MPCs. A sample from the South Fork of the Puerco River on September 21, 1982, provides a typical example (Table 9.5). Both radium-226 and lead-210 occurred at about 75 percent of their respective MPCs in this sample. Even though no radionuclide in the sample exceeded its MPC, the sum of the ratio of each radionuclide concentration to its MPC exceeds 1.00 (actual value, 1.66) and thus is in excess of specifications set forth in Part 4, Appendix A, Note 1 of the New Mexico Radiation Protection Regulations (NM EID, 1980). Uranium industry facilities licensed under these regulations are not permitted to release water of this quality to unrestricted areas. Yet, watercourses in the Grants Mineral Belt may receive water of this quality simply as a result of natural circumstances.

TABLE 9.3. Comparison of Total Concentrations of Trace Elements and Radioactivity in Natural Runoff with Livestock Watering Criteria.

CONSTITUENT	AMBROSIA LAKE MINING DISTRICT		CHURCH ROCK MINING DISTRICT		LIVESTOCK WATERING CRITERIA[a]
	Median	Maximum	Median	Maximum	
			mg/l		
As	0.13	0.26	0.08	0.30	0.2
Cd	0.006	0.05	0.003	0.06	0.050
Pb	0.52	2.0	0.17	2.0	0.1
Se	0.03	0.15	<0.005	0.03	0.05
V	0.61	3.2	0.40	0.92	0.1
Zn	1.5	1.7	0.38	8.5	25
			pCi/l		
Gross alpha	1,200	2,100	720	1,600	15
Ra-226	15	321	19	47	5[b]

[a] The criteria are from NAS/NAE (1972).

[b] The criterion applies to combined radium-226 and radium-228.

TABLE 9.4. Comparison of Total Radioactivity in Natural Runoff with Maximum Permissible Concentrations for Releases to Unrestricted Areas. All concentrations are in picocuries per liter (pCi/l).

RADIONUCLIDES	AMBROSIA LAKE MINING DISTRICT		CHURCH ROCK MINING DISTRICT		MAXIMUM PERMISSIBLE Concentration[a]
	Median	Maximum	Median	Maximum	
Pb-210	88	720	53	74	100
Po-210		43[b]	80	450	700
Ra-226	15	321	19	47	30
Th-228			22	43	7,000
Th-230			24	42	2,000
Th-232			24	43	2,000
U-natural	68	379	149	203	30,000

[a] The maximum permissible concentrations are from Table II of Appendix A to Part 4 of the New Mexico Radiation Protection Regulations (NM EID, 1980). The concentrations are not applicable to natural runoff and are used only for comparison purposes.

[b] Only a single measurement is available.

TABLE 9.5. Total Radionuclide Concentration/Maximum Permissible Concentration Ratios for the South Fork of the Puerco River on September 21, 1982.

RADIONUCLIDE	CONCENTRATION (pCi/l)	MPC[a] (pCi/l)	CONCENTRATION/MPC RATIO
Pb-210	74 ± 12	100	0.74
Po-210	90 ± 3	700	0.13
Ra-226	23 ± 6	30	0.77
Th-230	42 ± 4	2,000	0.02
U-natural	14	30,000	0.0005
		TOTAL	1.66

[a]The maximum permissible concentrations are from Table 11 of Appendix A to Part 4 of the New Mexico Radiation Protection Regulations (NM EID, 1980). The concentrations are not applicable to natural surface waters and are used only for comparison purposes.

9.3 URANIUM MINE WASTE PILES AND OPEN PITS

A potential concern about degradation of surface water quality from uranium mining is runoff from uranium mining operations - specifically, from mine waste piles and open pit operations. Both surface and underground mining produce waste piles. While the waste piles vary considerably in respect to ore content, the existence of the piles creates the potential for trace elements and radioactivity to be carried by runoff into surface water courses. Similarly, open pit mining exposes the ore body and creates the potential for contamination of surface waters through runoff. Furthermore, open pit mines have large waste piles nearby which may be subject to erosion.

Investigation of the largest open pit mine in the Grants Mineral Belt, the Jackpile-Paguate mine, indicates that while certain radioactive parameters are significantly elevated downstream from the mine, water quality both upstream and downstream is consistent with the livestock watering use. Investigation of mine waste piles in the Ambrosia Lake mining district, however, indicates that runoff from the piles is of a considerably lesser quality than natural runoff. Thus, such runoff is definitely not suitable for livestock watering and raises concerns about its levels of radioactivity. Similar results are expected to be found in the Church Rock district.

9.3.1. Runoff From Mine Waste Piles

Runoff from uranium mine waste piles exerts a potentially significant impact on surface water quality in the Grants Mineral Belt because of the trace elements and radioactivity associated with sediment carried by this runoff. Similar to the situation with natural runoff, livestock may ingest such turbid waters.

Total concentrations of arsenic, cadmium, lead, selenium, vanadium, gross alpha particle activity, and radium-226 found in mine waste pile runoff in the Ambrosia Lake District are not consistent with ingestion of this water by livestock (Table 9.6). This conclusion remains true even after the gross alpha activity is corrected for the alpha activity due to natural uranium (1 mg/l is equivalent to 667 pCi/l), which is not included in the livestock watering criterion. The median and maximum uranium values of 389 and 41,800 pCi/l are far below the measured gross alpha activity levels. In fact, for all constituents except arsenic, maximum concentrations are one to four orders of magnitude above livestock watering criterion. Even for arsenic, the maximum concentration exceeds the livestock watering criterion by over seven times. The median concentration of arsenic, though, is at its criterion level and selenium levels normally do not exceed its criterion.

Even though maximum permissible concentrations (MPCs) for release of radionuclides to unrestricted areas do not apply to runoff from mine waste piles, comparison with MPCs provides a means of evaluating the relative importance of radionuclides concentrations. Even median concentrations of lead-210 and radium-226 exceed MPCs by an order magnitude and maximum concentrations exceed MPCs two and three orders of magnitude, respectively (Table 9.7). While natural uranium concentrations are normally below its MPC, this level was exceeded by the maximum measured concentration.

TABLE 9.6. Comparison of Total Concentrations of Trace Elements and Radioactivity in Mine Waste Pile Runoff in the Ambrosia Lake Mining District with Livestock Watering Criteria.

CONSTITUENT	MEDIAN	MAXIMUM	LIVESTOCK WATERING CRITERIA[a]
mg/l			
As	0.21	1.5	0.2
Pb	0.56	2.5	0.1
Se	0.03	0.85	0.05
V	1.1	24.8	0.1
pCi/l			
Gross alpha	10,800	420,000	15
Ra-226	650	34,900	5[b]

[a] The criteria are from NAS/NAE (1972).

[b] The criterion applies to combined radium-226 and radium-228.

TABLE 9.7. Comparison of Total Radioactivity in Mine Waste Piles in the Ambrosia Lake Mining District with Maximum Permissible Concentrations for Releases to Unrestricted Areas. All concentrations are in mg/l.

RADIONUCLIDE	MEDIAN	MAXIMUM	MAXIMUM PERMISSIBLE CONCENTRATIONS[a]
Pb-210	1,000	30,050	100
Ra-226	650	34,900	30
U-natural	389	41,800	30,000

[a] The maximum permissible concentrations are from Table II.of Appendix A to Part 4 of the New Mexico Radiation Protection Regulations (NM EID, 1980). The concentrations are not applicable to natural runoff and are used only for comparison purposes.

When the results of comparison with livestock watering criteria and MPCs are considered together, the obvious conclusion is that while the quality of natural runoff in the Ambrosia Lake mining district is poor, mine waste pile runoff is worse. While information on the quality of mine waste pile runoff in the Church Rock district was not collected, this same conclusion is expected to hold in that district also.

9.3.2. Effect of an Open-Pit Mine on Surface Water Quality

Streams above and below the Jackpile-Paguate open-pit mine are likely to be used for livestock watering. In comparison to water quality in the Rio Paguate and the Rio Moquino above the mine, total dissolved solids and dissolved levels of gross alpha particle activity and radium-226 are significantly elevated in the Rio Paguate below the mine. In addition, dissolved concentrations of some trace elements are slightly elevated.

Comparison of livestock watering criteria with dissolved concentrations below the mine indicates that all constituents except for gross alpha and radium-226 are much less than recommended criteria (Table 9.8). Only the recommended criterion for gross alpha activity is apparently exceeded. The criterion, however, based on the criterion for domestic water supply (NAS/NAE, 1972), excludes uranium and the mean natural uranium concentration of 0.12 mg/l below mine accounts for 81 pCi/l of alpha activity. Therefore, the gross alpha activity is within the standard and the streams both above and below the Jackpile-Paguate mine are suitable for livestock use.

9.4. RELATIONSHIP OF RUNOFF QUALITY TO STREAM QUALITY

Under natural conditions (i.e., without mine dewatering), flow in San Mateo Creek below the community of San Mateo and the Puerco River consists of waters derived from runoff. Comparison of natural runoff from storms with livestock watering criteria indicates that such waters are not suitable for livestock watering primarily because of excessive concentrations of lead, vanadium, gross alpha particle activity, and radium-226. Data, while restricted to the Ambrosia Lake mining district, indicates that runoff from uranium mine waste piles is even less suited for livestock watering because of even higher concentrations of the same constituents.

Nonetheless, there are two lines of evidence that, when considered together, suggest that the direct effects of runoff, natural or uranium mine waste pile, on water quality are primarily local in extent. First, trace elements and radionuclides in runoff are bound up with sediment. Both trace element and radionulcide concentrations in runoff have been found to have linear, first-order statistical correlations with sediment concentrations. Further, leach tests did not produce significant leaching of trace elements from mine wastes. In addition, investigations of the partitioning of lead-210 and radium-226 between suspended and dissolved phases of runoff indicate that almost all of the radioactivity is associated with the suspended phase.

Secondly, sediments from an area become mixed with other sediments carried by the watercourse and thus diluted and then deposited along the stream bottom. The investigations of sediment deposition downstream from the San Mateo mine waste pile serve as a case example. Sediments originally identifiable as having the waste pile as their source on the basis of trace element and radionuclide concentrations,

TABLE 9.8 Comparison of Dissolved Concentrations of Total Dissolved Solids, Trace Elements, and Radioactivity in the Rio Paguate below the Jackpile-Paguate Mine with Livestock Watering Criteria.

CONSTITUENT	MEDIAN CONCENTRATION	LIVESTOCK WATERING CRITERIA[a]
	mg/l	
TDS	1,705	3,000
As	0.006	0.2
Cd	0.002	0.050
Pb	<0.005	0.1
Se	0.006	0.05
V	0.010	0.1
Zn	<0.25	25
	pCi/l	
Gross alpha	79 ± 18[b]	15
Ra-226	3.7 ± 0.14	5[c]

[a] The criteria are from NAS/NAE (1972).

[b] The gross alpha particle criterion excludes alpha activity due to natural uranium. Therefore, while the mean apparently exceeds the criterion, actually the gross alpha is accounted for by the mean natural uranium concentration of 0.12 mg/l, which is equivalent to 81 pCi/l.

[c] The radium criterion applies to combined radium-226 and radium-228.

eventually become so mixed with other sediments as to no longer be chemically distinguishable. This phenomon has been noted by Popp and others (1983).

Watercourses of the Grants Mineral Belt, nonetheless, are dynamic systems. While dilution and deposition of sediments serve as natural mechanisms that limit adverse water quality impacts of runoff, such sediments do not necessarily remain deposited on channel bottoms. Instead, storm runoff or flow resulting from mine dewatering may entrain sediment and thus result in resuspension, further mixture, and later redeposition downstream. Thus, re-entrainments and later redeposition serves as a process for carrying trace elements and radioactivity downstream in Grants Mineral Belt watercourses.

9.~~6~~5 IMPACT OF MINEWATER DISCHARGES ON SURFACE WATER QUALITY

In terms of both quantity and quality, discharged minewaters are the dominant type of surface waters in the Grants Mineral Belt. Treated minewaters are used directly for livestock watering and irrigation and thus should be evaluated for suitability for these uses. Further, they infiltrate to shallow alluvial aquifers and may thus secondarily be used as a source of domestic water supply. Therefore, direct comparison of treated minewater quality with domestic water supply standards indicate the changes in chemical quality, whether by natural means or treatment, that treated minewaters must undergo to be suitable as domestic water sources.

In the Ambrosia Lake mining district, the treated minewater constituents of greatest concern in relation to water uses are selenium, radium-226, and secondarily molybdenum (Table 9.9). Selenium normally exceeds standards and criteria established for livestock watering, irrigation, and domestic water supply. Selenium is of special concern as it remains soluble as minewaters flow downstream. Median radium-226 concentrations slightly exceed both the livestock watering and irrigation criteria and the New Mexico Water Supply Regulations standard for domestic water supply. The maximum radium-226 concentration also exceeds the New Mexico Ground Water Regulations standard for protection of ground waters for domestic water supply use. While radium-226 readily becomes adsorbed onto sediment or is co-precipitated and thus through these mechanisms tends to become deposited on stream bottoms, the radium-226 associated with sediments may also be later entrained and transported downstream by runoff or dewatering effluents.

While minewaters are not known to be used for irrigation in the Ambrosia Lake mining district, the use of minewaters for irrigation in the Church Rock district indicates that potential for such use exists. Molybdenum levels are normally more than a magnitude higher than the criterion recommended by Vleck and Lindsay (1977) to prevent excessive plant uptake of molybdenum. Further, while molybdenum levels normally meet the considerably higher New Mexico Ground Water Regulations standard for protection of ground water for irrigation use, the maximum measured molybdenum level even exceeds that less restrictive standard by a factor of three. Molybdenum like selenium remains in solution.

Concentrations of other constituents shown on the table raise further concerns about the use of treated minewaters in the Ambrosia Lake mining district. Total dissolved solids and sulfate concentrations normally exceed the New Mexico Ground Water Regulations standard for protection of ground waters for irrigation and domestic water supply use. Arsenic meets the livestock watering criterion, but the

TABLE 9.9 Comparison of Total Concentrations in Minewater Discharges in the Ambrosia Lake Mining District with Water Use Criteria and Standards.

CONSTITUENT	MINEWATER CONCENTRATIONS		USE CRITERIA AND STANDARDS					
			Livestock Watering	Irrigation			Domestic Water Supply	
	Median	Maximum	(NAS/NAE)	(NAS/NAE)	(The Molybdenum Project	(NM Ground Water Regulations)	(NM Water Supply Regulations)	(NM Ground Water Regulations)
	mg/l							
TDS	1,610	2,615	3,000			1,000		1,000
SO_4	755	1,370				600		600
As	0.011	0.20	0.2	0.10		0.1	0.05	0.1
Ba	0.21	1.7				1.0	1.	1.0
Mo	0.80	3.2			0.020	1.0		
Se	0.09	1.0	0.05	0.02		0.05	0.01	0.05
U natural	1.56	3.0				5.0		5.0
V	0.029	0.29	0.1	0.10				
	pCi/l							
Gross Alpha[a]	635	1,760	15				15	
Ra-226[b]	6.4	200	5	5			5	30

NOTE: Information on the sources of the use criteria and standards is found in Table 9.1.

[a]The gross alpha particle activity criteria exclude alpha activity due to natural uranium. Therefore, while the measured concentrations apparently are exceedances, the median and maximum natural uranium concentrations account for 1,060 and 2,030 pCi/l, respectively.

[b][illegible]

maximum arsenic level exceeds its irrigation criterion and standard and its domestic water supply standards. While barium levels normally meet the New Mexico Water Supply Regulations standard for domestic water supply and the New Mexico Ground Water Regulations standard for protection of ground waters for irrigation and domestic water supply use, the maximum barium level exceeds these standards. In a similar manner, vanadium levels normally meet and the maximum level exceeds livestock watering and irrigation criteria.

Gross alpha particle activity levels, which exceed the numeric levels of both the livestock watering criterion and the New Mexico Water Supply Regulations standard for domestic water supply, are accounted for by the alpha activity of natural uranium and thus are not exceedances as the criterion and the standard do not include alpha activity due to natural uranium. There is actually a large disparity between the calculated natural uranium alpha activity and the lower measured gross alpha activity levels as the median and maximum alpha activity levels for uranium are 1,060 and 2,030 pCi/l, respectively. Such differences, though, are common as a result of the difficulties of measuring gross alpha activity.

In the Church Rock mining district, the treated minewater constituents of greatest concern in relation to water uses are selenium and radium-226 (Table 9.10). Selenium normally exceeds criteria and standards established for livestock watering, irrigation, and domestic water supply. Maximum radium-226 concentrations exceed livestock watering and irrigation criteria and domestic water supply standards.

Of lesser concern in the Church Rock district are barium and molybdenum. Barium is normally below its New Mexico Ground Water Regulations standard for protection of ground waters irrigation and domestic water supply, but the maximum observed concentration was slightly higher than twice the standard of 1.0 mg/l. Molybdenum levels are normally less than the irrigation criterion recommended by Vleck and Lindsay (1977) and even the maximum level is only about one-half the New Mexico Ground Water Regulations standard for protection of ground waters for irrigation use. The irrigation criterion, however, is exceeded by the maximum observed level. While the maximum measured total dissolved solids concentration of 1,190 mg/l exceeds the New Mexico Ground Water Regulations standard for protection of ground waters for irrigation and domestic water supply use, concentrations are normally less than half the standard.

Gross alpha particle activity exceeds the numeric level of both the livestock watering criterion and the New Mexico Water Supply Regulations standard for domestic use since the criterion and the standard do not include alpha activity due to natural uranium, these levels are not exceedances. The median and maximum natural uranium concentrations are equivalent to 724 and 1,220 pCi/l of alpha activity, respectively. The differences between gross alpha activity and the calculated alpha activity due to natural uranium are attributable to the difficulties of measuring accurate gross alpha activity levels accurately.

In summary, comparisons of treated minewater quality with criteria and standards raises concern about the suitability of these waters for livestock watering, irrigation, and domestic water supply uses. Treated minewaters in the Ambrosia Lake district are poorer in quality and less suitable for these uses than those in the Church Rock district (Table 9.11). Overall, the major constituents affecting the suitability of treated minewaters are selenium, molybdenum, radium-226, total dissolved solids, and sulfate. Of these five, total dissolved solids and sulfate are the least important, as these waters are not known to be used as domestic water

TABLE 9.1? Comparison of Total Concentations of Minewate' ischarges in the Church Rock Mining District with W' er Use Criteri and Standards.

CONSTITUENT	MINEWATER CONCENTRATION		USE CRITERIA AND STANDARDS					
			Livestock Watering	Irrigation			Domestic Water Supply	
	Median	Maximum	(NAS/NAE)	(NAS/NAE)	(The Molybdenum Project	(NM Ground Water Regulations)	(NM Water Supply Regulations)	(NM Ground Water Regulations)
	mg/l							
TDS	452	1,190	3,000			1,000		1,000
SO_4	136	600				600		600
As	<0.005	0.02	0.2			0.1	0.05	0.1
Ba	0.413	2.1				1.0	1.	1.0
Mo	0.01	0.6			0.020	1.0		
Se	0.042	0.3	0.05	0.02		0.05	0.01	0.05
U-natural	1.07	1.8				5.0		5.0
V	0.012	0.07	0.1	0.10				
	pCi/l							
Gross Alpha[a]	440	1,200	15				15	
Ra-226[b]	2.0	89	5	5			5	30

NOTE: Information on the sources of the use criteria and standards is found in Table 9.1.

[a]The gross alpha particle activity criteria exclude alpha activity due to natural uranium. Therefore, while the measured concentrations apparently are exceedance, the median and maximum natural uranium concentrations account for 724 and 1,220 pCi/l, respectively.

TABLE 9.11. Constitutents of Treated Minewaters and Affected Water Uses. Major constituents affecting water uses are indicated by M; secondary constituents by S.

Constituent	AMBROSIA LAKE MINING DISTRICT			CHURCH ROCK MINING DISTRICT		
	Livestock Watering	Irrigation	Domestic Water Supply	Livestock Watering	Irrigation	Domestic Water Supply
TDS		M	M		S	S
SO_4		M	M			
As		S	S			
Ba		S	S		S	S
Mo		M			S	S
Se	M	M	M	M	M	M
V	S	S				
Ra-226	M	M	M	S	S	S

NOTE: A constituent affecting a water use is considered major if the median concentration exceeds the most sensitive criterion or standard given in Table 9.1 for a specific use (i.e., measured levels normally exceed the criterion). A constituent is considered secondary if the median meets, but the maximum exceeds the most sensitive criterion or standard for a specific use (i.e., while measured levels normally meet the criterion, exceedances are found).

supplies or, in the Ambrosia Lake district where total dissolved solids concentrations are higher, for irrigation. Further, a compliance evaluation of total dissolved solids and sulfate in relation to irrigation use would need to consider individual ions, soils, crops, and acceptable yields. As mentioned earlier, radium-226 decreases as waters flow downstream from adsorption and co-precipitation and deposition, but may be resuspended. Selenium and molybdenum, however, remain soluble and thus continue to affect water use downstream as well as at the point of discharge.

Most radionuclides in treated minewaters are well below the maximum permissible concentrations (MPCs) for releases to unrestricted areas except for radium-226 (Table 9.12). While the MPCs apply only to state-licensed facilities and not to treated minewaters, here again MPCs serve as a useful basis for comparison. Radium-226 concentrations are normally below its MPC, but maximum levels exceed the MPC by almost three and seven times in the Church Rock and Ambrosia Lake mining districts, respectively. The maximum levels reflect poor operation of treatment systems. The only other radionuclide present in significant amounts in relation to its MPC is lead-210 in the Ambrosia Lake district. The median and maximum measured concentrations are 1/7 and 1/3 the MPC, respectively. Both radium-226 and lead-210 are usually lost from by becoming sediment-bound and deposited on stream bottoms, but may later be resuspended.

Animals exposed to Puerco River water tend to have higher concentrations of radionuclides in their tissues than control animals (Ruttenber and others, 1980). Evidence suggests that observed radionuclide concentrations have resulted from prolonged ingestion of contaminants predominantly derived from mine dewatering effluents and native soils. A separate EID study (Lapham and Millard, 1983) is intended to examine livestock throughout the Grants Mineral Belt and to quantify the risk to people who eat these animals.

While no current health standard for uranium was exceeded in treated minewaters, recent data suggest that chemical and radiological toxicities for uranium have been substantially underestimated. The New Mexico Ground Water Regulations standard of 5.0 mg/l was established for chemical toxicity, and the MPC for releases to unrestricted areas, equivalent to 44.3 mg/l, is based on radiotoxicity. In contrast, suggested maximum daily limits for potable water, developed from recent data by the U.S. Environmental Protection Agency (1983), are 0.21 mg/l and 0.015 mg/l based on chemical toxicity and radiotoxicity, respectively. If these more stringent limits are used for comparison, virtually none of the effluent affected waters would be considered suitable for potable water without further treatment.

9.6 IMPACT OF MINEWATER DISCHARGES ON GROUND WATER QUALITY

Dewatering effluents have infilterated shallow alluvial aquifers to such an extent that ground waters along San Mateo Creek downstream from the Ambrosia Lake mining district to the Otero well cluster and in localized areas along the Puerco River downstream from the Church Rock mining district now have a strong chemical resemblance to treated minewaters. Comparison of mean values for five wells along San Mateo Creek and two wells on the Puerco River determined to be affected by minewaters with use criteria and standards indicates that only molybdenum, selenium, and perhaps gross alpha are currently found in high enough concentrations to raise concerns about the suitability of shallow ground waters for livestock watering, irrigation, and domestic water supply uses (Table 9.13). Concentrations of other constituents are well below use criteria and standards.

TABLE 9.12. Comparison of Total Radioactivity in Minewater Discharges with Maximum Permissible Concentrations for Releases to Unrestricted Areas. All concentrations in pCi/l.

RADIONUCLIDES	AMBROSIA LAKE MINING DISTRICT		CHURCH ROCK MINING DISTRICT		MAXIMUM PERMISSIBLE CONCENTRATION[a]
	Median	Maximum	Median	Maximum	
Pb-210	14 ± 5	33 ± 6	---	10 ± 2[b]	100
Po-210	1.1 ± 0.4	14 ± 2	9.8 ± 7.4	15 ± 5	700
Ra-226	6.4 ± 1.2	200 ± 10	2.0 ± 0.2	89 ± 5	30
Ra-228	0 ± 2	0 ± 2	---	0 ± 2[b]	30
Th-228	<0.1	<0.3	---	<0.2[b]	7,000
Th-230	0.7 ± 0.2	4.0 ± 0.5	---	3.9 ± 0.5[b]	2,000
Th-232	<0.1	<0.1	---	<0.2[b]	2,000
U-natural[c]	1,060	2,030	724	1,220	30,000

[a] Maximum permissible concentrations are from Table II of Appendix A to Part 4 of the New Mexico Radiation Regulations (NM EID, 1980). The concentrations are not applicable to treated minewaters and are used only for comparison.

[b] Only two samples were analyzed for this radionuclide in the Church Rock mining district.

[c] Uranium radioactivity was calculated from total concentrations in mg/l by using the conversion facor, 1.0 mg/l equals 677 pCi/l.

TABLE 9.13. Mean Concentrations of Ground Water Constituents Exceeding Use Criteria and Standards.

WELL	MOLYBDENUM Mean Concentrations (mg/l)	MOLYBDENUM Affected Use	SELENIUM Mean Concentrations (mg/l)	SELENIUM Affected Use	GROSS ALPHA Mean Concentrations (pCi/l)	GROSS ALPHA Affected Use
San Mateo Creek						
SAN-1			0.018	DWS	184 ± 38	LW, DWS
SAN-2			0.018	DWS	209 ± 69	LW, DWS
OTE-1	0.381	IRR	0.080	LW, IRR, DWS		
OTE-2	0.261	IRR	0.072	LW, IRR, DWS		
OTE-4			0.102	LW, IRR, DWS		
Puerco River						
CON-3	0.170	IRR	0.011	DWS		

NOTE: The following use criteria and standards were used in preparing the table:

LW (livestock watering)

Se	0.05 mg/l	NAS/NAE (1972)
Gross alpha	15 pCi/l	NAS/NAE (1972)

IRR (irrigation)

Mo	0.150 mg/l	The Molybdenum Project (Vleck and Lindsay, 1977)
Se	0.02 mg/l	NAS/NAE (1972)

DWS (domestic water supply)

Se	0.01 mg/l)	New Mexico Water Supply Regulations (NM EIB, 1977)
Gross alpha	15 pCi/l (except for uranium and radon)	New Mexico Water Supply Regulations (NM EIB, 1977)

Selenium is the major constituent affecting the suitability of ground water for present and future use. The most sensitive use is domestic water supply; the least sensitive, livestock watering. Selenium concentrations in all five wells along San Mateo Creek and in one of the two wells (CON-3) on the Puerco River exceed the standard for public water supplies in the New Mexico Water Supply Regulations. The mean for CON-3, though, is essentially at the level of the standard. In addition, the three wells located farthest downstream on the San Mateo have selenium concentrations well above use criteria and thus are not suitable for livestock watering and irrigation. The molybdenum criterion for irrigation is exceeded at two wells in the Otero cluster along San Mateo Creek and at CON-3 on the Puerco River.

Gross alpha particle activity is generally elevated in ground waters influenced by dewatering effluents, but this increase is usually the result of natural uranium and thus does not constitute an exceedance of the livestock watering criterion and public water supply standard of 15 pCi/l. Only SAN-1 and SAN-2 had excess gross alpha activities of 34 and 39 pCi/l, respectively, not accounted for by natural uranium levels. Because of the difficulties involved in measuring gross alpha particle activity accurately and resulting errors associated with such measurements, these excess levels may be artifacts.

Comparison of ground water quality with use criteria and standards raises definite concerns about shallow alluvial aquifers along San Mateo Creek. The suitability of these ground waters for future use has already been affected. Unfortunately, sufficient data are not available to examine trends and to make predictions on future water quality.

Conclusions on ground waters along the Rio Puerco are not so clear-cut. The alluvium along the Rio Puerco is less permeable than along San Mateo Creek with the results that affected areas are more localized. Further, effects of the UNC tailings spills in local areas on the shallow aquifer has obscured possible effects related to dewatering. The levels of selenium and molybdenum, however, in CON-3, while lower than levels in wells along San Mateo Creek, indicate that there is a potential for sufficient degradation of ground water along the Puerco River to affect future water uses.

No current health standard for uranium is exceeded in alluvial ground waters. If the more stringent suggested limits discussed in section 9.5 are used for comparison, however, virtually none of the minewater affected ground waters would be suitable for potable water without further treatment. Because elevated levels of uranium may persist in alluvial aquifers for a decades, this treatment would have to be sustained for long period of time.

X. LEGAL AND REGULATORY MECHANISMS

Uranium mine operations in New Mexico are subject or potentially subject to a number of federal and state laws and regulations. No single statute addresses all significant water quality impacts resulting from uranium mining. Therefore, in order to deal with the major water pollution problems discussed in this report, the full range of currently and potentially applicable laws and regulations is evaluated in order to determine the most effective means of control.

Applicable water pollution control statutes are the federal Clean Water Act and the New Mexico Water Quality Act. Other statutes that bear less directly on water quality, but are relevant to the overall effort to protect water resources are the New Mexico Radiation Protection Act, the New Mexico Abandoned Mine Reclamation Act, the federal Resource Conservation and Recovery Act, and the federal Comprehensive Environmental Response, Compensation and Liability Act.

10.1. CLEAN WATER ACT

The Clean Water Act is the cornerstone of federal water pollution control programs. The objective of the Act as stated in Section 101(a) is "... to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." Among the national goals established by the Act to achieve this objective are elimination of the discharge of pollutants into navigable waters and prohibition of the discharge of toxic pollutants in toxic amounts (Sections 101(a)(1) and (3)).

Section 402 of the Act establishes the National Pollutant Discharge Elimination System (NPDES), to regulate discharges of pollutants into navigable waters through a permit program. Under Section 502(7) "navigable waters" are defined as "waters of the United States, including the territorial seas." The courts have broadly construed "navigable waters" to mean not only perennial rivers but also their tributaries, including intermittent streams flowing through normally dry arroyos. NPDES permits for discharges in New Mexico are issued by the EPA Region VI office in Dallas, Texas.

To implement the NPDES permit program, the EPA establishes effluent limitation guidelines for various categories of discharges. These serve as a basis for effluent limitations in specific NPDES permits. The effluent limitations guidelines specify both the pollutants and the allowable discharge concentrations or loads for a type of discharge.

Under the program, uranium mines are classed as part of the ore mining and dressing point source category. Effluent limitation guidelines, published in 40 CFR Part 440, have been established for the following constitutents of uranium mine discharges:

total suspended solids
chemical oxygen demand
uranium
zinc
total radium-226
dissolved radium-226
pH

While effluent limitation guidelines normally serve as the permit conditions, NPDES permits can be made more stringent than the guidelines as a consequence either of a case-specific analysis by the EPA or of more stringent permit conditions imposed through state certification. Section 401 of the Act requires the EPA to include effluent limitations, other limitations, and monitoring requirements certified by a state as necessary to meet Clean Water Act requirements and state law, regulations, and standards in a permit. In New Mexico, NPDES permits are certified by the EID as part of its responsibilites delegated by the New Mexico Water Quality Control Commission (WQCC). As a result of state certification, NPDES permits for uranium mines in New Mexico include monitoring and reporting requirements, but do not specify numeric limitations, for the following parameters:

barium
manganese
molybdenum
selenium
vanadium
lead-210
polonium-210

NPDES permit conditions for uranium minewater discharges in the Grants Mineral Belt are summarized in Table 10.1. The NPDES permit for Gulf Mineral Resources/Mt. Taylor does not include all the normal monitoring and reporting requirements because the omitted parameters are being regulated under the state Ground Water Regulations.

In practice, the NPDES permit program has not proved to be an effective means to regulate minewater discharges. Almost all NPDES permits issued to uranium mines in New Mexico have been legally challenged by the mine operators. Until these cases are finally resolved by the courts, NPDES regulations preclude EPA from taking enforcement action against the contesting permittees.

The mine operators have asserted that the EPA lacks jurisdiction because they are discharging into ephemeral streams which, they contend, are not "navigable waters" within the meaning of the Clean Water Act. This jurisdictional challenge has been rejected by every court decision thus far. In fact, in June, 1985, the U.S. Court of Appeals for the Tenth Circuit upheld an EPA administrative ruling affecting the Homestake Mining Company mines and the Kerr-McGee (Quivira Mining Company) Ambrosia Lake and Lee mines. In the August 5, 1983, order, EPA ruled that San Mateo Creek and Arroyo del Puerto can be considered waters of the United States that are subject to EPA regulation because a surface connection can exist between them and navigable waters during intense rainfalls. On January 13, 1986 the U.S. Supreme Court announced it would not review the Court of Appeals decision, thus indirectly upholding the decision. The Homestake Mining Company permit was stayed, and thus remained unenforceable, from 1972 through 1985.

10.2. NEW MEXICO WATER QUALITY ACT

In 1967 the New Mexico Legislature enacted the Water Quality Act. This Act created the WQCC and authorized the Commission to "adopt water quality standards as a guide to water pollution control" and also "adopt, promulgate and publish regulations to prevent or abate water pollution in the state." The Act defines water to include "water situated wholly or partly within or bordering upon the state,

TABLE 10 1 NPDES Permit Conditions for Uranium Minewater Discharges. An asterisk indicates that while the permit does not specify a numeric limitation, monitoring and reporting are required.

URANIUM MINEWATER DISCHARGE (NPDES PERMIT NUMBER)	PERMIT CONDITION TIME FRAME	Flow (mgd)	Temperature (°F)	TSS (mg/l)	COD (mg/l)	U-total (mg/l)	Zn-total (mg/l)	Ra-226 (pCi/l) - total	- dissolved	Ba (mg/l)	Mn (mg/l)	Mo-total (mg/l)	Se-total (mg/l)	V-total (mg/l)	Pb-210 (pCi/l)	Po-210 (pCi/l)	pH Range	TDS (kg/day-lb/day)	BIOMONITORING
Ambrosia Lake Mining District																			
Gulf Mineral Resources/Mt. Taylor	Daily Ave.	*		20	100	2.0	0.5	10	3			*	*	*			6.0-		No
(NM0028100)	Daily Max.	*	*	30	200	4.0	1.0	30	10			*	*	*			9.0		
Homestake Mining Company[1]	Daily Ave.	*		20	100	2.0	0.5	10	3			*	*	*	*	*	6.6-		
(NM0020389)	Daily Max.	*	*	30	200	4.0	1.0	30	10			*	*	*	*	*	8.6		No
Kerr-McGee (Quivira)/Ambrosia Lake[1]	Daily Ave.	*		20	100	2.0	0.5	10	3	*	*	*	*	*	*	*	6.0-		Yes
(NM0020532)	Daily Max.	*	*	30	200	4.0	1.0	30	10	*	*	*	*	*	*	*	9.0		Yes
Kerr-McGee (Quivira)/Lee Mine[1]	Daily Ave.	*	*	20	100	2.0	0.5	10.0	3.0	*	*	*	*	*	*	*	6.0-		Yes
(NM0028207)	Daily Max.	*	*	30	200	4.0	1.0	30.0	10.0	*	*	*	*	*	*	*	9.0		
Church Rock Mining District																			
Kerr-McGee (Quivira)/Church Rock	Daily Ave.	*.		20	100	2.0	0.5	10	3	*	*	*	*	*	*	*	6.0-	*	Yes
(NM002524)	Daily Max.	*	*	30	200	4.0	1.0	30	10	*	*	*	*	*	*	*	9.0-	*	Yes
United Nuclear Corp./NE Church Rock Mine	Daily Ave.	*		20	100	4.0	1.0	10	*	*	*	*	*	*	*	*	6.0-	909	Yes
(NM0020401)	Daily Max.	*	*	30	200	4.0	1.0	30	10	*	*	*	*	*	*	*	9.0-	2,000	No

TABLE 10.1 (Continued)

URANIUM MINEWATER DISCHARGE (NPDES PERMIT NUMBER)	PERMIT CONDITION TIME FRAME	Flow (mgd)	Temperature (°F)	TSS (mg/l)	COD (mg/l)	U-total (mg/l)	Zn-total (mg/l)	Ra-226 (pCi/l) - total	- dissolved	Ba (mg/l)	Mn (mg/l)	Mo-total (mg/l)	Se-total (mg/l)	V-total (mg/l)	Pb-210 (pCi/l)	Po-210 (pCi/l)	pH RANGE	TDS (kg/day-lb/day)	BIOMONITORING
United Nuclear Corp./Old Church Rock Mine	Daily Ave.	*		20	100	2.0	0.5	10	3			*	*	*			6.0-	*	No
(NM0028550)	Daily Max.	*	*	30	200	4.0	1.0	30	10			*	*	*			9.0		
Other Mining Areas																			
Bokum Resources	Daily Ave.	*		20	100	2	0.5	10	3			*	*	*	*	*	6.8-		
(NM002815)	Daily Max.	*	*	30	200	4	1.0	30	10			*	*	*	*	*	8.6		Yes
Kerr-McGee (Quivira)/Marquez Mine	Daily Ave.	*		20	100	2.0	0.5	10	3	*	*	*	*	*	*	*	6.0-		
(NM0028754)	Daily Max.	*	*	30	200	4.0	1.0	30	10	*	*	*	*	*	*	*	9.0		No
Kerr-McGee (Quivira)/Rio Puerco	Daily Ave.	*		20	100	2	*	10	3	*	*	*	*	*	*	*	6.0-		Yes
NM0028169)	Daily Max.	*	*	30	200	4	*	30	10	*	*	*	*	*	*	*	9.0		
Phillips Uranium Corp./Nose Rock Mine 1, 2	Daily Ave	*		20	100	2.0	0.5	10	3	*	*	*	*	*	*	*	6.6-		
(NM0028274)	Daily Max	*	*	30	200	4.0	1.0	30	10	*	*	*	*	*	*	*	8.6-	*	No

[1] Permit is under ajudication.
[2] Per mit also includes monitoring and reporting requirements for daily average and daily maximum concentrations of alkalinity, sulfate, total aluminum, fluoride, and phenols.

whether surface or subsurface, public or private except private waters that do not combine with other surface or subsurface water."

The WQCC has determined that the federal NPDES permit program should be the primary mechanism for controlling discharges of pollutants to surface waters in the state. Consequently, state Regulations for Discharges to Surface Waters, Part 2 of the Commission regulations (NM WQCC, 1984), include a mechanism to prevent dual regulation of NPDES permittees. Discharge limitations contained in these regulations are not applicable to an NPDES permittee unless the permittee has received written notification from the EPA of a violation and the violation has not been corrected within thirty days of receipt of the notice.

The Regulations for Discharges to Surface Waters, however, are not an effective means of regulating uranium minewater discharges even after the applicability provisions of EPA notification and non-correction of violations have been satisfied. The regulations need to be amended to include numeric discharge limitations for additional parameters. Currently, the regulations specify discharge limitations only for the following parameters:

biochemical oxygen demand
chemical oxygen demand
fecal coliform bacteria
settleable solids
pH

Of this list, only two (chemical oxygen demand and pH) are among the seven constituents of uranium minewater discharges with NPDES effluent limitation guidelines. The state regulations do not address any of the constituents for which monitoring and reporting is being required through state NPDES certification.

In its state certification of NPDES permits for uranium minewater discharges, the EID has used the general standards, Section 1-102 of the state surface water quality standards (NM WQCC, 1985), to incorporate conditions on monitoring and reporting and, when appropriate, on salinity into the permits. The general standards apply to all surface waters of the state which are "suitable for recreation and support of desirable aquatic life presently common in New Mexico waters". Among the contaminants addressed by the general standards are toxic substances and radioactivity (sections 1-102.F. and G.). The standard for toxic substances specifies that:

> Toxic substances... shall not be present in receiving waters in concentrations which will change the ecology of receiving waters to an extent detrimental to man or other organisms of direct or indirect commercial, recreational, or aesthetic value.

Under the standard, toxic concentrations are determined by appropriate bioassay techniques or by other accepted means, which may include use of established water quality criteria. Radioactivity is to "be maintained at the lowest practical level and in no case is to exceed" the numeric maximum permissible concentrations of the New Mexico Radiation Protection Regulations (NM EID, 1980).

The applicability of the general standards to ephemeral watercourses has been challenged. The uranium mine operators contend the stream standards do not apply because the watercourses to which they discharge do not support desirable aquatic life.

The EID has used the state Ground Water Regulations, Part 3 of the WQCC regulations, to regulate uranium minewater discharges, because the discharged constituents may move into ground water downstream from the discharge point. The regulations expressly exempt constituents covered by an effective and enforceable NPDES permit in order to avoid dual state and federal regulations. The regulations may be applied, however, to those constituents of a uranium minewater not covered by the NPDES for the discharge. The regulations may also be applied to all constituents of a discharge where the NPDES permit is stayed because of a legal challenge and thus is neither effective nor enforceable. Nevertheless, the Ground Water Regulations are designed specifically to protect ground water quality and the regulatory design places limitations on the effectiveness of these regulations for protecting surface water quality.

The state Ground Water Regulations establish numeric standards for the protection of ground water quality for present and potential use as agricultural and domestic water supply. The regulations require that a discharger demonstrate in a discharge plan that the discharger will not cause these standards to be violated in ground water at any place of present or foreseeable future use. Where ground water quality already exceeds a numeric standard, the ambient concentration of the constituent becomes the standard.

The design of the Ground Water Regulations makes the standards a measure of ground water quality and not discharge limitations. If a discharge plan can demonstrate that physio-chemical conditions will result in a constituent meeting its standard at any place of present or foreseeable future use of ground water, a discharger may release effluents with concentrations of a constituent in excess of its standard and still comply with the regulations.

The Ground Water Regulations have been used to regulate minewater discharges to surface watercourses at the Phillips Uranium Corporation Nose Rock mine and the Kerr-McGee Corporation (Quivira Mining Company) Lee mine because the NPDES permits were stayed because of legal challenges. In both cases the mine operators elected to comply with regulatory requirements by specifying that the mine dewatering effluents should meet the ground water standards at the point of discharge. The discussion in Chapter 8 of existing degradation of ground water by mine dewatering effluents and of physico-chemical attenuation mechanisms make it evident that dewatering effluents of much poorer quality than the ground water standards would still not result in violations of the standards for most constituents at any place of present or foreseeable future withdrawal. The exceptions are those constituents, such as selenium, which are not reduced in concentration by attenuation mechanisms.

With regard to the regulation of mine uranium waste piles, the regulatory provision of greatest potential significance is Section 2-201 of the Regulations for Discharges to Surface Waters. This section, titled 'Disposal of Refuse', states:

> No person shall dispose of any refuse into a watercourse or in a location and manner where there is a reasonable probability that the refuse will be moved into a natural watercourse by leaching or otherwise.

Under Section 1-101.00 of the WQCC regulations, "refuse" includes "all unwholesome material". There is precedent for defining mine and mill tailings as refuse. EID has used this regulatory provision to require removal of spilled copper tailings and molybdenum tailings from watercourses. This provision should also cover pond treatment sludges, which have high levels of radium-226.

The language of Section 2-201 clearly negates any argument that the refuse must have actually entered a watercourse before a violation occurs. The EID may require corrective action where there is a definitive likelihood that refuse will enter the watercourse at some future time and such action may be taken where the refuse is mine wastes, as well as in the case of other "unwholesome materials".

Leachate that results from the direct natural infiltration of precipitation through uranium mine wastes may be subject to regulation by the Ground Water Regulations if a hazard to public health exists. Results of leaching tests conducted for this study, however, suggest that the leachate would not be hazardous to public health and thus would be exempted from the discharge plan requirement.

10.3. NEW MEXICO RADIATION PROTECTION ACT

The New Mexico Radiation Protection Act was passed by the New Mexico Legislature in 1971. The Act empowers the New Mexico Environmental Improvement Board (EIB) to develop regulations for governing the health and environmental aspects of radiation. It authorizes regulation of all persons who receive, possess, use, transfer, or acquire any source of radiation, except where regulated by another agency or where the source is specifically exempted from these regulations.

The Radiation Protection Regulations promulgated by the Board (NM EID, 1980) establish rules for the transportation storage, handling, and disposal of a variety of radioactive materials. Among the materials licensed are the "wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content" (Section 1-102.G.). Wastes produced by milling (i.e., mill tailings) or by ion-exchange recovery facilities are thus covered by the regulations.

Uranium mining wastes (i.e., mine spoils piles), on the other hand, are not covered by the Radiation Protection Regulations. In fact, Section 3-110.B. specifically exempts "unrefined and unprocessed ore" from regulation. Nonetheless, this exemption is not required by the New Mexico Radiation Protection Act. The Act merely provides that the Act "shall not apply to mining [or] extraction of radioactive ores or uranium concentrates that are regulated by the United States Bureau of Mines or any federal or state agency having authority unless the authority is ceded by such agency to the board" (Section 74-3-10.c. NMSA 1978 [emphasis added]). To date, no federal or state agency regulates mine wastes in New Mexico. Consequently, the EIB is free to regulate mine wastes, should the EIB see fit to amend its regulations accordingly.

10.4. NEW MEXICO ABANDONED MINE RECLAMATION ACT

The New Mexico Abandoned Mine Reclamation Act establishes a state program to promote the reclamation of mined areas pursuant to Title 4 of the federal Surface Mining Control and Reclamation Act. To qualify, the mined areas must have been left without adequate reclamation prior to the enactment of the federal statute.

Further, in their present, unreclaimed state, the mined areas must continue to substantially degrade the quality of the environment, prevent or damage the beneficial use of land or water resources, or endanger the health or safety of the public. Funds received by New Mexico pursuant to Title 4 of the federal statute are placed in the Abandoned Mine Reclamation Fund, a special purpose fund created by the Abandoned Mine Reclamation Act.

While both state and federal acts have the primary purpose of providing for reclamation of coal mines, both acts do authorize reclamation expenditures for mines other than coal mines under certain conditions. Mirroring provisions of the federal statute, the New Mexico Abandoned Mine Reclamation Act states that "voids and open and abandoned tunnels, shafts and entryways resulting from <u>any previous mining operation</u> constitute a hazard to the public health or safety and... surface impacts of <u>any underground or surface mining operations</u> may degrade the environment" (Section 69-25B-6.B NMSA 1978 [emphasis added]). Upon prior approval by the Governor and the United States Secretary of the Interior, the director of the Mining and Minerals Division of the New Mexico Energy and Minerals Department is authorized to use the Abandoned Mine Reclamation Fund to correct structural and physical hazards and to reclaim surface impacts that could endanger life and property, constitute a hazard to public health and safety, or degrade the environment. Thus, the Abandoned Mine Reclamation Act allows expenditures of the Abandoned Mine Reclamation Fund for non-coal-mining reclamation, including uranium mine reclamation. It should be noted that the federal statute only allows the Secretary of the Interior to approve non-coal-mining reclamation where a request is made by the governor of a state and all coal-related reclamation has been completed in the state except when the requested non-coal-mining reclamation is related to the protection of public health and safety.

10.5. RESOURCE CONSERVATION AND RECOVERY ACT

A potentially significant statute for the regulation of solid wastes and sludges generated at uranium mines, is the Resource Conservation and Recovery Act (RCRA). The 1976 passage of RCRA by the U.S. Congress established a comprehensive framework for the management of municipal solid wastes and hazardous wastes. For this assessment, the most relevant feature of the Act is the Subtitle C program, which governs hazardous waste management. The most significant aspect of Subtitle C is an elaborate hazardous waste management program which guides the treatment, storage, and disposal of hazardous waste from "cradle to grave". This program has been delegated to the EID by the EPA and is governed by the New Mexico Hazardous Waste Management Regulations (NM EIB, 1984), which are equivalent to the RCRA regulations promulgated by the EPA. Under the memorandum of understanding between the EPA and the EID, the state regulations must be revised to conform when federal RCRA regulations are revised by the EPA.

In 1981 the U.S. Congress amended RCRA so as to suspend RCRA regulation of mine wastes (including uranium mine wastes) pending completion of a study by the EPA to determine whether mine wastes should be dealt with as other "hazardous wastes" are under RCRA. That EPA study (U.S. EPA, 1985) was recently submitted to Congress with preliminary recommendations on RCRA regulation of mining wastes. A recommendation whether to regulate uranium mine wastes has not been reached by EPA. The Agency is concerned that radioactive wastes may pose a threat to human health and the environment, but it does not have enough information to conclude that they do. EPA will continue to gather information to determine whether these wastes should be regulated by RCRA.

In the event that the EPA concludes that mine wastes should be covered by RCRA hazardous waste management regulations, some pre-1981 EPA actions suggest what may be expected from the EPA in regard to uranium mine waste regulation. In 1978 the EPA proposed that uranium mine wastes containing radium-226 concentrations greater than 5 pCi/g be listed as "hazardous wastes" under RCRA. At the same time the EPA also proposed special waste standards for the treatment, storage, and disposal of overburden and waste rock (see 43 Fed. Reg. 58946-59028, Dec. 18, 1978).

10.6. COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION AND LIABILITY ACT

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), signed into law in 1980, allows the federal government to respond to threats from uncontrolled abandoned or inactive hazardous waste sites. More specifically, CERCLA is designed for the cleanup of existing or potential contamination problems resulting from improper waste disposal practices which may present an imminent and substantial danger to public health or to the environment.

The remedial measures carried out by the federal government under CERCLA are financed by the Hazardous Substance Response Trust Fund, commonly referred to as "Superfund". Most of the Trust Fund (86.2 percent) is provided by industry through taxes, with the remaining portion appropriated from general revenues.

The guiding policy for the use of the Trust Fund is provided by CERCLA itself. In cases where the responsibility for wastes causing contamination can be traced to private parties with financial resources, CERCLA requires that the financial responsibility for cleanup be placed on those companies. This requirement helps assure that the Superfund will be available to clean up as many sites as possible where no solvent responsible party can be found.

Before a site is considered for Superfund action, each site must be quantitatively evaluated for relative ranking on the National Priorities List. Factors considered in the evaluation are the following: the population at risk, the hazard potential of hazardous substances at the facility, the potential for contamination of drinking-water supplies, the potential for direct human contact, and the potential for destruction of sensitive ecosystems. The CERCLA list of hazardous constituents includes a general radiation standard which may apply to uranium mine waste. The relative rankings of many sites in the Grants Mineral Belt, however, may be low due to sparse populations in the vicinity of uranium mining areas.
CERCLA additionally provides the EPA with authority to take enforcement actions against owners of sites not on the National Priorities List in order to compel the owners to clean up the sites. Moreover, CERCLA authorizes suits by a state against a site owner to recover response costs and damages to natural resources whether or not a site is on the National Priorities Lists.

XI. RECOMMENDED ACTIONS

The analysis of water quality impacts of uranium mining presented in this report reveals three major water quality concerns that require administrative, regulatory, or court action. Comparison of the results of the regional assessment with established criteria and standards indicates that discharge of mine dewatering effluents into surface watercourses and runoff from uranium mine waste piles are major water quality concerns. In addition, the sludges generated by treatment of minewaters have high levels of radium-226 and other radionuclides; the potential for these to be introduced into watercourses is a major concern. The relationship of these water quality concerns to the various administrative, regulatory, and judicial mechanisms discussed previously is depicted in Figure 11.1. Specific recommendations are discussed below.

11.1. CONTROL OF MINE DEWATERING EFFLUENTS

11.1.1. Background

Comparison with established use criteria and standards indicates that the quality of uranium mine dewatering effluents is not consistent with the existing use of these discharged minewaters for livestock watering and irrigation, or for their potential use for domestic water supply. This conclusion applies to both Ambrosia Lake and Church Rock Mining Districts, despite significant differences in water quality between the two districts. The constituents that most often affect the suitability of the effluents are selenium, molybdenum, radium-226, sulfate, and total dissolved solids. Concentrations of arsenic, barium, and vanadium may also exceed criteria and standards (see section 9.6).

The overview of regulatory mechanisms indicates that there are three mechanisms currently available for regulation of the discharge of mine dewatering effluents into surface watercourses: the NPDES permit program, the New Mexico Regulations for Discharges to Surface Waters, and the New Mexico Ground Water Regulations. The WQCC has determined that the NPDES permit program should be the primary avenue for controlling discharges of pollutants to surface watercourses.

Of the eight constituents listed above as affecting the suitability of dewatering effluents for livestock watering, irrigation, and domestic water supply, only radium-226 is among the constituents of uranium minewater discharges with established NPDES effluent guidelines. While radium-226 is represented twice (both as total and as dissolved) among the seven constituents having NPDES effluent guidelines, the numeric effluent guidelines for radium-226 reflect radium-removal technology and may therefore not be sufficiently stringent for resultant in-stream flows to meet criteria and standards applicable to water uses in the Grants Mineral Belt. As was mentioned previously in the regulatory overview, numeric effluent guidelines may be made more stringent and the parameter coverage broadened for uranium

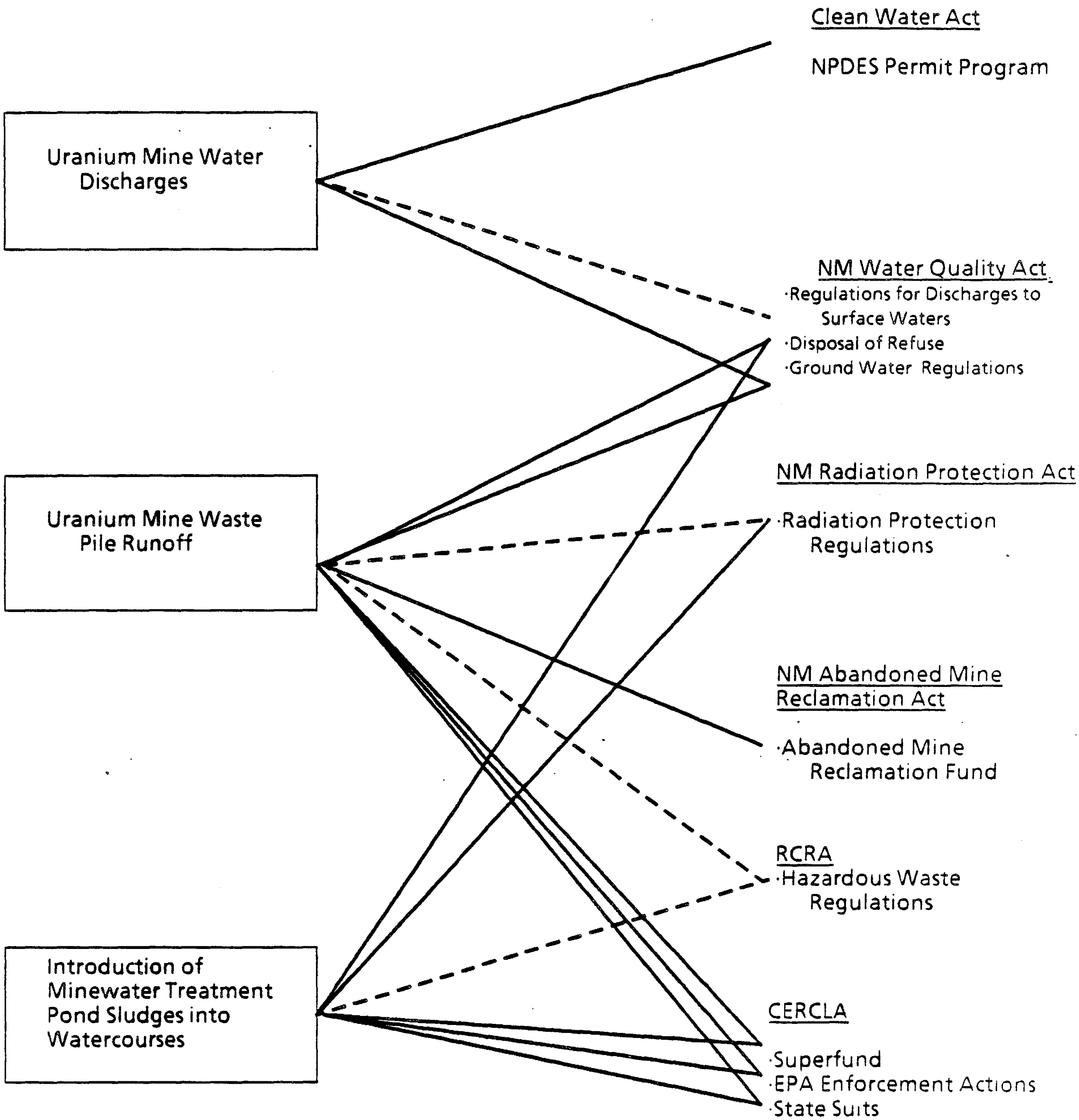


FIGURE 11.1. Legal and Regulatory Mechanisms for Controlling Major Water Quality Contaminants. Solid line indicates a currently applicable mechanism; dashed line indicates a potentially applicable mechanism.

minewater discharges in New Mexico as the result of case-specific analysis by the EPA or state certification by the EID.

Significant drawbacks currently exist, however, to the reliance on the NPDES permit program to regulate dewatering effluents. First, slightly more than one-fourth of the NPDES permits for uranium minewater discharges are under adjudication and hence, under EPA regulations, are not enforced. As noted earlier, one permit has been under adjudication for 13 years. Secondly, permits for new discharges are subject to the same legal challenge.

The New Mexico Regulations for Discharge to Surface Waters do not serve as an effective state alternative to the NPDES permit program for regulation of uranium minewater discharges for several reasons. First, a discharger with an NPDES permit is not subject to the state regulations until 30 days after the discharger has received notification of noncompliance from the EPA, provided that the discharge still remains noncompliant with permit conditions after the 30-day period. Of the 11 NPDES permits for uranium mine discharges, however, only seven are enforceable under EPA regulations. The remaining four are stayed pending resolution of adjudication. Further, the state regulations do not include discharge limitations for any trace element or radionuclide. In fact, of the seven constituents of minewater discharges for which the EPA has established numeric effluent guidelines, only two (chemical oxygen demand and pH) have discharge limitations in the state regulations. These discharge limitations are generally similar to, but not the same as, numeric effluent limitation for NPDES permits for uranium mine discharges (e.g., the state COD limitations of less than 125 mg/l compares to an NPDES daily average of 100 mg/l; and the state pH range is between 6.6 and 8.6, while the NPDES has pH ranges of 6.6 to 8.6 and 6.0 to 9.0, depending upon the specific permit).

The New Mexico Ground Water Regulations are designed to protect ground water quality for present and potential use as agricultural and domestic water supply. As was discussed earlier in this chapter, these regulations are not designed to protect surface water quality and therefore are not an effective means of regulating surface water quality.

The environmental consequences, however, of the current lack of effective regulation mine dewatering effluents are not so serious as they potentially could be. Some companies, while contesting their permits, have treated their minewaters so that discharges generally meet NPDES permit requirements. More importantly, since 1980 the uranium industry in New Mexico has experienced a major decline that is expected to continue for an indefinite period. The result is that of the 11 uranium mines with NPDES permits, seven have ceased discharging. Of the remaining four, two still have permits under adjudication. Nevertheless, the information presented in Chapters IV and VI clearly documents the impairment of water resources that occurred prior to 1980 and could resume if the industry revives while water pollution controls remain ineffective.

11.1.2. Recommendations

1. The EID should coordinate with the EPA so that new or renewal NPDES permits for uranium mine dewatering effluents in New Mexico include numeric effluent limitations for radium-226 and other parameters related to downstream uses of these waters. Factors to be considered in the development of these effluent limitations are present water uses, likelihood of future uses, and technology available for water treatment. At a minimum, the quality of the effluent should

meet the requirements specified in the "Hazardous Substances" and "Radioactivity" (1-102.G.) portions of Water Quality Standards for Interstate and Intrastate streams in New Mexico (WQCC, 1985). Such effluent limitations may be included in permits through state certification by the EID or case-specific analysis by the EPA.

2. The New Mexico Regulations for Discharges to Surface Waters should be substantially amended to serve as an effective means of regulating uranium mine dewatering effluents and other discharges to surface watercourses. Amendments should include comprehensive numeric discharge limits not only for those chemical constituents regulated by NPDES, but for other constituents necessary to protect water quality for agricultural or domestic use.

11.2. CONTROL OF RUNOFF FROM MINE WASTE PILES

11.2.1 Background

The extensive survey by Anderson (1980) provides a basis for estimating that 10 to 20 percent of all abandoned uranium mines and a few large active mines have waste piles that are eroding directly into surface drainage channels. Data developed for this report indicate that sediment carried by runoff from waste piles into surface watercourses has high levels of trace elements and radioactivity associated with it. Contaminated sediments are particularly evident in arroyos and drainage channels in close proximity to spoils piles. These sediments undergo recurring cycles of deposition on stream bottoms, resuspension, and transport further downstream. Eventually sediments from mine waste piles become so mixed and diluted with other sediments that they cannot be chemically differentiated on the basis of trace element and radioactivity levels. Nevertheless, these sediments do increase the total load of trace elements and radioactivity in affected drainages.

Moreover, turbid stream flows may be ingested by livestock. Levels of arsenic, cadmium, lead, selenium, vanadium, gross alpha particle activity, and radium-226 associated with mine waste pile runoff are not consistent with livestock watering.

Technical means for dealing with uranium mine waste piles, either by surface stabilization or by mine stope backfilling, are well known (e.g., EPA, 1973b; Maryland Department of Natural Resources 1983; New Mexico Coal Surface Mining Commission 1980; and Longmire 1985. Engineering options include backfill of abandoned mine workings with waste rock and low-grade ore; contouring waste piles to a slightly convex configuration; construction of berms upslope and downslope of the wastes to minimize runoff; and use of large boulders and waste rock to armor the contoured waste pile. Some Indian tribes and federal agencies (e.g., USDA Forest Service) do require contouring and stabilization of mine waste piles and disturbed mine sites, but those actions have affected only a few sites.

The economic impact of stabilization or removal of mine wastes is believed to be minor when prorated over the life of a mine. Relative to other uranium industry operations, the volume of potentially hazardous waste generated by uranium mines in New Mexico is quite low.

Legal mechanisms currently available for control of waste pile runoff include state regulations, the Abandoned Mine Reclamation Fund, and provisions of CERCLA. The provision in the WQCC regulations on disposal of refuse already has precedent for use as a means of requiring mine tailings stabilization. The New Mexico Ground

Water Regulations can be used to regulate leachates from mine waste piles that affect ground water quality, should a hazard to public health exist. However, the results of leaching tests conducted for this study suggest such conditions are this is unlikely.

The Abandoned Mine Reclamation Fund, while primarily intended for coal reclamation, can be used for non-coal-mining reclamation under special circumstances. Use of the fund for reclamation of uranium mine waste piles requires concurrence between the New Mexico Energy and Minerals Department, the Governor, and the U.S. Secretary of the Interior. In addition, use of the Fund is subject to federal statutory provisions that all coal-mining reclamation needs in the state have been addressed or, alternatively, that there are over-riding public health or safety considerations that justify dealing with non-coal-mining reclamation before coal-mining reclamation needs are met.

Superfund cleanup under CERCLA may potentially be useful for control of runoff from abandoned or inactive waste piles, but its availability will depend upon site-specific rankings of piles on the National Priorities List. Two other provisions of CERCLA, however, have definite potential for control of mine waste runoff. These are the authority given to the EPA to compel owners to clean up sites not on the National Priorities List, and the authorization of state suits to recover response costs and damages to natural resources.

In addition, the New Mexico Radiation Protection Regulations and RCRA are potential regulatory mechanisms for control of mine waste runoff. The former requires a decision by the EIB to amend these state regulations to extend their applicability to mine wastes. The latter requires a completion of a study by the EPA on uranium mine wastes.

11.2.2 Recommendations

1. The removal or stabilization of the largest uranium mine waste piles eroding directly into surface drainages should be pursued. Priority sites should include the Old San Mateo Mine near San Mateo Creek and the Jackpile-Paguate mine areas along the Rio Paguate. Technical criteria for stabilization or removal should be based on individual site conditions.

   a. The EID should require removal or stabilization actions based upon the provision of the WQCC regulations on Disposal of Refuse. Should the provision not be useful, the EID should then pursue reclamation through other available means. Such means include Superfund cleanup, EPA enforcement actions under CERCLA, and state-funded cleanup accompanied by state suits to recover cleanup costs and environmental damages.

   b. Where removal or stabilization cannot be accomplished through regulatory actions, the EID should consult with the Governor and the New Mexico Energy and Minerals Department on use of the Abandoned Mine Reclamation Fund for cleanup.

2. The EID should not take immediate action to regulate future uranium mine waste piles directly as it is anticipated that the EPA will present a recommendation to the U.S. Congress in 1986 on whether to control uranium mine wastes under RCRA. Should mine wastes be regulated under RCRA, it is unlikely that additional state regulations would be required.

3. Should uranium mine waste piles be excluded from RCRA regulation, the EID should recommend that the EIB amend the New Mexico Radiation Protection Regulations to extend their applicability to mine wastes.

11.3. CONTROL OF MINEWATER TREATMENT POND SLUDGES

11.3.1. Background

Minewater treatment pond sludges resulting from the settling, coagulation, and treatment of raw minewaters have high levels of radium-226 and other radionuclides. In fact, radium-226 concentrations probably average more than 200 pCi/gram. Therefore, the potential introduction of these sludges into surface watercourses through erosion is a matter of concern.

Management of sludges is widely performed, but not universal. In particular, mine operations that conduct ion-exchange removal of uranium from minewaters are usually required by New Mexico Radiation Protection Regulations to dispose of associated minewater treatment pond sludges properly. However, sludges resulting from coagulation and settling of radium-226 from raw minewaters remain unregulated.

Other legal mechanisms available for control of minewater treatment sludges are the provisions of the WQCC regulations on Disposal of Refuse and the provisions of CERCLA related to Superfund cleanup, EPA enforcement actions, and state suits for recovery of costs. In addition, as a result of the EPA uranium mine waste study, RCRA may regulate these sludges. RCRA is potentially the most effective regulatory mechanism for sludges generated in the future. Nonetheless, the state provision on Disposal of Refuse and CERCLA provisions on EPA enforcement actions and state suits appear to provide adequate means to deal with any cleanup or stabilization problems that may occur in the near future, but only on a case-specific ad hoc basis. Superfund cleanup should not be needed unless adequate provisions are not taken now to ensure proper stabilization or disposal of sludges.

11.3.2. Recommendation

The EID should rely on the same regulatory framework for minewater treatment pond sludges as for mine wastes. Therefore, EID should wait to see if RCRA will apply to uranium mine wastes, including these sludges, as RCRA regulation will probably obviate the need for additional state regulation. If such wastes are found to be exempt from RCRA regulation, the EID should recommend that the Environmental Improvement Board amend the New Mexico Radiation Protection Regulations to control these sludges fully and effectively.

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