DOE/EA - 0254

United States Department of Energy

Environmental Assessment

Remedial Action at the Riverton Uranium Mill Tailings Site Riverton, Wyoming

June, 1987

Uranium Mill Tailings Remedial Action Project UMTRAP

DISCLAIMER

DISCLAIMER

DOE/EA--0254

DE87 011700

ENVIRONMENTAL ASSESSMENT OF REMEDIAL ACTION AT THE RIVERTON URANIUM MILL TAILINGS SITE RIVERTON, WYOMING

TEXT

JUNE, 1987

U.S. Department of Energy
UMTRA Project Office
Albuquerque, New Mexico

ENVIRONMENTAL ASSESSMENT OF REMEDIAL ACTION AT THE RIVERTON URANIUM MILL TAILINGS SITE RIVERTON, WYOMING

U.S. DEPARTMENT OF ENERGY

ABSTRACT

This document assesses and compares the environmental impacts of various alternatives for remedial action at the inactive Riverton uranium mill tailings site 2 miles southwest of Riverton, Wyoming. The site covers 173 acres and contains 70 acres of tailings and some of the original mill structures. Title I of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), Public Law 95-604, authorized the U.S. Department of Energy to clean up the inactive site to reduce the potential health impacts associated with the residual radioactive materials remaining at the site and at associated properties off of the site. Title II of the UMTRCA authorized the U.S. Nuclear Regulatory Commission or agreement state to regulate the operations of active uranium mill sites and the eventual reclamation of these active sites. The U.S. Environmental Protection Agency promulgated standards for the remedial actions (Title 40, Code of Federal Regulations, Part 192, Subparts A through E). Remedial actions at the inactive and active mill sites must be performed in accordance with these standards and with the concurrence of the U.S. Nuclear Regulatory Commission. The proposed action is to relocate the Riverton tailings and contaminated materials to Gas Hills, an area 45 to 60 road miles east of the Riverton site that contains several active (Title II) uranium mill tailings sites. The Riverton (Title I) tailings and contaminated materials would be consolidated with the tailings at a selected active site and then stabilized in accordance with the active site's remedial action plan to be approved by the U.S. Nuclear Regulatory Commission.

For more information contact:

James R. Anderson
UMTRA Project Manager
U.S. Department of Energy
UMTRA Project Office
5301 Central Avenue, N.E., Suite 1720
Albuquerque, New Mexico 87108
505/844-3941

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF FIGURES

LIST OF TABLES

1.0 SUMMARY

1.1 PROJECT SUMMARY

The inactive Riverton tailings site is 2 miles southwest of Riverton in Fremont County, Wyoming (Figure 1.1). The site is on an alluvial terrace that forms the drainage divide between the Wind River and Little Wind River. The topography of the area consists of the Wind River basin surrounded by relatively flat, desert rangeland. Major topographic features are the Wind and Little Wind Rivers and the Wind River Mountain Range to the west.

The Riverton area has an arid to semi-arid climate with annual precipitation averaging 9 inches. Vegetation consists of willows and cottonwoods along the rivers and sagebrush and desert grasses on the rangeland. The dominant land uses are agriculture and livestock grazing. Riverton is the closest urban center with an estimated 1983 population of 10,438, and the nearest residence is 900 feet from the tailings pile.

The Riverton site consists of a rectangular tailings pile, part of the original mill structures and equipment, a potable water well with a pumphouse and metal water tower, and an active sulfuric acid plant. The site is bordered by drainage ditches and irrigation canals. The tailings pile covers 70 acres and contains approximately 1 million cubic yards of tailings. The total volume of contaminated materials including the tailings, contaminated soils beneath and around the tailings, and other associated materials is approximately 1.5 million cubic yards. The shallow ground water beneath the tailings has been contaminated by natural dewatering of the tailings, and lesser contamination continues due to precipitation filtering through the pile and possibly the rising of the shallow ground water into the pile. Twenty-five vicinity properties (e.g., homes, commercial sites, and vacant lots) have been identified as needing remedial action because they may have been contaminated by the use of tailings or crushed ore from the mill during their construction. These 25 vicinity properties contain an estimated 4,000 cubic yards of contaminated materials.

The principal potential hazard associated with the tailings results from the production of radon, a radioactive decay product of the radium contained in the tailings. Radon, a radioactive gas, can diffuse through the tailings and be released into the atmosphere where it and its radioactive decay products (radon daughters) may be inhaled by humans. If the concentration of radon and its decay products is high enough and the exposure time long enough, health effects (i.e., cancers) may develop in persons living and working near the pile. Exposure to gamma radiation, the inhalation of airborne radioactive particulates, the ingestion of contaminated food produced in the area around the tailings, and the ingestion of surface and ground waters contaminated by the tailings also pose potential hazards. If the tailings are not properly stabilized, erosion or human removal of the contaminated materials could spread the contamination over a much wider area and increase the potential public health hazards.

Title I of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), Public Law 95-604 (PL95-604), authorized the U.S. Department of Energy (DOE) to perform remedial action at the inactive Riverton tailings site (as well as at many other inactive sites) to reduce the potential

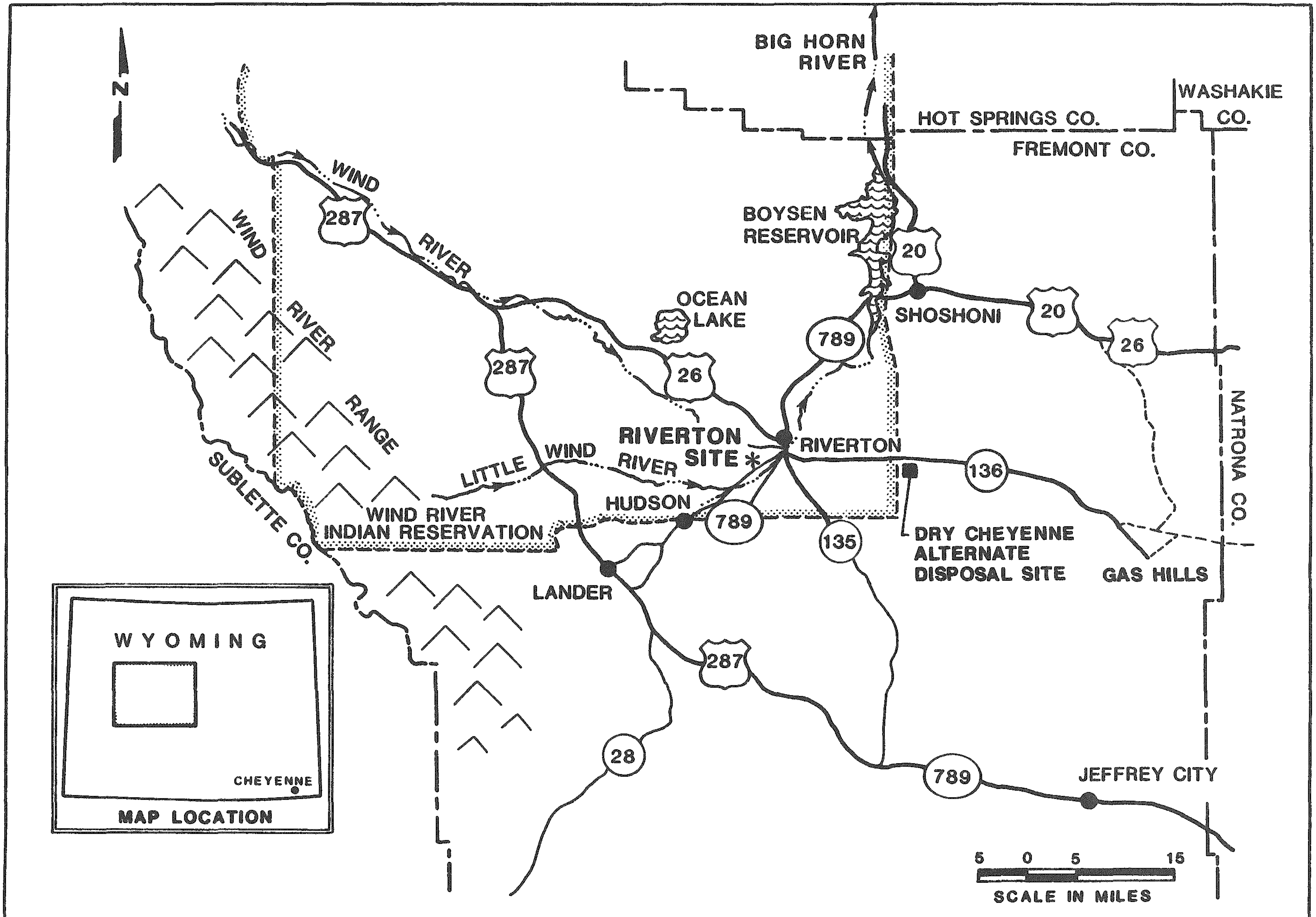


FIGURE 1.1 RIVERTON SITE LOCATION

public health impacts from the residual radioactivity remaining in the tailings. Title II of the UMTRCA authorized the U.S. Nuclear Regulatory Commission (NRC) or agreement state to regulate the operation and eventual reclamation of active uranium mill tailings sites. The U.S. Environmental Protection Agency (EPA) promulgated standards, Title 40, Code of Federal Regulations, Part 192, Subparts A through E (40 CFR Part 192, Subparts A through E), in March and December, 1983, for remedial actions at the inactive and active mill sites.

The proposed remedial action alternative for the inactive (Title I) Riverton tailings site is relocation to Gas Hills. Gas Hills is an area containing several, active (Title II) uranium mill tailings sites in the Gas Hills Uranium Mining District 45 to 60 road miles east of the Riverton site (Figure 1.1). Uranium mining and milling have occurred extensively in the Gas Hills District, but the land is also used for low-density livestock grazing. The district is sparsely populated with the closest urban center being Jeffrey City approximately 30 miles to the south. A specific site in Gas Hills has not yet been determined but would be selected by competitive bidding from owners and operators of active mill sites in the Gas Hills District. All of the tailings and contaminated materials would be moved from the Riverton site to the selected active site and then stabilized in accordance with the EPA standards for active sites (40 CFR Part 192, Subparts D and E) and a remedial action plan prepared by the owner and operator of the site and to be approved by the NRC. The Riverton site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, revegetated as necessary, and released for use consistent with existing land use controls.

The no action alternative would consist of taking no remedial action at the Riverton tailings site and vicinity properties. The tailings would remain in their present location and condition and would continue to be susceptible to erosion and unauthorized removal and use by man. The tailings and contaminated materials at the vicinity properties would not be cleaned up and would continue to pose potential public health hazards. This alternative would not be consistent with the UMTRCA (PL95-604) and would not result in the Riverton site's compliance with the EPA standards (40 CFR Part 192, Subparts A, B, and C).

Stabilization in place would involve consolidating all of the tailings and other contaminated materials with the existing tailings pile. The pile would be recontoured to have 20 percent sideslopes (5 horizontal to 1 vertical) and a slightly convex top. The pile would then be covered with 6 feet of compacted earth to inhibit radon emanation and water infiltration and to assure compliance with the EPA standards. The top and sides of the pile would be covered with 1-foot and 2-foot thick layers of graded rock, respectively, to protect the pile against erosion, penetration by animals, and inadvertent human intrusion. A tapered, riprap (rock) apron 5 feet thick and 32 feet wide would be placed around the base of the stabilized pile to protect it against erosion resulting from flooding and river meander. The top of the stabilized pile would be approximately 27 feet above the surrounding terrain. The ground surrounding the stabilized pile would be graded to divert surface runoff around and away from the pile. All areas disturbed by remedial action at the tailings site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, revegetated as necessary, and released for use consistent with existing land use controls.

Disposal at the Dry Cheyenne alternate disposal site would involve moving all of the tailings and contaminated materials to Federal land 15 road miles east of the tailings site (Figure 1.1). This land is administered by the Bureau of Land Management and is used primarily for low-density livestock grazing. The site is approximately 4 miles from the nearest residence. The tailings and contaminated materials would be consolidated in a partially below-grade pile and covered with compacted earth and graded rock similar to stabilization in place. The top of the stabilized pile would be an average of 30 to 35 feet above the surrounding terrain. The Riverton tailings site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, revegetated as necessary, and released for use consistent with existing land use controls.

All of the remedial action alternatives except no action include remedial action at the estimated 25 off-site vicinity properties.

1.2 IMPACT SUMMARY

The environmental impacts presented in this section (Table 1.1) and elsewhere in this environmental assessment (EA) are based on conservative assumptions and impact assessment procedures and thereby represent a realistic upper limit on the severity of the impacts that may occur. The actual impacts that would occur would probably be less severe than those identified in this EA. The environmental impacts presented in this EA are also based on continuous remedial action schedules (i.e., remedial action would be conducted throughout the year). In reality, inclement weather during the winter months would probably necessitate the cessation of remedial action, and the associated impacts would cease or decrease accordingly. Section 4.0 and the appendices to this EA contain descriptions of the impacts assessment assumptions and procedures.

The proposed remedial action for the inactive (Title I) Riverton tailings site is relocation to Gas Hills. Gas Hills is an area containing several active (Title II) uranium mill tailings sites in the Gas Hills Uranium Mining District, but a specific site in Gas Hills has not yet been determined. A specific site would be selected by competitive bidding from owners and operators of active tailings sites in the Gas Hills District.

For the impacts analyses in this EA, it was assumed that the selected active tailings site in Gas Hills is 45 to 60 miles east of the Riverton site. Therefore, the impacts identified for relocation to Gas Hills are conservative and represent a realistic upper limit on the severity of the impacts that may occur. It should be noted that the impacts identified for relocation to Gas Hills are the impacts of remedial action at the Riverton site and, when appropriate, the impacts along the transportation route to the Gas Hills selected site (i.e., impacts on gamma radiation levels, air quality, surface water, noise levels, traffic volumes, and traffic accident injuries and fatalities).

The remedial action at the active (Title II) tailings site would be consistent with the EPA standards for active sites (40 CFR Part 192, Subparts D and E) and would be performed in accordance with a remedial action plan prepared by the owner and operator of the site and to be approved by the NRC. The generic impacts of the EPA standards were addressed in an

Table 1.1 Environmental impacts of the proposed action, relocation to Gas Hills

Environmental component	Environmental impacts
Remedial action worker health[a]	0.009 fatal cancers; 28.1 injuries (from equipment use only).
Public health[a,b]	0.03 fatal cancers during 2.6 years of remedial action.
Air quality (non-radiological)[c]	Maximum 24-hour TSP concentrations at the Riverton tailings site (172 microg/m^3) and Little Wind borrow site (183 microg/m^3) temporarily exceed Federal secondary and State of Wyoming 24-hour TSP standards; possible temporary exceedances of Federal annual TSP standards at these sites.
Soils[d]	118 acres of soils lost; 172 acres of soils temporarily disturbed.
Mineral resources	Consumption of 438,000 cubic yards of borrow materials (earth and gravel).
Water resources	No contamination of surface water in the vicinity of the Riverton tailings site; gradual, natural cleansing of shallow, alluvial ground water at the Riverton tailings site with existing concentrations of contaminants being reduced to background concentrations in approximately 45 years.
Vegetation	360 acres of vegetation temporarily disturbed.
Wildlife	360 acres of habitat temporarily disturbed.
Threatened and endangered species[e]	No impacts at the Riverton tailings site; potential impacts at the Little Wind borrow site.
Land use	Release of the Riverton site for use consistent with existing land use controls.
Noise	Maximum noise level of 68 decibels at the nearest residence during the day; maximum noise level of 84 decibels along the transportation route during truck haulage; annoyance but no adverse hearing impacts.
Aesthetic resources	Tailings pile removed from Riverton.
Archaeological and historic resources[f]	Potential impacts at the Riverton tailings site and Little Wind borrow site.
Population	Short-term increase of up to 19 persons; negligible increase in the local population.

Table 1.1 Environmental impacts of the proposed action, relocation to Gas Hills (Continued)

Environmental component	Environmental impacts
Employment	Average employment of 70 persons for 31 months; peak employment of 93 persons for 1 year; indirect employment of up to 74 persons.
Social services	No impacts on local social services.
Transportation networks	Maximum of 950 trips per day on Wyoming State Highways 135 and 136 (each are two-lane, lightly travelled); 0.52 traffic accident fatalities; 9.29 traffic accident injuries.
Energy resources	Consumption of 2,082,000 gallons of fuel and 415,000 kilowatt-hours of electricity.
Water consumption[g]	5,580,000 gallons.
Construction costs (1987 dollars)[h]	$21,161,000.

[a]The estimated health impacts of relocation to Gas Hills do not include the health impacts during remedial action at the selected active uranium mill tailings site in Gas Hills. The health impacts at the selected active site in Gas Hills would be assessed by the NRC for its compliance with the National Environmental Policy Act, Public Law 91-190.

[b]Public health impacts were calculated for a constant population which includes the workers at the active sulfuric acid plant at the Riverton tailings site (see Section 4.1.4). The public health impacts for the no action alternative were calculated to be 0.2 fatal cancers in the first 10 years and 20 fatal cancers in 1,000 years. These impacts were calculated assuming that the tailings would not be dispersed in the future by natural erosion or man because there is no way to accurately predict the level or rate of dispersion. Without remedial action, dispersion would occur over time, and the actual health impacts for the no action alternative might be greater than those calculated.

[c]TSP - total suspended particulates; microg/m^3 - micrograms per cubic meter. The existing tailings pile would contribute suspended particulates to the ambient atmosphere due to dispersion of the tailings by winds. This contribution of particulates was not quantified but would be somewhat greater than that from undisturbed rangeland due to the sparse vegetative cover on the existing tailings pile (see Section 4.2). Remedial action would result in nitrogen oxide and carbon monoxide emissions that would exceed the EPA significance levels of 40 and 100 tons per year, respectively; however, the prevention of significant deterioration regulations (40 CFR Part 51) do not apply to temporary emissions sources such as those in the remedial action.

Table 1.1 Environmental impacts of the proposed action, relocation to Gas Hills (Concluded)

[d]For impacts assessment purposes, all contaminated soils, except those beneath the existing tailings pile, that are consolidated and stabilized with the tailings are lost. Soils that are stockpiled and then replaced or used to restore a disturbed area are temporarily disturbed.

[e]No threatened and endangered species are known to be present at the Riverton tailings site. There is a possibility for the occurrence of prairie dog towns, and hence the presence of the endangered black-footed ferret, at the Little Wind borrow site. Prior to remedial action, a site-specific survey of the Little Wind borrow site would be conducted to verify the presence or absence of the black-footed ferret (see Section 4.6).

[f]A Class III cultural resource survey of the Riverton tailings site identified a concentration of historic homestead materials near the site, and additional data are required to determine the eligibility to the National Register of Historic Places for this concentration. If this concentration is determined to be eligible and would be affected by remedial action, a data collection program would be developed and implemented. A Class III survey was not conducted at the Little Wind borrow site. Prior to remedial action, a Class III survey of the borrow site to be affected would be conducted to determine the presence or absence of archaeological or historic resources at the site (see Section 4.9.2).

[g]The gallons of water consumed are only those used for remedial action activities such as dust control. These amounts do not include the water consumed by in-migrant remedial action workers and their families. Peak in-migrant water consumption is estimated to be 1,900 gallons per day for 1 year for relocation to Gas Hills (see Sections 4.11 and 4.14).

[h]These construction costs do not include the remedial action cost for the estimated 25 off-site vicinity properties.

environmental impact statement published by the EPA (EPA 520/1-83-008-1 and 2). The short- and long-term impacts of remedial action at the active site would be assessed by the NRC for its compliance with the National Environmental Policy Act (NEPA), Public Law 91-190. It should be noted that the Riverton tailings and contaminated materials (1.5 million cubic yards) are only 31 percent of the smallest active tailings pile (4.8 million cubic yards) in Gas Hills that could be selected as the final disposal site.

The borrow sites included in this EA were selected as the sources of the necessary borrow materials for impacts analyses purposes. Although the borrow sites to be used for the remedial action will be selected during the final design, the impacts identified for the borrow sites included in this EA are conservative and represent a realistic upper limit on the severity of the impacts that may occur. All of the remedial action alternatives except no action include remedial action at the estimated 25 off-site vicinity properties; however, only those impacts of remedial action at the vicinity properties that make an appreciable contribution to the impacts of the overall remedial action are included in this EA (e.g., excess health effects to the general public and remedial action workers and impacts on soils). The impacts of remedial action at the vicinity properties were previously assessed by the DOE in a programmatic environmental report (UMTRA-DOE/AL-150327.0000).

Relocation to Gas Hills - the proposed action

Implementation of this alternative would reduce the radiological hazards of the inactive (Title I) Riverton tailings site to a level consistent with the EPA standards for the cleanup of open lands and habitable buildings. The tailings and contaminated materials would be removed from the vicinity of the city of Riverton in accordance with a remedial action plan prepared by the DOE and stabilized at an active (Title II) mill site in Gas Hills in accordance with a remedial action plan prepared by the owner and operator of the active site. Both remedial action plans would be consistent with the EPA standards for inactive and active sites (40 CFR Part 192, Subparts B through E) and would be approved by the NRC. The Riverton site would be released for use consistent with existing land use controls.

The shallow, alluvial ground water beneath and southeast of the Riverton tailings pile has been contaminated primarily by percolating leachate generated by the natural dewatering of the tailings during and immediately after the uranium milling. Lesser but continuing contamination is due to precipitation filtering through the tailings pile and possibly the rising of the shallow ground water into the pile. This contamination does not pose a public health hazard, and the natural flow of the shallow ground water toward the Little Wind River dissipates the contamination. Relocation of the tailings and contaminated materials to Gas Hills would remove the source of any future contamination, and the natural flow and discharge of the shallow ground water into the Little Wind River would reduce the existing concentrations of contaminants to background levels in approximately 45 years. At this time, aquifer restoration would not be a cost-effective means of controlling or cleaning up the ground-water contamination at the Riverton site.

When the EPA issues revisions to the water protection standards (40 CFR Part 192.20(a)(2)-(3)) that were remanded by the U.S. Tenth Circuit

Court of Appeals, the DOE will re-evaluate the ground-water issues at the Riverton site to assure that the revised standards are met. Performing remedial action to relocate the tailings prior to the EPA issuing new standards will not affect the measures that are ultimately required to meet the revised EPA water protection standards. The DOE has characterized the conditions at the Riverton site and does not anticipate that any substantial changes to the remedial action would be necessary. However, after the EPA re-issues the water protection standards, the DOE will determine the need for institutional controls, aquifer restoration, or other controls and will take appropriate action so as to comply with the re-issued standards.

No action alternative

Selection of the no action alternative would not be consistent with the intent of Congress in the UMTRCA (PL95-604) and would not result in the Riverton site's compliance with the EPA standards (40 CFR Part 192, Subparts A, B, and C). In Title I of the UMTRCA, the U.S. Congress authorized the DOE to perform remedial action at the inactive Riverton site consistent with the standards developed by the EPA. The Riverton site would not meet the EPA standards without remedial action.

This alternative would result in the continued dispersion of the tailings over a wide area by water and wind erosion. The shallow ground water would continue to be contaminated. The tailings would not be protected against unauthorized removal by humans. Continued dispersion and unauthorized removal and use of the tailings could cause radiological contamination of other areas and could result in greater public health impacts than those calculated for this alternative.

Stabilization in place alternative

The major environmental impacts of the stabilization in place alternative would be:

- o The stabilized tailings and contaminated materials would remain 2 miles southwest of the city of Riverton, and 80 acres of land would be subject to restricted use.
- o In terms of restricted access and foreseeable future land uses, the Riverton tailings site would be more valuable than the selected active mill site in Gas Hills.
- o The stabilization in place alternative would result in 2 estimated excess fatal cancers over the next 1,000 years.
- o Stabilization in place would result in temporary exceedances of Federal secondary and State of Wyoming 24-hour TSP standards.
- o Stabilization in place would result in the consumption of approximately 1 million cubic yards of mineral resources and 22 million gallons of water.
- o Stabilization in place would substantially decrease the generation and migration of contamination from the tailings pile, and the natural movement and discharge of the unconfined ground water into

the Little Wind River would reduce the existing concentrations of contaminants to background levels in approximately 65 years.

- The construction costs of the stabilization in place alternative (excluding the cost of remedial action at the vicinity properties) would be approximately $10 million.

Dry Cheyenne disposal alternative

The major environmental impacts of the Dry Cheyenne disposal alternative would be:

- The Dry Cheyenne alternative would result in 0.03 estimated excess fatal cancers over the next 1,000 years.

- The Dry Cheyenne alternative would result in temporary exceedances of Federal secondary and State of Wyoming 24-hour TSP standards.

- Disposal at the Dry Cheyenne site would result in a maximum of 762 trips per day on Wyoming State Highways 135 and 136.

- The Dry Cheyenne alternative would result in the consumption of approximately 1 million cubic yards of mineral resources and 35 million gallons of water.

- Relocation of the tailings and contaminated materials to the Dry Cheyenne site would remove the source of any future ground-water contamination, and the natural flow and discharge of the shallow ground water into the Little Wind River would reduce the existing concentrations of contaminants to background levels in approximately 45 years.

- The construction costs of the Dry Cheyenne alternative (excluding the cost of remedial action at the vicinity properties) would be approximately $19 million.

2.0 REMEDIAL ACTION ALTERNATIVES

2.1 THE NEED FOR REMEDIAL ACTION

2.1.1 Background

In response to public concern over the potential public health hazard related to uranium mill tailings and the associated contaminated materials left abandoned or otherwise uncontrolled at inactive processing sites throughout the United States, Congress passed the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), Public Law 95-604, which was enacted into law on November 8, 1978. In the UMTRCA, Congress found that uranium mill tailings located at inactive mill sites may pose a potential health hazard to the public and identified 24 sites that were in need of remedial action. The Riverton tailings site is one of these sites.

Title I of the UMTRCA authorized the U.S. Department of Energy (DOE) to enter into cooperative agreements with affected states or Indian tribes to clean up those inactive sites contaminated with uranium mill tailings and required the Secretary of the DOE to designate sites to be cleaned up. On December 23, 1983, the DOE and the State of Wyoming entered into a cooperative agreement under Title I of the UMTRCA. The cooperative agreement set forth the terms and conditions for the DOE and Wyoming cooperative remedial action efforts including the DOE's development of a remedial action plan (concurred in by Wyoming), the DOE's preparation of an appropriate environmental document, real estate responsibilities, and other concerns.

All remedial actions performed under Title I of the UMTRCA must be completed in accordance with the U.S. Environmental Protection Agency (EPA) standards discussed below and with the concurrence of the U.S. Nuclear Regulatory Commission (NRC). The NRC has not and does not intend to issue regulations applicable to the Title I remedial actions at the inactive uranium mill tailings sites but will issue licenses for the long-term surveillance and maintenance (including monitoring) of the disposal sites after the remedial actions are complete. These licenses may require the DOE or other Federal agency having custody of the sites to perform such surveillance, maintenance, and contingency measures as necessary to ensure that the sites continue to function as designed.

Title II of the UMTRCA authorized the NRC or agreement state to regulate the operation of active uranium mill tailings sites. An agreement state is a state that regulates the active mill sites within its boundaries in accordance with NRC regulations through a cooperative agreement with the NRC. Following the cessation of milling, remedial actions at the active mill sites are the responsibilities of the mill owners and operators pursuant to a remedial action plan approved by the NRC or agreement state. Within the Gas Hills area are several active (Title II) uranium mill sites whose remedial action plans will be subject to approval, or have been conditionally approved, by the NRC.

The UMTRCA also required the EPA to promulgate standards, Title 40, Code of Federal Regulations, Part 192, Subparts A through E (40 CFR Part 192, Subparts A through E), for remedial actions at the inactive (Title I) and active (Title II) uranium mill tailings sites. The EPA published environmental impact statements (EIS) on the development and impacts of the standards (EPA, 1983; 1982). Final standards for the active sites (40 CFR Part 192, Subparts D and E) were issued in Volume 48, Federal Register, pages 45926 through 45947 (48 FR 45926-45947), and became effective on December 6, 1983; final standards for the inactive sites (40 CFR Part 192, Subparts A, B, and C) were issued in Volume 48, Federal Register, pages 590 through 604 (48 FR 590-604), and became effective on March 3, 1983. In developing these standards, EPA determined "that the primary objective for control of tailings should be isolation and stabilization to prevent their misuse by man and dispersal by natural forces" and that "a secondary objective should be to reduce the radon emissions from the piles." A third objective should be "the elimination of significant exposure to gamma radiation from tailings piles." Detailed discussions of the EPA standards as they pertain to the inactive tailings sites are provided in various DOE documents (DOE, 1986; 1985a, b; 1984a, b).

The EPA standards are essentially the same for the inactive (Title I) and active (Title II) uranium mill tailings sites except that the water protection standards for the active sites are, by design, fundamentally different than those for the inactive sites. The EPA water protection standards for active sites are clearly intended to be applied to "regulated units" that are in operation and require specific design features for water protection (e.g., leak prevention and detection features) (DOE, 1987a).

On September 3, 1985, the United States Tenth Circuit Court of Appeals set aside the EPA water protection standards for the Title I, Uranium Mill Tailings Remedial Action (UMTRA) Project sites, 40 CFR Part 192.20(a)(2)-(3). The water protection standards were remanded to the EPA for further consideration in light of the Court's opinion that the water standards promulgated by the EPA on March 7, 1983, were site specific rather than of general application as required by the legislation. The EPA has not identified a date for re-issuance of 40 CFR Part 192.20(a)(2)-(3), and it is anticipated that such re-issuance will not occur until after remedial action has been initiated at the Riverton tailings site.

At inactive (Title I) uranium mill tailings sites (e.g., Riverton, Wyoming), the EPA standards require characterization of the hydrogeologic regime at and around each site. These standards state that "Judgements on the possible need for remedial or protective actions for ground-water aquifers should be guided by relevant considerations described in EPA's hazardous waste management system (47 FR 32274, July 26, 1982) and by relevant State and Federal Water Quality Criteria for anticipated or existing uses of water over the term of the stabilization." Until the EPA issues revisions to the water protection standards, the DOE will continue to guided by these relevant considerations and criteria. When the EPA issues revisions to the water protection standards, the DOE will re-evaluate the ground-water issues at the Riverton site to assure that the revised standards are met. Performing remedial action to relocate the tailings to Gas Hills prior to the EPA issuing new standards will not affect the measures that are ultimately required to meet the revised EPA water protection standards. The DOE has characterized the conditions at the Riverton site and does not anticipate that any substantial changes to the remedial action would be required. However, after the EPA re-issues the water protection standards, the DOE will determine the need for institutional controls, aquifer restoration, or other controls and will take appropriate action so as to comply with the reissued standards.

2.1.2 The remedial action process

The remedial action process for the Riverton tailings site began with site characterization and will conclude with completion of the remedial action. Preliminary radiological investigations and engineering assessments have been completed and published. Related studies that address the site-specific engineering concepts have been prepared.

2.1.3 The Riverton tailings site

The Riverton tailings site is in Fremont County, Wyoming, 2 miles southwest of the city of Riverton (Figures 2.1 and 2.2). The site is on private land that is within the boundaries of the Wind River Indian Reservation (Arapahoe and Shoshone Indian Tribes).

The tailings site is on alluvial deposits that form the drainage divide between the Wind River to the north and the Little Wind River to the south. The confluence of the rivers is 2.5 miles east of the site. The climate of the area is arid to semi-arid with average annual precipitation of 9 inches. Vegetation consists of species common to the river valleys (e.g., willow, cottonwood, and grasses) and the surrounding desert shrubland (e.g., sagebrush, grasses, and forbs).

The former Susquehanna-Western mill was operated at the Riverton site from 1958 until 1963. Remaining at the site are the tailings pile, part of the original mill building, some of the associated mill structures and equipment (scale and wash houses and process bins), a potable water well with a pump house and metal water tower, and an active sulfuric acid plant. The site is bordered by drainage ditches and irrigation canals (Figure 2.2).

Tailings are the residue of the uranium ore processing operations and are in the form of finely ground rock, much like sand. The rectangular tailings pile in the southern half of the site covers 70 acres of the 173-acre designated site and contains approximately 1 million cubic yards of tailings. The total amount of contaminated materials, including the tailings, soils beneath and around the tailings, and materials at 25 vicinity properties (off-site locations contaminated with tailings), is estimated to be 1.5 million cubic yards. The shallow ground water beneath the pile has been contaminated by natural dewatering of the tailings,

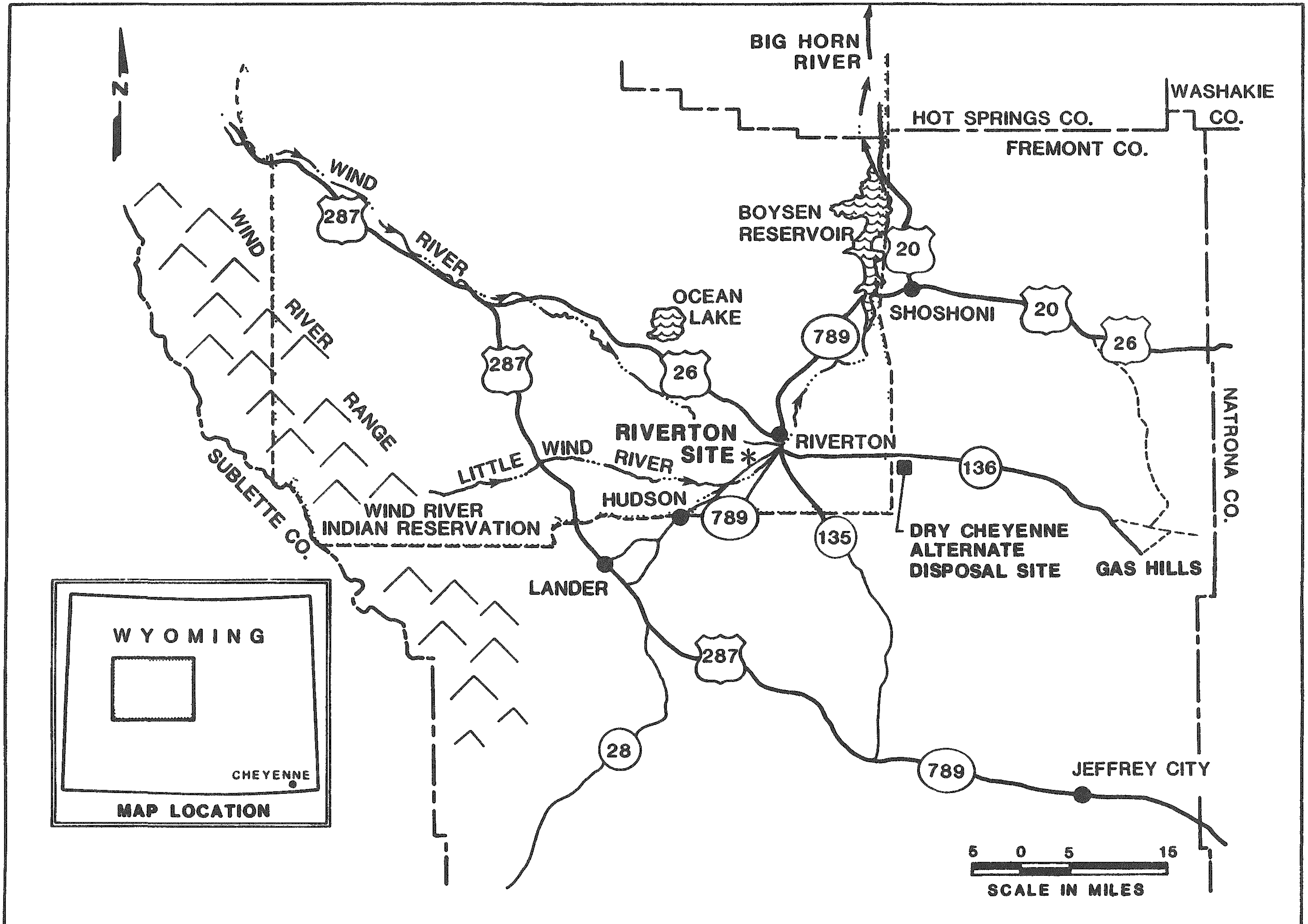


FIGURE 2.1 RIVERTON SITE LOCATION

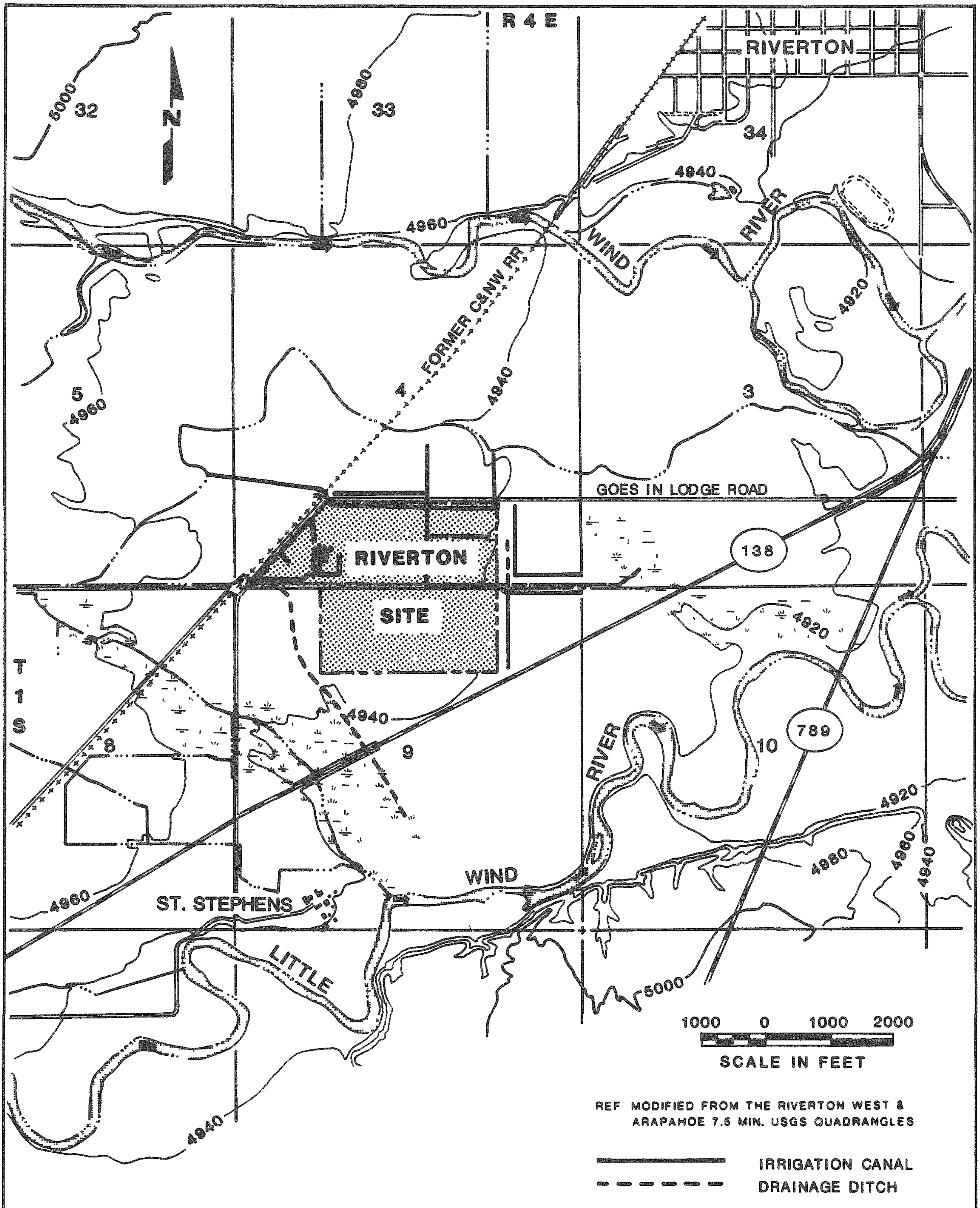


FIGURE 2.2
RIVERTON TAILINGS SITE

and lesser contamination continues due to precipitation filtering through the pile and possibly the rising of the shallow ground water into the pile.

The principal potential hazard associated with the tailings pile results from the production of radon, a radioactive gas, from the radioactive decay of the radium contained within the tailings. Radon can move through the tailings into the air. Increased exposure to radon and its decay products will increase the probability that health effects (i.e., cancers) may develop in persons living and working near the tailings.

Exposure to gamma radiation, the inhalation and ingestion of airborne radioactive particulates, the ingestion of surface or ground water contaminated by the tailings, and the ingestion of contaminated food produced in the area around the tailings also pose potential hazards. If the tailings and the associated contaminated materials are not properly stabilized, natural processes such as water and wind erosion or removal of the material by man could spread the contamination and increase the potential public health hazards.

2.1.4 The purpose of this document

This environmental assessment (EA) is prepared pursuant to the National Environmental Policy Act (NEPA), Public Law 91-190, which requires Federal agencies to assess the impacts that their actions may have on the environment. This EA examines the short-term and long-term effects of the proposed remedial action for the Riverton tailings site. Alternatives to the proposed action are also examined.

The information and analyses presented here will be used to determine whether the proposed action would have a significant impact on the environment. If the impacts are determined to be significant, an "environmental impact statement" (EIS) will be prepared. If the impacts are not judged to be significant, an official "Finding of No Significant Impact" (FONSI) will be issued and the proposed action will be implemented. These procedures and documents are defined in regulations issued by the Council on Environmental Quality (CEQ) in 40 CFR Parts 1500 through 1508.

Section 2.0 of this EA describes the proposed action, relocation to Gas Hills, and the alternatives to it. Gas Hills is an area containing several active (Title II) uranium mills, one of which would be selected through the Federal procurement process for disposal of the Riverton (Title I) tailings and contaminated materials. Prior to relocation to Gas Hills, the NRC would approve a remedial action plan (developed by the active mill owner and operator) for reclamation of the selected active site and the Title I inactive wastes. In addition, the DOE has prepared a remedial action plan that addresses relocation of the inactive wastes and restoration of the Riverton site (DOE, 1987b). Following remedial action, the NRC would issue a license for the long-term surveillance and maintenance of the selected site.

The remedial action at the selected active site in Gas Hills would be consistent with the EPA standards for active sites (40 CFR Part 192, Subparts D and E), and the generic impacts of these standards were addressed in an EIS published by the EPA (EPA, 1983). The NRC would comply with the NEPA by preparing an environmental document that assesses the short- and long-term impacts of the remedial action at the selected active site (Pettingill, 1987). Therefore, this EA does not contain descriptions of the present condition of the environment or the remedial action impacts at Gas Hills. For the proposed action, relocation to Gas Hills, this EA provides descriptions of the present condition of the environment and the remedial action impacts at the Riverton tailings site and along the transportation route to Gas Hills.

Section 3.0 of this EA discusses the present condition of the environment; Section 4.0 assesses the environmental impacts of the proposed action and other alternatives. This EA does not contain all of the details of the studies on which it is based. The details are contained in the appendices at the end of this EA and in the referenced supporting documents.

In summary, remedial action at the Riverton site is needed to minimize or eliminate the potential health hazards produced by the radioactive materials in the tailings pile and associated off-site materials. The U.S. Congress has mandated that remedial action be performed, and the EPA has issued standards applicable to such actions.

2.2 THE PROPOSED ACTION - RELOCATION TO GAS HILLS

The proposed action for the inactive (Title I) Riverton tailings site is relocation to Gas Hills 45 to 60 road miles east of the Riverton site (Figure 2.1). The Gas Hills area contains several active (Title II) uranium mill tailings sites in the Gas Hills Uranium Mining District. Uranium mining and milling have occurred extensively in the district, but the land is also used for low-density livestock grazing. The district is sparsely populated, and the closest urban center is Jeffrey City approximately 30 miles to the south. The tailings and contaminated materials would be moved from the Riverton site and vicinity properties, consolidated with the tailings at the selected active mill site in Gas Hills, and then stabilized. Remedial action at the selected active site would be consistent with the EPA standards for active sites (40 CFR Part 192, Subparts D and E) and would be conducted in accordance with a remedial action plan to be prepared by the active mill owner and operator for approval by the NRC. The Riverton tailings site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, revegetated as necessary, and released for use consistent with existing land use controls.

The conceptual design for relocation to Gas Hills was developed to comply with the EPA standards for the cleanup of open lands and habitable buildings and the major design features are summarized below. Details of the conceptual design are provided in Section A.2 of Appendix A, Conceptual Designs, and in the remedial action plan for relocation to Gas Hills (DOE, 1987b).

Design objectives

The purpose of all remedial actions under the UMTRCA (Titles I and II) is to stabilize and control the uranium mill tailings and associated contaminated materials in a manner that complies with the EPA standards. Consistent with the EPA standards applicable to relocation and with remedial action objectives, the following major design objectives were established:

- Reduce contaminant levels of radium-226 (Ra-226) in areas released for unrestricted use to 5 picocuries per gram (pCi/g) averaged in the first 15 centimeters (cm) of soil below the surface, and 15 pCi/g averaged in 15-cm-thick layers of soil more than 15 cm below the surface.

- Make a reasonable effort to achieve, in any occupied or habitable building, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 working level (WL). In any case, the radon decay product concentration (including background) shall not exceed 0.03 WL, and the level of gamma radiation shall not exceed the background level by more than 20 microroentgens per hour (microR/hr).

- Protect against releases of contaminants from the Riverton site during construction.

- Minimize the areas disturbed at the Riverton site during construction and minimize human exposure to contaminated materials.

- Ensure, to the extent practicable, that existing or anticipated beneficial uses of surface and ground waters at the Riverton site are not adversely affected.

Major construction activities

For relocation to Gas Hills, the major construction activities at the Riverton tailings site would be:

Site preparation

- Grubbing and clearing (as necessary), erection of a temporary security fence, and construction of an off-site staging area and on-site access roads.

- Demolition of the mill building and wash house at the site.

- Construction of a waste-water retention pond according to applicable regulations (Appendix G, Permits, Licenses, and Approvals) to protect against the release of contaminants from the site during construction.

- Construction of drainage control measures according to applicable regulations (Appendix G, Permits, Licenses, and Approvals) to direct all generated waste-water and storm-water runoff to the retention pond during construction.

- o Installation of measures to control erosion from all disturbed areas during remedial action.

- o Decontamination of the scale and pump houses at the site.

Tailings relocation

- o Consolidation of contaminated materials from the windblown areas and vicinity properties onto the tailings site.

- o Excavation of all tailings and contaminated materials from the tailings site and relocation of all of the materials (including demolition debris) by truck to Gas Hills.

Borrow materials

- o Excavation of the earthen borrow materials required for site restoration from the Little Wind borrow site (Figure 2.3).

Site restoration

- o Backfilling, recontouring to promote surface drainage, and revegetation (as necessary) of all areas disturbed at the Riverton site during remedial action.

- o Reclamation of the Little Wind borrow site according to applicable regulations (Appendix G, Permits, Licenses, and Approvals).

It is estimated that relocation to Gas Hills would be completed in 31 months.

Description of final condition

The Riverton tailings and contaminated materials would be relocated to an active (Title II) uranium mill tailings site in Gas Hills to be stabilized in accordance with a remedial action plan prepared by the owner and operator of the active site and to be approved by the NRC. After decontamination of the Riverton tailings site, the disturbed areas at the site (153 acres) would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, and revegetated as necessary. The Riverton site (173 acres) would then be released for use consistent with existing land use controls.

Radon control and long-term stability

Control of radon emanation from the Riverton tailings site would be accomplished by relocating all of the tailings and contaminated materials to Gas Hills.

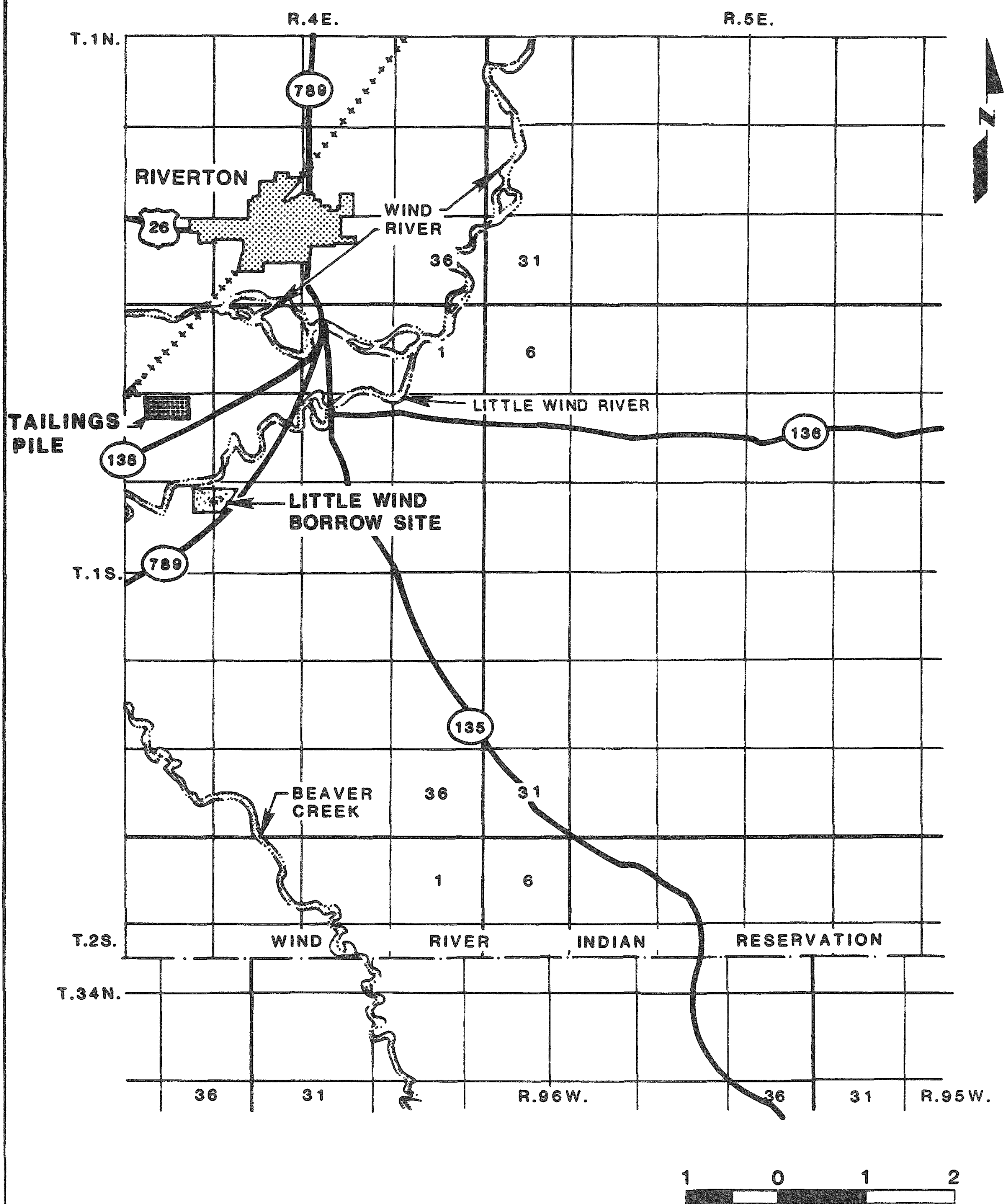


FIGURE 2.3 LOCATION OF LITTLE WIND BORROW SITE

Ground-water protection

The shallow ground water beneath and southeast of the tailings pile has been contaminated primarily by percolating leachate generated by the natural dewatering of the tailings during and immediately after the uranium milling. Lesser but continuing contamination is due to precipitation filtering through the tailings pile and possibly to the rising of the shallow ground water into the pile. Relocation of the tailings and contaminated materials to Gas Hills would remove the source of any future ground-water contamination at the Riverton site, and the natural flow and discharge of the shallow ground water into the Little Wind River would reduce the existing concentrations of the contaminants to background levels in approximately 45 years. At this time, aquifer restoration would not be a cost-effective means of controlling or cleaning up the ground-water contamination at the Riverton site (Section C.2.6 of Appendix C, Water).

When the EPA issues revisions to the water protection standards (40 CFR Part 192.20 (a)(2)-(3)) that were remanded by the U.S. Tenth Circuit Court of Appeals, the DOE will re-evaluate the ground-water issues at the Riverton site to assure that the revised standards are met. Performing remedial action to relocate the tailings prior to the EPA issuing new standards will not affect the measures that are ultimately required to meet the revised EPA water protection standards. The DOE has characterized the conditions at the Riverton site and does not anticipate that any substantial changes to the remedial action would be required. However, after the EPA re-issues the water protection standards, the DOE will determine the need for institutional controls, aquifer restoration, or other controls and will take appropriate action so as to comply with the re-issued standards.

Construction estimates

Estimates of equipment and personnel requirements, energy and water consumption, volumes of materials, construction costs, and the remedial action schedule for relocation to Gas Hills are provided in Sections A.2 and A.5 of Appendix A, Conceptual Designs.

2.3 OTHER ALTERNATIVES

The alternatives to the proposed action, no action, stabilization in place at the Riverton tailings site, and disposal of the tailings at the Dry Cheyenne site, are discussed here. The alternate disposal site (Dry Cheyenne) was selected through the site selection process discussed in Section 2.6. Figure 2.1 shows the location of this alternate disposal site.

The design objectives for the stabilization in place and Dry Cheyenne disposal alternatives are identical to those objectives selected for the proposed action and also include the following objectives for the disposal site:

- o Reduce the average radon flux from the site to 20 picoCuries per square meter per second (pCi/m^2s) or 0.5 picoCuries per liter (pCi/l) above background outside the disposal site.

- Design controls to remain effective for up to 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years.
- Minimize the land area to be occupied by the stabilized tailings.
- Prevent inadvertent human intrusion into the stabilized tailings.
- Minimize plant root penetration and burrowing by animals into the stabilized tailings.

These design objectives are discussed in Section 2.2 and Section A.1 of Appendix A, Conceptual Designs. The conceptual design for stabilization in place is based on field studies, laboratory testing, and various modeling techniques. The conceptual design for the Dry Cheyenne disposal alternative is based on existing published data. If the alternate disposal site were to be selected, additional site-specific data would be obtained before the final engineering design was prepared.

All of the remedial action alternatives except no action include remedial action at the estimated 25 off-site vicinity properties. Conceptual details and engineering estimates for remedial action at the vicinity properties are included in Section A.6 of Appendix A, Conceptual Designs. The engineering estimates for the vicinity properties are included in the text of this document only when they have an appreciable effect on the overall remedial action estimates.

2.3.1 No action

This alternative consists of taking no steps toward remedial action at the tailings site or the vicinity properties. The tailings would remain in their present location and condition and would continue to be subject to dispersal by water and wind erosion and unauthorized removal and use by man. The tailings and contaminated materials at the vicinity properties would not be cleaned up and would continue to pose a potential public health hazard. The selection of this alternative would not be consistent with the intent of Congress in the UMTRCA (PL95-604) and would not result in compliance with the EPA standards (40 CFR Part 192, Subparts A, B, and C).

2.3.2 Stabilization in place

Stabilization in place would consist of stabilizing the tailings pile at its present location in the southern half of the inactive Riverton site. All contaminated materials from around the pile and from the vicinity properties would be consolidated with the tailings, and the pile would be covered with compacted earth (radon barrier) to inhibit radon emanation, water infiltration, and plant root penetration. A rock erosion protection barrier would be placed over the pile to protect against erosion and burrowing by animals and to discourage human intrusion. The erosion protection barrier would tie into a riprap (rock) apron around the base of the pile to protect the stabilized pile against flooding and river meander. Details of the conceptual design are provided in Sections A.3 and A.5 of Appendix A, Conceptual Designs.

The top of the stabilized pile would be approximately 27 feet above the surrounding terrain. An unpaved access road would be located on top of the riprap apron, and a drainage ditch would be constructed around the outside edge of the riprap apron. A security fence with locked gates and warning signs would enclose the 80-acre site containing the pile, access road, and drainage ditch. After remedial action, the remaining 93 acres of the 173-acre designated tailings site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, revegetated as necessary, and released for use consistent with existing land use controls. It is estimated that stabilization in place would be completed in 2 years.

2.3.3 Disposal at the Dry Cheyenne site

The Dry Cheyenne alternate disposal site (Figure 2.1) is 15 road miles east of the Riverton tailings site on Federal land administered by the Bureau of Land Management (BLM). The area around the site is used for low-density grazing of livestock and oil and gas development. The nearest residence is approximately 4 miles northeast of the Dry Cheyenne site.

The Dry Cheyenne disposal alternative would consist of moving the tailings and contaminated materials from the inactive Riverton tailings site and adjacent areas and consolidating them into a gently contoured pile at the Dry Cheyenne site. A disposal area would be constructed partially below grade at the site. The surface materials excavated from the disposal area would be stockpiled and used later to cover the pile and restore disturbed areas at the Riverton site. The tailings and contaminated materials would be covered with a compacted, earthen radon barrier to control radon emanation and inhibit water infiltration and plant root penetration. The radon barrier would be covered with rock to protect against water and wind erosion.

The completed disposal area would be a gently contoured, stabilized pile occupying an area of 40 acres within the Dry Cheyenne site. The maximum height of the pile above the surrounding terrain would be 30 to 35 feet. The rock layers over the stabilized pile would tie into an unpaved access road and drainage ditch around the toe of the pile. A security fence with locked gates and warning signs would enclose the 47-acre area containing the pile, access road, and drainage ditch. After completion of the stabilized pile at the disposal site and decontamination of the Riverton tailings site, the disturbed areas at each site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, and revegetated as necessary or reclaimed according to applicable regulations (Appendix G, Permits, Licenses, and Approvals). It is estimated that this alternative would be completed in 2.5 years.

2.4 REJECTED ALTERNATIVES

Alternate disposal sites

The DOE used an extensive process to locate, evaluate, and select alternate disposal sites for the Riverton tailings. The State of Wyoming, Federal and local agencies, concerned individuals, and industry representatives were contacted to locate possible disposal sites. Private, state, tribal, and Federal lands were considered in the alternate disposal site selection process (FBDU, 1981).

Originally, 18 alternate disposal sites were considered, and a reconnaissance survey was made of each. Eleven of the original 18 sites were eliminated from further consideration because of possible residential development, excessive haulage distance, steep terrain, excessive surface drainage, or insufficient borrow materials for the stabilization cover. Between 1978 and 1981, an additional site was identified, and the resulting eight alternate disposal sites were evaluated further (FBDU, 1981).

The eight alternate disposal sites were evaluated on the basis of existing hydrologic, meteorologic, geologic, ecologic, and economic conditions. Hydrologic and meteorologic conditions were assessed for factors such as water and wind erosion, water contamination, drainage and flooding characteristics, precipitation, and location of confined aquifers. Special consideration was given to drainage basin configuration, surface and subsurface drainage, and natural storage basin features. Geologic evaluation addressed stability and soil characteristics such as the presence of slides or faults and types of unconsolidated and bedrock materials. The ecologic evaluation assessed land use potential, animal habitats, proximity to population centers, and aesthetics. Economic considerations included estimates of impacts to support facilities such as highways, distance from the Riverton site, and the extent of site preparation and long-term maintenance (FBDU, 1981). This evaluation led to the selection of three alternate disposal sites for detailed evaluation.

The detailed evaluation of the three alternate disposal sites used criteria from various sources which were developed to be appropriate for below-grade disposal of the tailings and to meet the EPA standards. These criteria included geology and geologic hazards, hydrology, economics, land ownership and use, and potential public conflict (FBD, 1983). The detailed evaluation resulted in the DOE's selection of the Dry Cheyenne and Little Wind River alternate disposal sites. The DOE later deleted the Little Wind River site because it is on lands of the Wind River Indian Reservation, and the Arapahoe and Shoshone Indian Tribes have expressed strong opposition to relocation of the tailings onto their lands. The Little Wind River site is also less than 1 mile from a developing housing project. The Dry Cheyenne alternate disposal site (Figure 2.1) is addressed in this document.

Since completion of the above evaluations, detailed consultation has continued with the State of Wyoming, the NRC, industry representatives, and other concerned individuals to identify other uranium mill tailings sites within a reasonable distance of the Riverton site for disposal of the tailings and contaminated materials. On the basis of this consultation, a variety of specific sites within the Gas Hills Uranium Mining District were considered to be acceptable. Therefore, relocation to Gas Hills is considered in this document.

In addition to evaluating alternate disposal sites, the DOE also considered two alternative methods for disposal of the Riverton tailings: returning the tailings to the original source mines and reprocessing the tailings.

Returning the tailings to the original source mines

It was determined that it would not be feasible to return the tailings to the mines from which the uranium ores were originally obtained. The ores came from many mines scattered over a wide area, and these mines are much farther from the Riverton site than Gas Hills and the Dry Cheyenne alternate disposal site. This alternative disposal method was not considered further (FBDU, 1981).

Reprocessing the tailings

The feasibility of reprocessing the tailings to recover residual uranium, vanadium, and molybdenum was evaluated. A drilling and sampling program was conducted to determine the total recoverable amounts of these metals in the tailings and underlying materials. Laboratory testing determined that heap leaching would be the most technically and economically feasible method of reprocessing the tailings, and the economics of this reprocessing method were evaluated (MSRD, 1982).

The evaluation concluded that the technical feasibility of recovering vanadium from the tailings was marginal and that the capital cost of a vanadium extraction process would be much greater than the recoverable value. The recovery of uranium and molybdenum from the tailings is technically feasible but would not be economical at the present market values for these products ($32 per pound combined value in 1982). The market values for uranium and molybdenum would have to increase to $153 and $57 per pound, respectively, for the reprocessing to "break even" (MSRD, 1982).

Reprocessing of the tailings would not reduce the radium content of the tailings. Since radioactive decay of radium is the source of radon gas, there would be no reduction of the hazard from radon and radon daughters; hence, the reprocessed tailings would still require remedial action to meet the EPA standards. Reprocessing was therefore eliminated from further consideration.

Borrow sites

The proposed action, relocation to Gas Hills, would require earthen borrow materials for restoration of the areas disturbed at the Riverton tailings site during remedial action. The Little Wind borrow site (Table 2.1 and Figure 2.3) was chosen as the source of these borrow materials. This borrow site is within the Wind River Indian Reservation, but both the surface and minerals of the site are privately owned. Gravel for the access roads at the Riverton site would be purchased from a commercial source.

Table 2.1 Borrow sites for the remedial action alternatives

Remedial action alternative	Borrow sites	
	Earth	Gravel and rock
Relocation to Gas Hills	Little Wind borrow site	None
Stabilization in place	Borrow site 10	Boulder Flats borrow site
Disposal at Dry Cheyenne site	Dry Cheyenne disposal site	Borrow site 2

The stabilization in place and Dry Cheyenne disposal alternatives would require earthen and rock borrow materials for road construction, stabilization of the tailings and contaminated materials, and restoration of disturbed areas at the affected sites. For these alternatives, the earthen and rock materials used for stabilization of the tailings would be required to have specific engineering properties (e.g., rock size and durability for erosion protection). Initially, ten sites were identified as potential sources of borrow materials for remedial action at the Riverton site. Preliminary investigations eliminated three of these sites from further consideration because of unsuitable conditions such as insufficient quantities of materials and existing drainage patterns. Detailed studies and evaluations of the remaining seven sites resulted in the selection of borrow sites 2 and 10 as sources of borrow materials (Figure 2.4).

Borrow site 2 was originally selected as the source of gravel and rock for both stabilization in place and disposal at the Dry Cheyenne site. This borrow site is within the designated tailings site, and the surface and minerals of the site are privately owned. Completion of the flood analysis for the tailings site revealed that stabilization in place would require large-diameter rocks to armor the stabilized tailings pile against erosion from flooding and river meander. The rock sizes required are not available from borrow site 2, and another investigation was conducted to identify sites as potential sources of the required rock sizes. Only one site could be identified nearby, and this site, the Boulder Flats borrow site (Figure 2.5), was chosen as the source of gravel and rock for stabilization in place (Table 2.1). This site is within the Wind River Indian Reservation, but both the surface and minerals of the site are privately owned. Borrow site 2 would be used as the source of gravel and rock for the Dry Cheyenne alternative (Table 2.1).

Earthen borrow materials for stabilization in place would be obtained from borrow site 10 (Table 2.1). This site is on Federal land administered by the BLM. Earthen borrow materials for the Dry Cheyenne alternative would be obtained from the partially below-grade excavation of the disposal site itself.

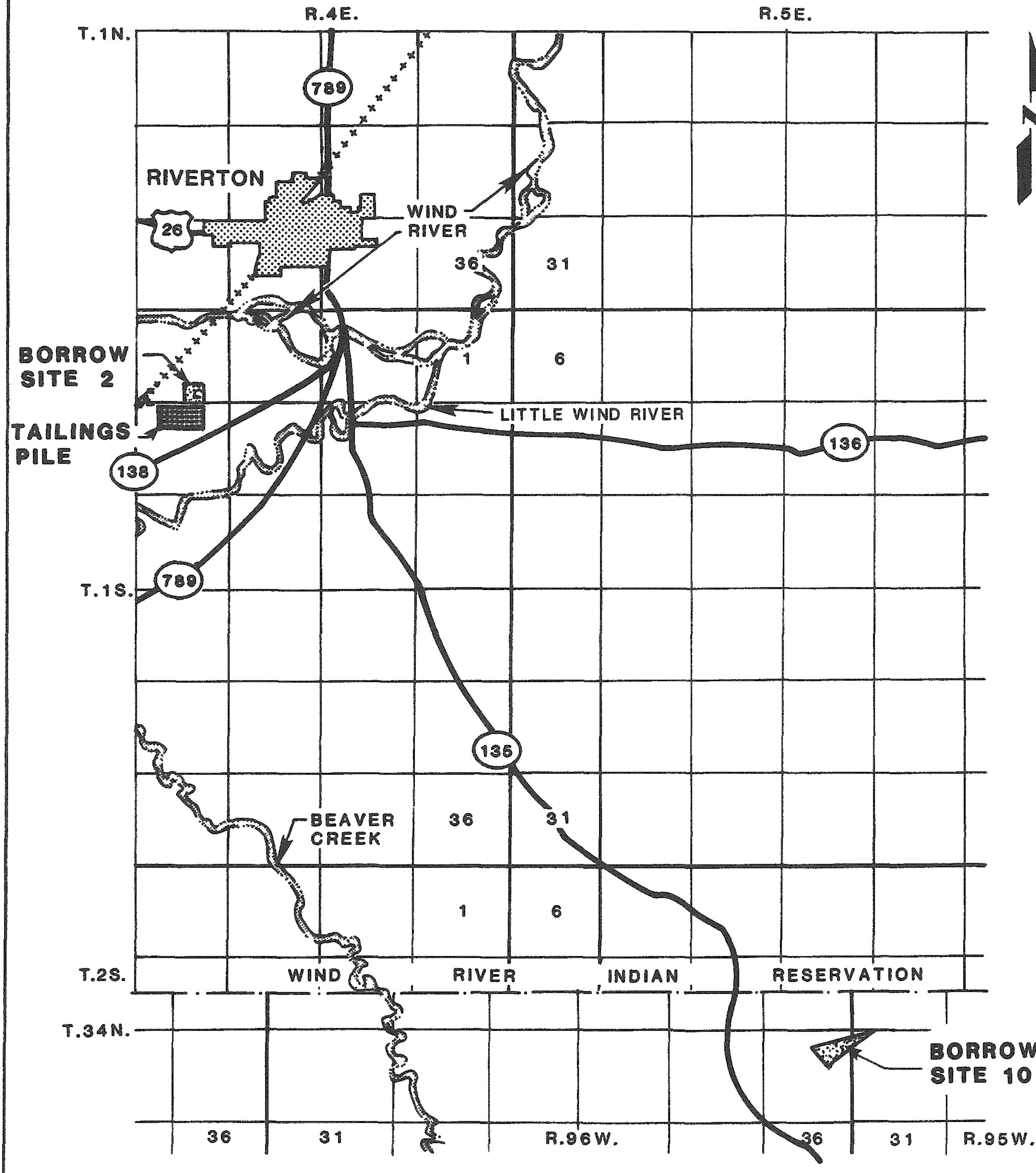


FIGURE 2.4 LOCATIONS OF BORROW SITES 2 AND 10

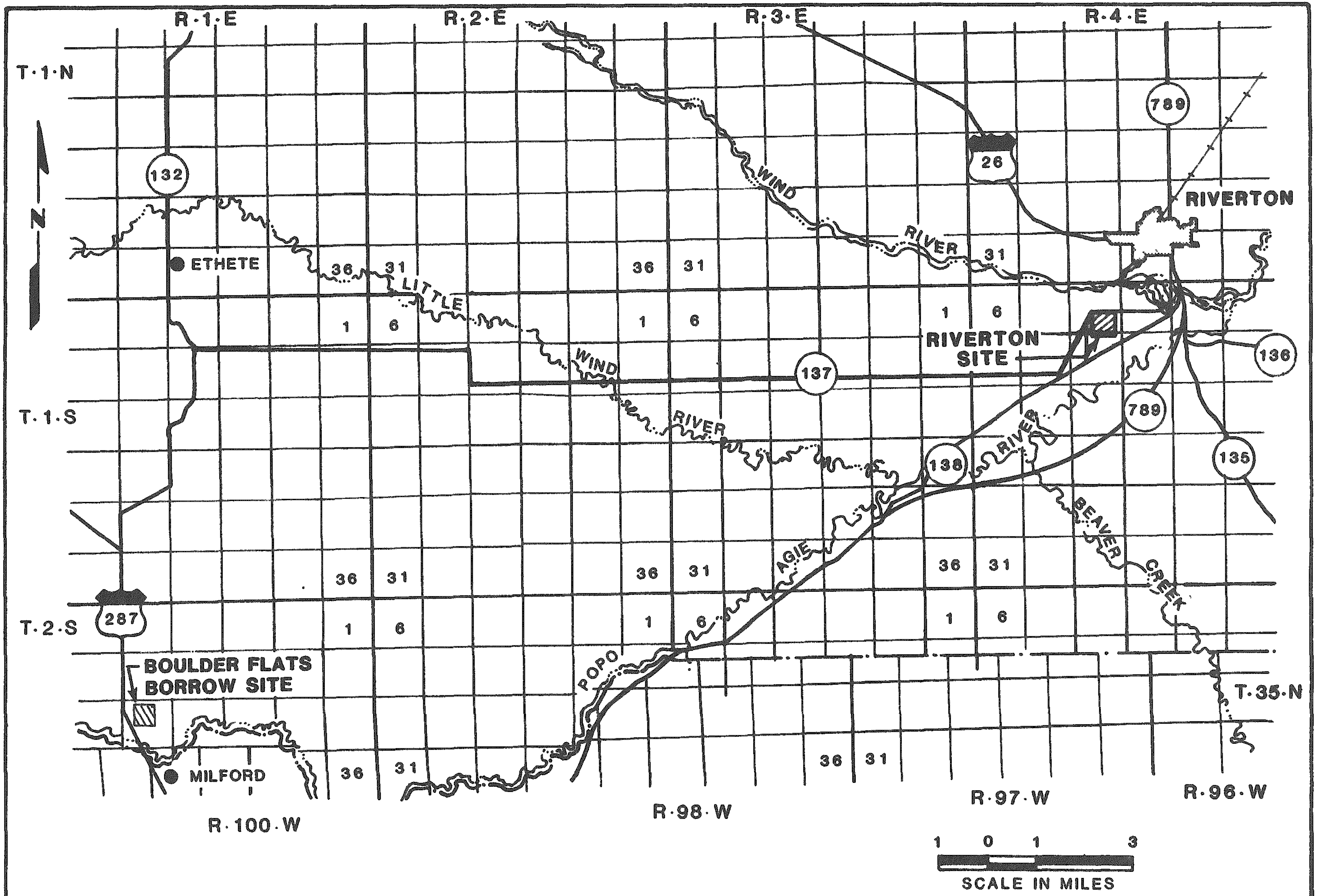


FIGURE 2.5
LOCATION OF BOULDER FLATS BORROW SITE

The borrow sites included in this EA were selected as the sources of the necessary borrow materials for impacts analyses purposes. Although the borrow sites to be used for the remedial action will be selected during the final design, the impacts identified for the borrow sites included in this EA are conservative and represent a realistic upper limit on the severity of the impacts that may occur.

Stabilization in place with a slurry wall

Originally, the design for stabilization in place included the construction of an underground bentonite slurry wall around the perimeter of the stabilized tailings pile to minimize the migration of contaminants from the pile into the underlying alluvial aquifer. This slurry wall would be approximately 3 feet wide by 30 feet deep, extending 5 feet into the subsurface bedrock.

Further evaluation of the slurry wall (Section C.2.6 of Appendix C, Water) has shown that the wall would not be an effective means of controlling contaminant migration. The slurry wall would create a second contaminant plume beneath the tailings pile, and this second plume would have much higher concentrations of contaminants than the original plume because it would not be dissipated by the natural ground-water flow in the alluvial aquifer. The long-term stability of the slurry wall could not be assured, and the second contaminant plume would eventually breach the wall to move downgradient toward the Little Wind River. The second plume would also take a longer time to dissipate than the original contaminant plume due to the slurry wall's effect on the flow pattern of the alluvial aquifer. The slurry wall was therefore deleted from the conceptual design for stabilization in place.

REFERENCES FOR SECTION 2.0

DOE (U.S. Department of Energy), 1987a. "DOE Plan for Water Protection Standards," unpublished draft prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1987b. Remedial Action Plan for Stabilization of the Inactive Uranium Mill Tailings Site at Riverton, Wyoming," UMTRA-DOE/AL-050507.0000, being prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1986. "Remedial Actions at the Former Climax Uranium Company Uranium Mill Site, Grand Junction, Mesa County, Colorado," DOE/EIS-0126-D, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1985a. Environmental Assessment of Remedial Action at the Lakeview Uranium Mill Tailings Site, Lakeview, Oregon, UMTRA-DOE/EA-0271, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1985b. Remedial Actions at the Former Vanadium Corporation of America Uranium Mill Site, Durango, La Plata County, Colorado, DOE/EIS-0111F, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1984a. Environmental Assessment of Remedial Action at the Shiprock Uranium Mill Tailings Site, Shiprock, New Mexico, DOE/EA-0232, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1984b. Plan for Implementing EPA Standards for UMTRA Sites, UMTRA-DOE/AL-163, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

EPA (U.S. Environmental Protection Agency), 1983. Final Environmental Impact Statement for Standards for the Control of Byproduct Materials from Uranium Ore Processing (40 CFR 192), EPA 520/1-83-008-1 and 2, Washington, D.C.

EPA (U.S. Environmental Protection Agency), 1982. Final Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192), EPA 520/4-82-013-1 and 2, Washington, D.C.

FBD (Ford, Bacon & Davis Inc.), 1983. "Evaluation of Alternate Disposal Sites for the Riverton, Wyoming, UMTRA Site," UC-451-320, UMTRA-SNL/68 8605, unpublished report prepared by FBD, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

FBDU (Ford, Bacon & Davis Utah Inc.), 1981. Engineering Assessment of Inactive Uranium Mill Tailings, Riverton Site, Riverton, Wyoming, DOE/UMT-0106, FBDU-360-19, UC 70, prepared by FBDU, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

MSRD (Mountain States Research and Development), 1982. Economic Evaluation of Inactive Uranium Mill Tailings, Riverton Site, Riverton, Wyoming, UMTRA-DOE/AL-0178, prepared by MSRD, Tucson, Arizona, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Pettingill, Harry, 1987. Personal communication with Harry Pettingill, U.S. Nuclear Regulatory Commission, Uranium Recovery Field Office, Denver, Colorado, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 30, 1987.

3.0 AFFECTED ENVIRONMENT

The existing environmental conditions at the Riverton tailings site, Dry Cheyenne alternate disposal site, and borrow sites are described in this section. Gas Hills is an area 45 to 60 road miles east of the Riverton tailings site that contains several active (Title II) uranium mill tailings sites in the Gas Hills uranium mining district. A specific site in Gas Hills for the disposal of the inactive (Title I) Riverton tailings and contaminated materials would be selected by competitive bidding from owners and operators of active tailings sites in the Gas Hills District. The descriptions for the Riverton and Dry Cheyenne sites also apply to the transportation route from the Riverton site to Gas Hills (Wyoming State Highway 136) except where specifically noted in this section. The existing environmental conditions at the selected active site in Gas Hills would be described by the U.S. Nuclear Regulatory Commission (NRC) for its compliance with the National Environmental Policy Act (NEPA), Public Law 91-190 (Pettingill, 1987).

3.1 BRIEF DESCRIPTION OF THE AFFECTED AREA

The Riverton tailings site, Gas Hills, and the Dry Cheyenne alternate disposal site are in Fremont County, Wyoming. Figure 3.1 shows the location of each site and the major demographic features of the area. The closest urban center is the city of Riverton with a 1983 estimated population of 10,438. The nearest residence is 900 feet from the tailings pile.

The climate of the area ranges from arid to semi-arid with an average annual precipitation of 9 inches. Prevailing winds are from the west, and the strongest winds are from the north.

The tailings site is within the Wind River and Little Wind River valleys. Vegetation consists of willows, cottonwoods, and grasses in the valley bottoms along the rivers and sagebrush, forbs, and grasses in the desert rangeland surrounding the valleys. The disposal sites are in the desert rangeland east of the tailings site.

The tailings site is on the drainage divide between the Wind and Little Wind Rivers (Figure 3.2). Although situated within the boundaries of the Wind River Indian Reservation, the site and adjacent lands to the north, east, and west are privately owned. The land immediately south of the site is owned by the Arapahoe Indians. The land around the tailings site is used for residential, agricultural, and grazing purposes. Some of the original mill structures and an active sulfuric acid plant are immediately northwest of the tailings pile, and the tailings site is bordered by drainage ditches and irrigation canals.

Gas Hills is 45 to 60 road miles east of the Riverton tailings site (Figure 3.1) and contains several active (Title II) uranium mill tailings sites in the Gas Hills Uranium Mining District. Uranium mining and milling have occurred extensively in the district, but the land is also used for low-density livestock grazing. The district is sparsely populated, and the closest urban center is Jeffrey City approximately 30 miles to the south.

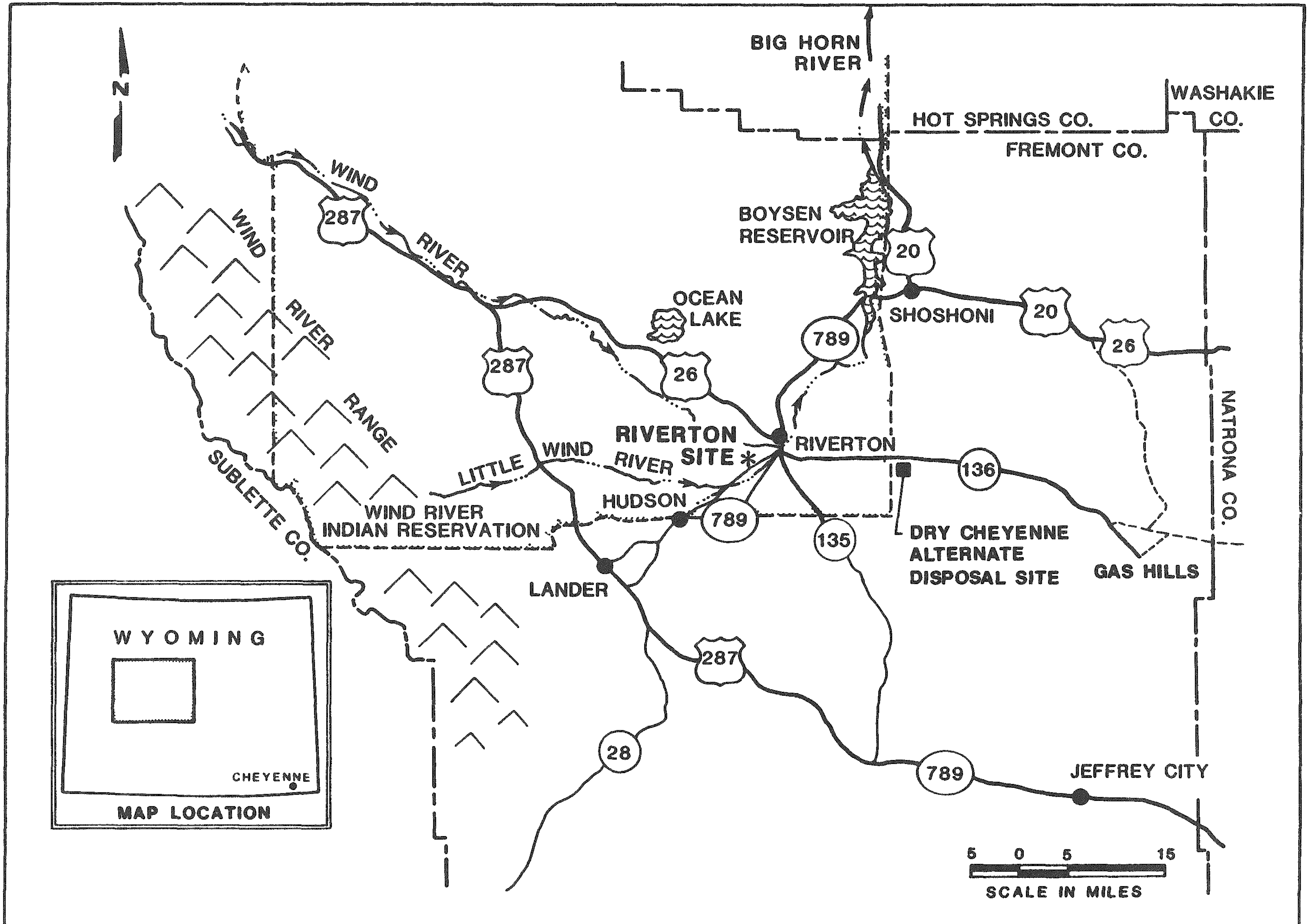


FIGURE 3.1 RIVERTON SITE LOCATION

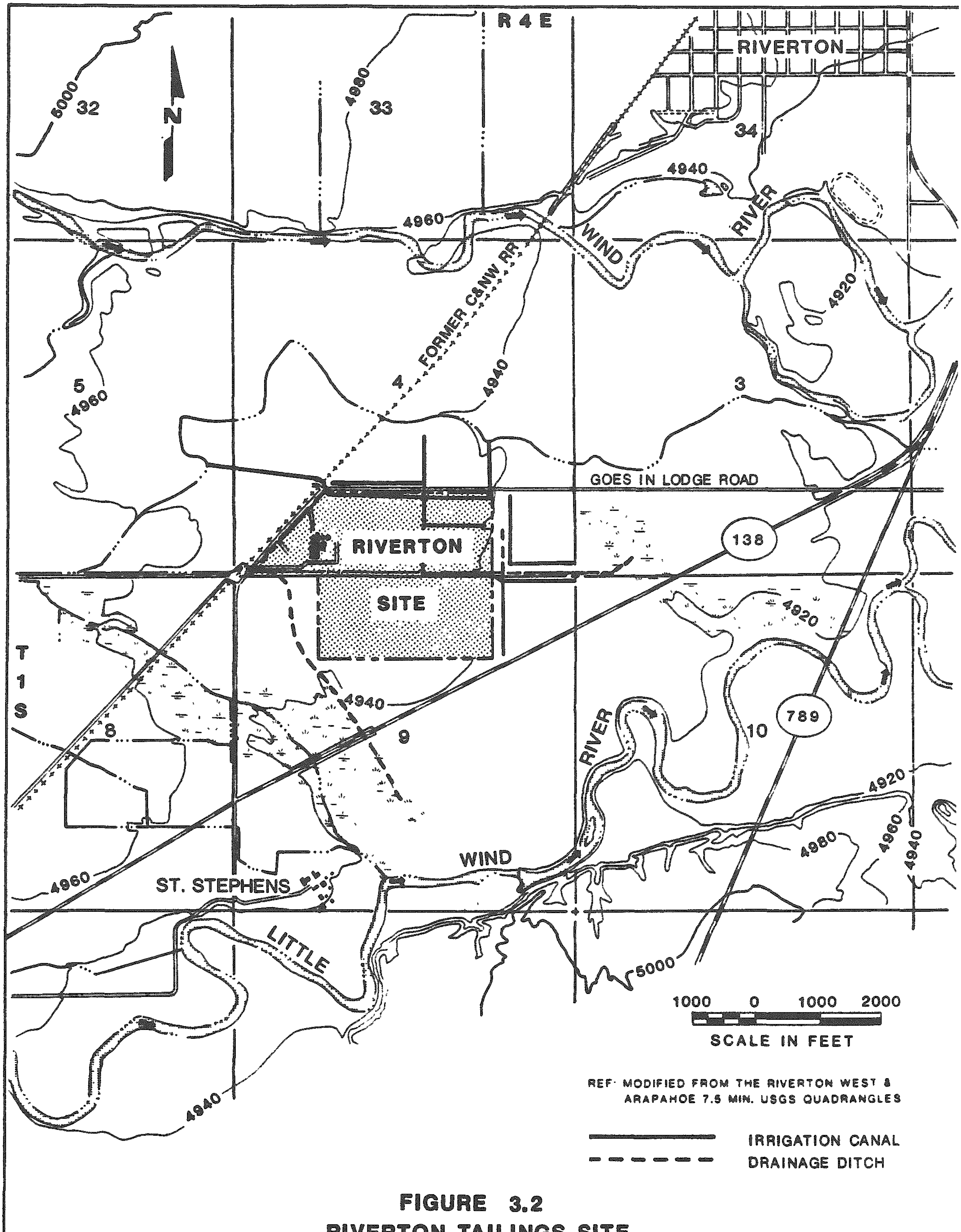


FIGURE 3.2
RIVERTON TAILINGS SITE

The Dry Cheyenne alternate disposal site is 15 road miles east of the tailings site (Figures 3.1 and 3.3) on gently rolling terrain on a northeast-facing slope at the head of a small ephemeral drainage. The site is on Federal land which is administered by the Bureau of Land Management (BLM) and used for low-density livestock grazing. The closest residence is approximately 4 miles away.

Implementation of any of the remedial action alternatives except no action would require the acquisition of earthen and rock materials from borrow sites. Four sites have been selected as sources of the necessary borrow materials (Figures 3.4 and 3.5).

3.2 DESCRIPTION OF THE EXISTING TAILINGS PILE

The mill at the Riverton tailings site was constructed in 1958 and operated initially by Fremont Minerals, Inc., to treat a variety of uranium ores from the surrounding area. The milling company's name was subsequently changed to Susquehanna-Western, Inc., who operated the mill until it was shut down in mid-1963 (FBDU, 1981).

The mill included both acid and carbonate circuits to provide flexibility for the many types of uranium ore received. The initial capacity of the mill was 500 tons of ore per day. By 1960, the mill capacity had been increased to 450 to 500 tons of ore per day in the acid circuit and 250 to 300 tons of ore per day in the carbonate circuit. During its 4 years of operation, approximately 900,000 tons of ore were processed at the mill. The mill also included a sulfuric acid plant which used sulfur made from sour gas (FBDU, 1981), and this acid plant is still in operation.

The waste solids from the milling of the uranium ores were transferred to the tailings pile. This rectangular pile (Figure 3.6) covers 70 acres, has an average thickness of 9 feet, and contains approximately 1 million cubic yards of tailings. The moisture content of the tailings averages 6 percent, and the bulk density ranges from 69 to 128 pounds per cubic foot (MSRD, 1982).

The tailings pile slopes gently downward toward the east and has an average height of 9 feet above the surrounding terrain. The ground around the base of the pile has been graded to divert runoff around and away from the pile or impound runoff from the pile itself. The pile has been contoured and stabilized with an earthen cover averaging 18 inches in thickness. This cover consists of well mixed, river-run aggregate including rocks with a maximum size of 6 inches. Planted wheatgrass and invading natural vegetation (weeds) grow without irrigation on about 20 percent of the pile. The earthen cover and vegetation appear to have controlled wind and water erosion to some degree. The pile is fenced with barbed wire, but the fence has deteriorated substantially (FBD, 1983a; FBDU, 1981).

Dispersion of the tailings by wind has contaminated 47 acres of the land adjacent to the tailings pile and outside the designated site boundary. Another 71 acres within the 173-acre designated site have been contaminated by wind dispersion of the tailings and by activities around the

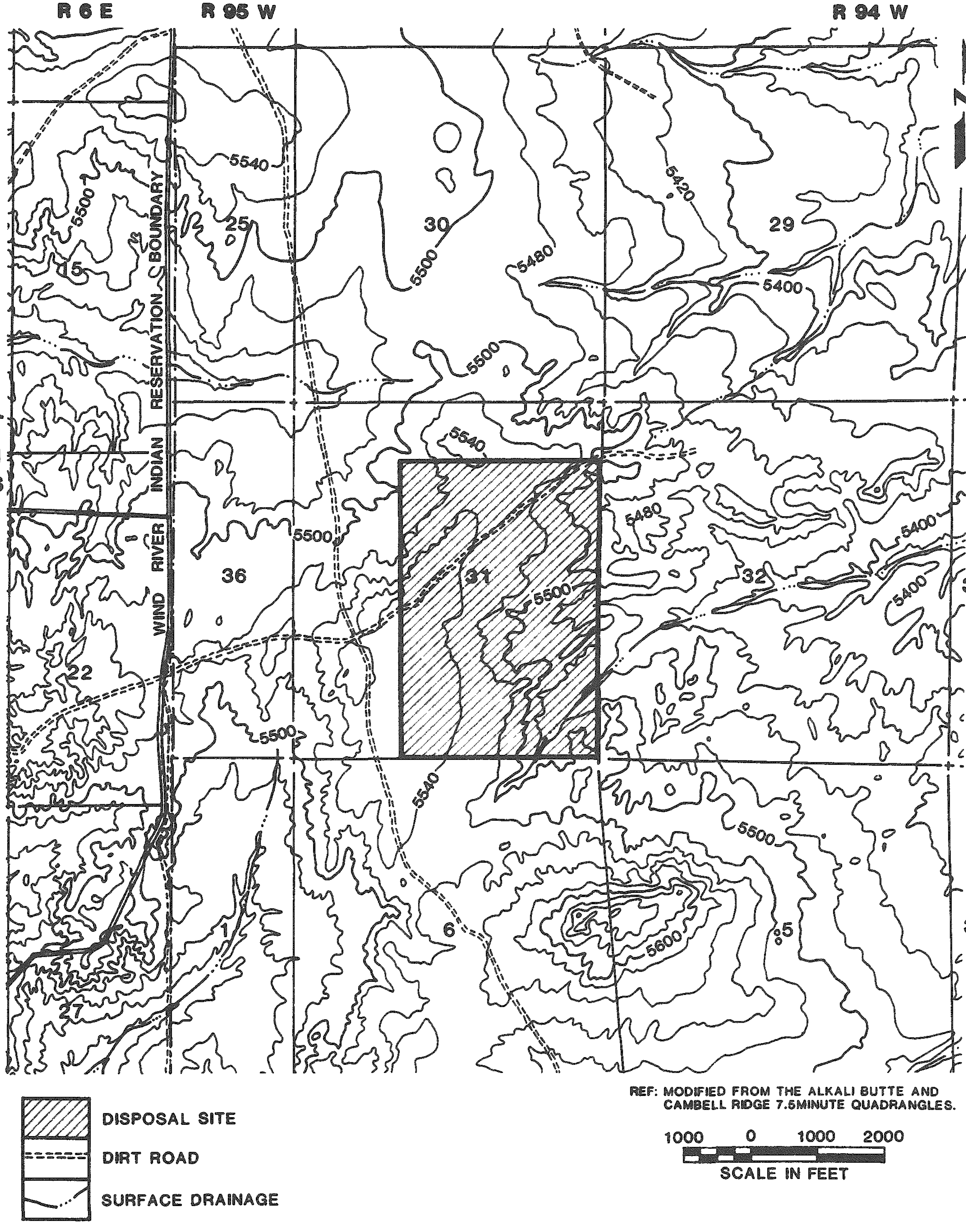


FIGURE 3.3
DRY CHEYENNE ALTERNATE DISPOSAL SITE

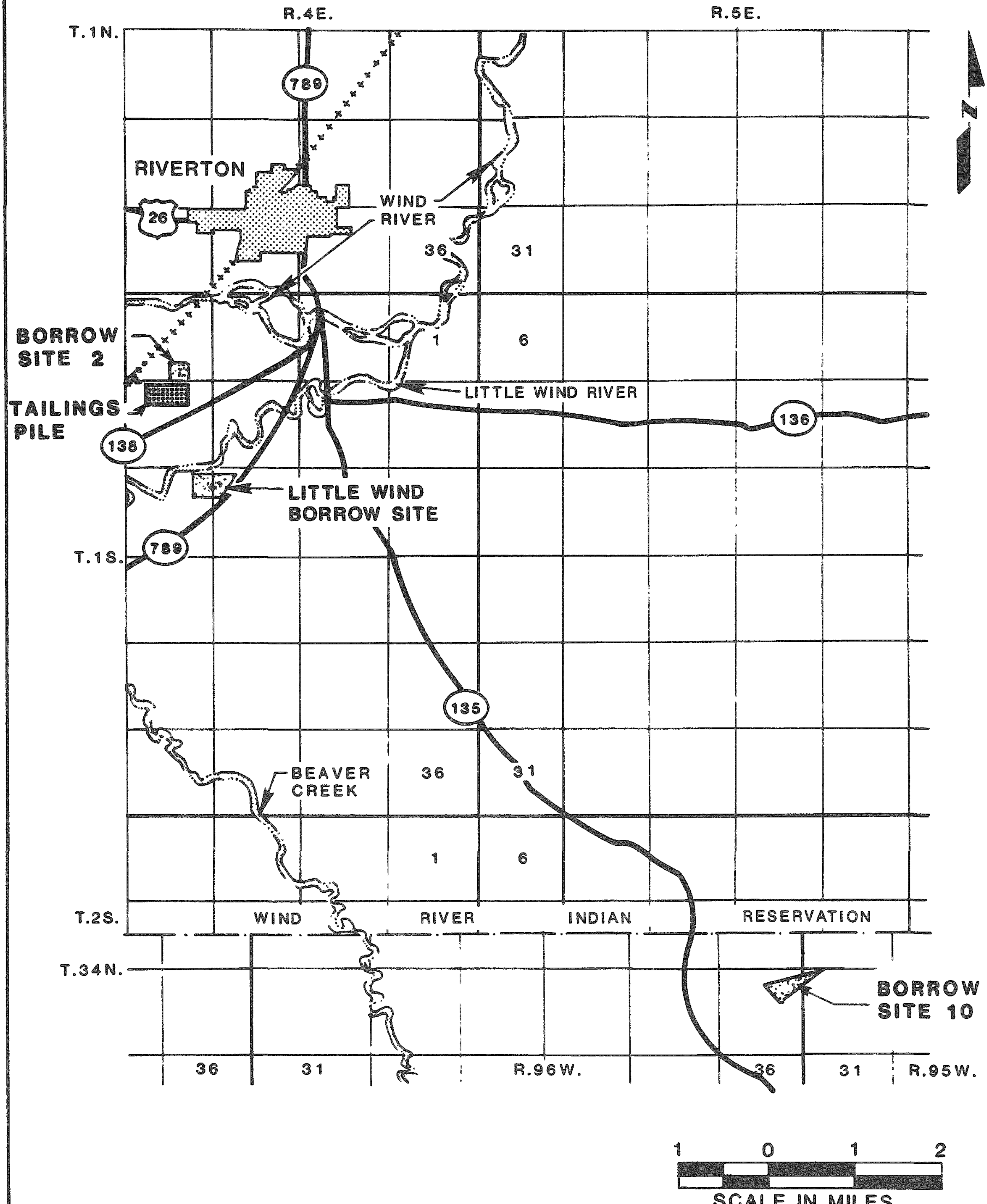


FIGURE 3.4
LOCATIONS OF LITTLE WIND BORROW SITE AND BORROW SITES 2 AND 10

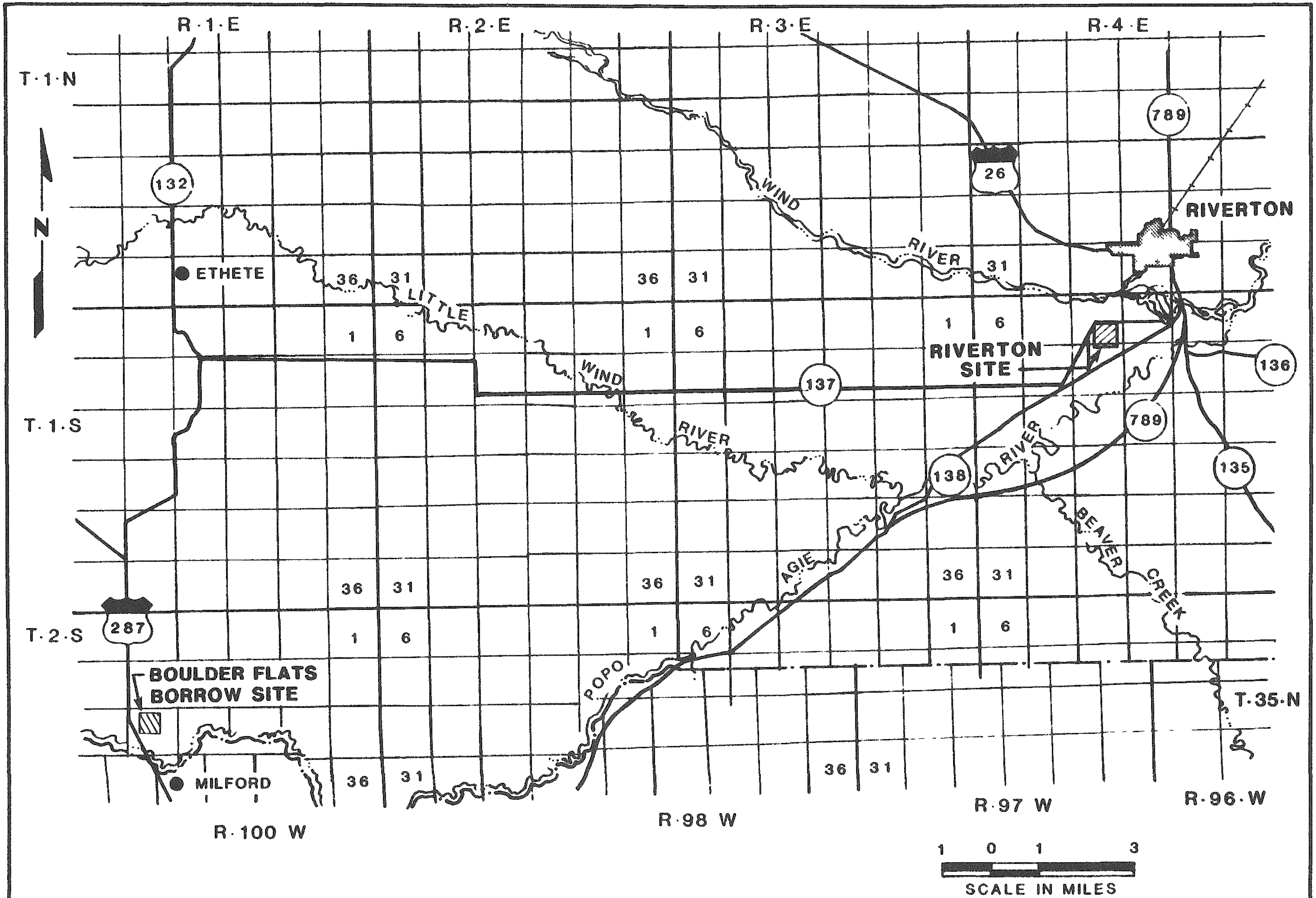


FIGURE 3.5

LOCATION OF BOULDER FLATS BORROW SITE

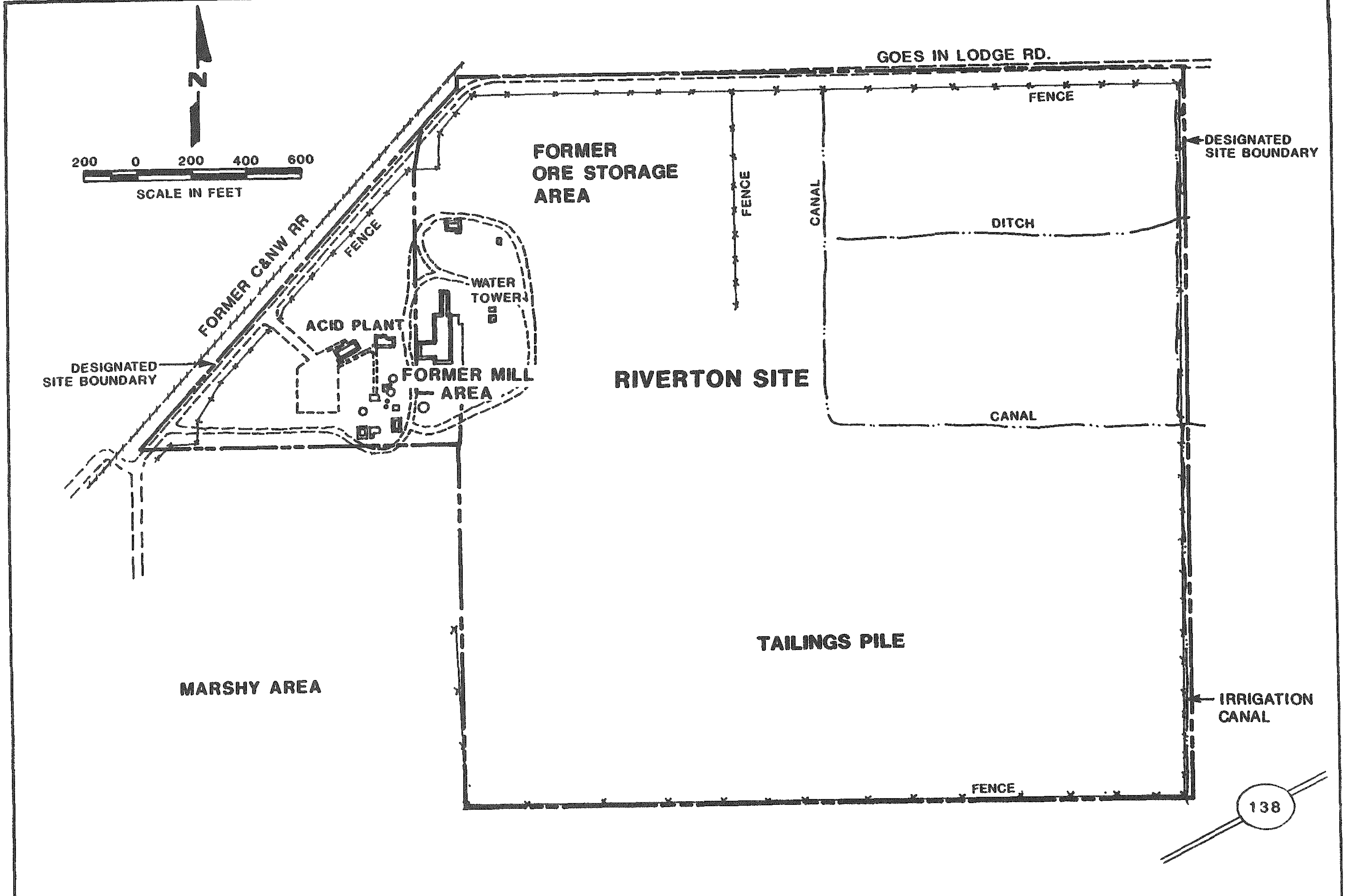


FIGURE 3.6
PRESENT CONFIGURATION OF THE RIVERTON SITE

mill buildings and in the former ore storage area. Twenty-five vicinity properties (e.g., homes, commercial sites, and vacant lots) have been identified as needing remedial action because they may have been contaminated by the use of tailings or crushed ore from the mill during their construction. These 25 off-site vicinity properties contain an estimated 4,000 cubic yards of contaminated materials. The total volume of contaminated materials, including the tailings and underlying soils and materials at the off-site vicinity properties, is estimated to be 1.5 million cubic yards.

Part of the original mill building, some of the associated mill structures and equipment (scale and wash houses and process bins), a potable water well with pump house and metal water tower, and the sulfuric acid plant remain at the tailings site. The acid plant on the west side of the site is still in operation and consists of a parking lot, administration and laboratory buildings, process tanks, and the acid plant. The original mill scale house is used in the acid plant operations, and the potable water well and tower provide water for the acid processing and fire protection. Access to the tailings site is restricted to a minimal extent by chain-link fencing and gates at the entrance to the acid plant.

3.3 WEATHER

The climate in the Riverton area is semi-arid to arid, due largely to the influence of nearby, large mountain ranges which hinder the passage of moisture. The meteorological data cited below are derived from U.S. Department of Commerce reports (DOC, 1976; 1970). Detailed meteorological data are provided in Appendix B, Weather and Air Quality.

The average annual precipitation in Riverton for a 30-year period from 1931 to 1960 was 8.79 inches, with the greatest amount occurring from April through June. Much of the precipitation is in the form of showers and thundershowers from the spring through the fall. Snow occurs primarily in the fall and spring months with an annual average of 35.8 inches.

The Riverton area experiences wide and sudden variations in temperature due to the high elevation and presence of dry air which permits much radiation of heat. Due to its location, Riverton is influenced both by cold masses from Canada and prevailing, warm westerly winds. The highest and lowest temperatures recorded in Riverton from 1931 to 1960 were 104 degrees Fahrenheit (°F) and -45°F, respectively. During the same period, an average of 202 days per year had minimum temperatures less than or equal to 32°F, and an average of 37 days per year had maximum temperatures of 90°F or greater. In general, the warmest months are July and August, and the coldest period is from December through February. The average monthly temperature ranges between 15°F in January to 70°F in July.

The predominant wind direction at Riverton is westerly, occurring 10 percent of the time. The average annual wind speeds for all 16 compass directions for which measurements were recorded are quite similar, ranging from 6 to 8 miles per hour. Periods of calm occur 32 percent of the time. On a seasonal basis, winter winds are generally stronger (14 to 15 miles per hour) than summer winds (9 to 10 miles per hour).

No site-specific meteorological data exist for the Dry Cheyenne alternate disposal site. However, the site is 15 miles from Riverton, and meteorological conditions are likely to be very similar to those of the Riverton area.

3.4 AIR QUALITY

The Riverton tailings site, the transportation route to Gas Hills (Wyoming State Highway 136), and the Dry Cheyenne alternate disposal site lie within the Casper Intrastate Air Quality Control Region, a large airshed in the central portion of Wyoming. The air quality in this region is generally good with only total suspended particulate (TSP) concentrations approaching the limits of applicable ambient air quality standards. Detailed air quality data and standards are presented in Appendix B, Weather and Air Quality.

Air quality monitoring data are currently not gathered in these areas. The most recent monitoring data for the Riverton area were collected in 1981 when annual and 24-hour TSP concentrations were recorded. The geometric mean annual TSP concentration for 1981 was 51.7 micrograms per cubic meter (microg/m^3), and the maximum 24-hour concentration was 111 microg/m^3 (Dailey, 1987; WDEQ, 1983a). Both concentrations are within Federal primary and secondary ambient air quality standards. The Federal primary annual TSP ambient air quality standard is 75 microg/m^3, and the Federal secondary annual standard is 60 microg/m^3. The Federal primary and secondary 24-hour TSP standards are 260 microg/m^3 and 150 microg/m^3, respectively (40 CFR Part 50). The State of Wyoming TSP standards are the same as the Federal secondary TSP standards (WDEQ, 1985).

It is likely that TSP concentrations along Wyoming State Highway 136 and at the Dry Cheyenne alternate disposal site are less than the concentrations in Riverton due to the absence of man-made emission sources.

3.5 SURFACE AND SUBSURFACE FEATURES

The Riverton tailings site lies within the Wind River basin, part of the Wyoming Basin subdivision of the Middle Rocky Mountain physiographic province. The Laramide orogeny that formed the Rocky Mountains was also responsible for the formation of the Wyoming Basin which subsided and received terrestrial sediments during the Cenozoic era (ANL, 1979). Structurally, the Wind River basin is bounded by Precambrian uplifts to the north, south, and west and by a broad structural upfold to the east (Hausel and Holden, 1978).

The topography of the Wind River basin has been greatly influenced by glaciation during the Quaternary period (1 million years ago) and is characterized by glacial and post-glacial deposits including terrace and pediment gravels and modern river alluvium (SHB, 1985). Major topographic features in the area are the Wind and Little Wind Rivers and the Wind River and Owl Creek Mountains with peaks up to 13,000 feet above mean sea level. The elevation of the site is approximately 4,950 feet above mean sea level.

The regional stratigraphy (Figure 3.7) is dominated by the Wind River Formation of Eocene age (36 to 58 million years ago). This sedimentary formation consists of an interbedded sequence of lenticular, nearly horizontal, fine- to coarse-grained sandstones, siltstones, and shales with smaller amounts of bentonite, tuff, and limestone (GECR, 1983). The stratigraphic units extend to a depth of at least 2,000 feet (FBDU, 1981).

Riverton tailings site

The tailings site is situated on the valley floor between the Wind and Little Wind Rivers, 5 feet above the low-flow level of the Wind River. Most of the surficial deposits on the valley floor are fluvial deposits of the Wind and Little Wind Rivers (SHB, 1985), and the origin of these deposits is evident from river meander scars that are visible on aerial photographs. The fluvial deposits consist mostly of sandy gravel that is imbricated and locally cross-bedded, and a thin layer of fine-grained sand fills some of the abandoned meander scars. The layers of sandy gravel and fine sand act as a water table aquifer in connection with the underlying sandstone layer. The fluvial or alluvial materials were deposited on an irregularly eroded bedrock surface and may vary in thickness beneath the tailings site from 5 to 15 feet (FBD, 1983a).

Directly beneath the tailings pile, borings show discontinuous, fine-grained, brown and gray, silty sands in layers varying from zero to 3 feet in thickness. A deposit of cobbly alluvium underlies the entire tailings pile, and, toward the east side, the cobbles are overlain by sandy gravel (CSU, 1983a). A cross-section (Section C.2.4 of Appendix C, Water), indicates that the alluvium is relatively uniform in thickness over a large distance, with thicknesses ranging from 14 feet beneath the pile to 18 feet southeast of the pile. It appears that the alluvium lies unconformably on the upper shale and siltstone unit of the Wind River Formation between the southern part of the tailings site and the Little Wind River. The alluvium may actually rest on the second sandstone unit of the formation just north of the Little Wind River, probably due to migration of the river southward and associated incision of the bedrock.

The upper sandstone unit of the Wind River Formation has a maximum thickness of 14 feet in the northwest portion of the tailings site and appears to grade out to zero thickness toward the southeast corner of the tailings pile. Likewise, the shale and sandstone layers that underlie the upper sandstone unit grade to zero thickness between the southeast corner of the pile and the Little Wind River. The maximum total thickness of these shale and sandstone layers is 14 feet beneath the pile. Below the shale and sandstone layers lie 15 to 40 feet of sandstone, followed by alternating layers or stringers of shales, siltstones, claystones, and sandstones.

Near-surface soils around the tailings pile within the designated tailings site are highly disturbed but generally consist of sandy loam over gravel (Bigwin series) and sandy loam formed on alluvial fans (Apron series) (Iiams, 1984). The Bigwin series consists of somewhat poorly drained, sandy loams that are underlain by sand and gravel to a depth of 20 to 40 inches. The Apron series consists of well-drained, sandy loams that formed on alluvial fans. Runoff is slow, and the hazard of water erosion is slight for both soils (SCS, 1974).

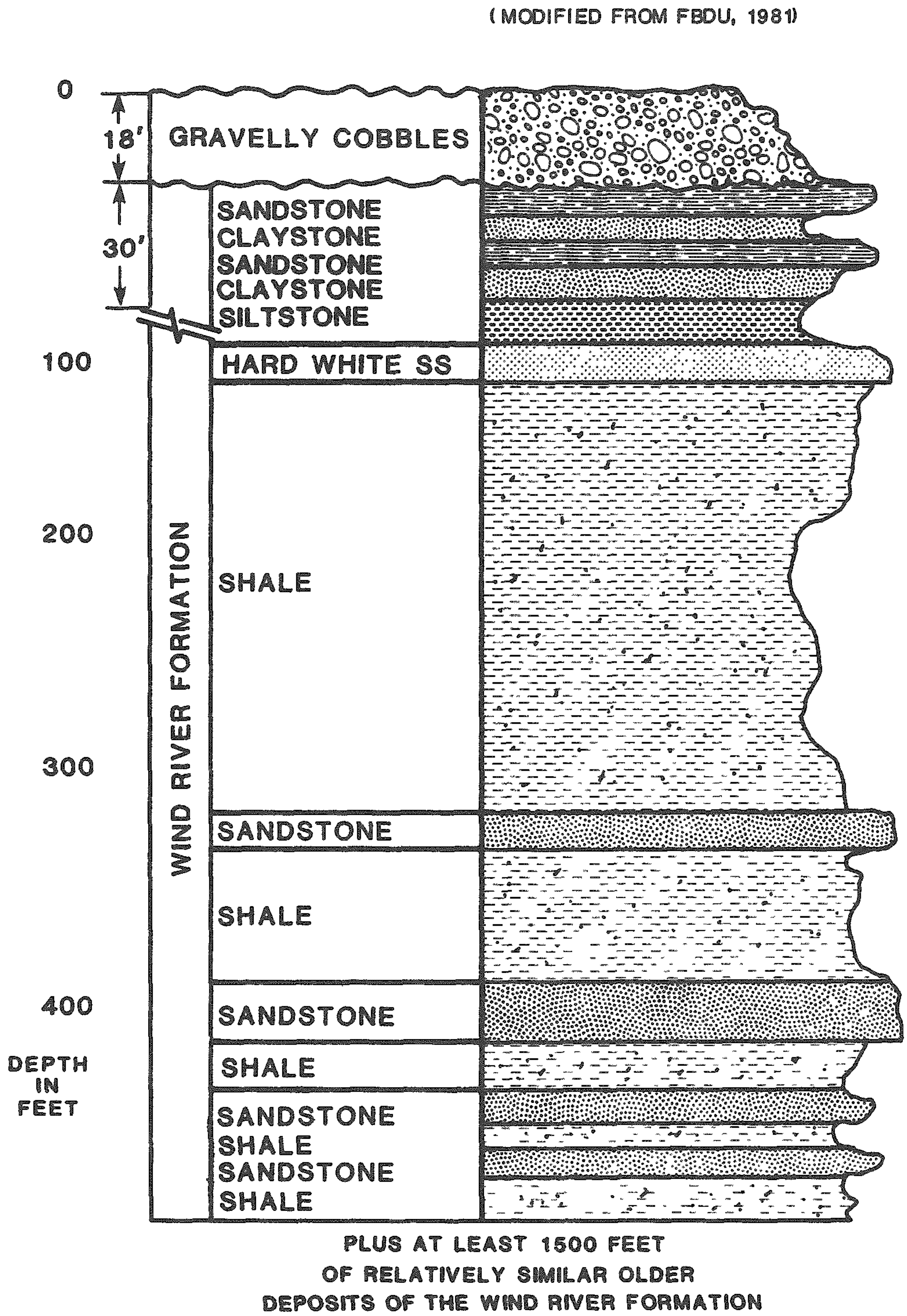


FIGURE 3.7
GENERALIZED STRATIGRAPHIC COLUMN, RIVERTON AREA

No earthquakes greater than intensity VI (modified Mercalli scale) have been recorded in the Riverton area. One earthquake, interpreted as intensity VII, occurred in 1897 near Casper which is approximately 110 miles east of Riverton. Few people lived in the Casper area in 1897, and the interpretation of this earthquake is questionable. In general, the region has a low seismic risk (ANL, 1979).

For establishing earthquake design parameters, the impact of a Maximum Credible Earthquake (MCE) was used. An MCE of magnitude 6.8 (Richter scale) was estimated for the North Granite Mountain fault system 29 miles southeast of the existing tailings site. An earthquake of this magnitude would generate an on-site horizontal ground acceleration of 0.13 g (gravity, g, is a force expressed as acceleration equal to 32 feet per second per second). The effective duration of ground motion greater than 0.05 g would range from 11 to 16 seconds in soil and 3 to 8 seconds in rock (SHB, 1983).

There are important deposits of industrial minerals, fossil fuels, and metallic ores in the Wind River basin and the adjacent Precambrian uplifts. Oil and gas exploration and development are ongoing in the area around Riverton. Alluvial sand and gravel deposits exist beneath and around the tailings site, and similar deposits are widespread throughout the Wind River valley. The mineral rights for the designated site are privately owned and, therefore, are not subject to mining claims or mineral or oil and gas leasing.

Dry Cheyenne alternate disposal site

The area surrounding the Dry Cheyenne disposal site is characterized by low-lying mesas, buttes, and hills that have been highly dissected by ephemeral streams. Surficial materials consist of shallow (less than 20 inches) colluvial and alluvial soils (Youngston and Worland series) that have originated from the Wind River Formation (Womack, 1984). Bedrock in the vicinity is part of the Wind River Formation which consists of siltstone and claystone with a few fine-grained, sandy lenses (FBD, 1983b). The area is seismically stable with little risk of an earthquake of large magnitude (SHB, 1983).

Potential conflicts with mineral resources are minimal. The surficial materials at and around the site may have a potential value as borrow materials. There are oil and gas exploration and development in the general area, and the site is within an existing oil and gas lease. There is no oil and gas activity at the site itself, and no mining claims or mineral leases are on file for the site (Weber, 1987).

Borrow sites

Four borrow sites are proposed as sources of borrow materials for remedial action. The Little Wind borrow site is 3 road miles south of the tailings site and would be the source of earthen materials for relocation to Gas Hills. The borrow site is on a gravel terrace south of the Little Wind River, and the moderately deep soils (20 to 40 inches) at the site are well drained loam to clayey loams (Iiams, 1987). The mineral rights for the Little Wind borrow site are privately owned and are not subject to mining claims or mineral or oil and gas leasing (Birk, 1987; Nation, 1987).

Borrow site 2 is within the designated tailings site immediately north of the tailings pile and would be a source of gravel and rock for the Dry Cheyenne disposal alternative. Deposits consist of moderately deep (20 to 40 inches) sandy loam soil underlain by sand and gravelly cobbles (Iiams, 1984). The mineral rights for borrow site 2 are privately owned and are not subject to mining claims or mineral or oil and gas leasing.

Borrow site 10 is 13 road miles southeast of the tailings site and is proposed as a source of earthen materials for stabilization in place. Moderately deep to deep soils formed over bedrock are present. Textures are generally sandy loam, loam, and sandy clay loam. There are oil and gas exploration and development in the general area, and a small portion of the site is within an existing oil and gas lease. However, there is no oil and gas activity at the site, and there are no mining claims or mineral leases on file for the site (Weber, 1987; Womack, 1984).

The Boulder Flats borrow site is 27 road miles southwest of the tailings site and is proposed as a source of gravel and rock for stabilization in place. Moderately deep soils are formed over parent material derived from glacial outwash deposits. Textures range from loam to sandy gravel, with sandy lenses throughout the soil profile (Iiams, 1985). The mineral rights for the Boulder Flats borrow site are privately owned and are not subject to mining claims or mineral or oil and gas leasing.

3.6 WATER

3.6.1 Surface water

Section 3.6.1 describes surface-water features, flow patterns, uses, and quality for the Riverton tailings site, the Dry Cheyenne alternate disposal site, borrow sites 2 and 10, and the Little Wind and Boulder Flats borrow sites. The transportation route to Gas Hills (Wyoming State Highway 136) crosses the Little Wind River and numerous small, ephemeral drainages. Additional details on surface water are provided in Section C.1 of Appendix C, Water.

Riverton tailings site

The Riverton tailings site is on a nearly level alluvial terrace in the Wind River basin, 2.5 miles upstream of the confluence of the Wind and Little Wind Rivers. The Wind River is 1 mile north of the site, and the Little Wind River is 0.5 mile southeast of the site (Figure 3.1). The site is bordered by drainage ditches and irrigation canals (Figure 3.8).

The Wind River has a drainage basin of approximately 2,300 square miles. The Little Wind River drains an area of approximately 2,000 square miles. Peak monthly flows for both rivers generally occur during the month of June as a result of snowmelt runoff

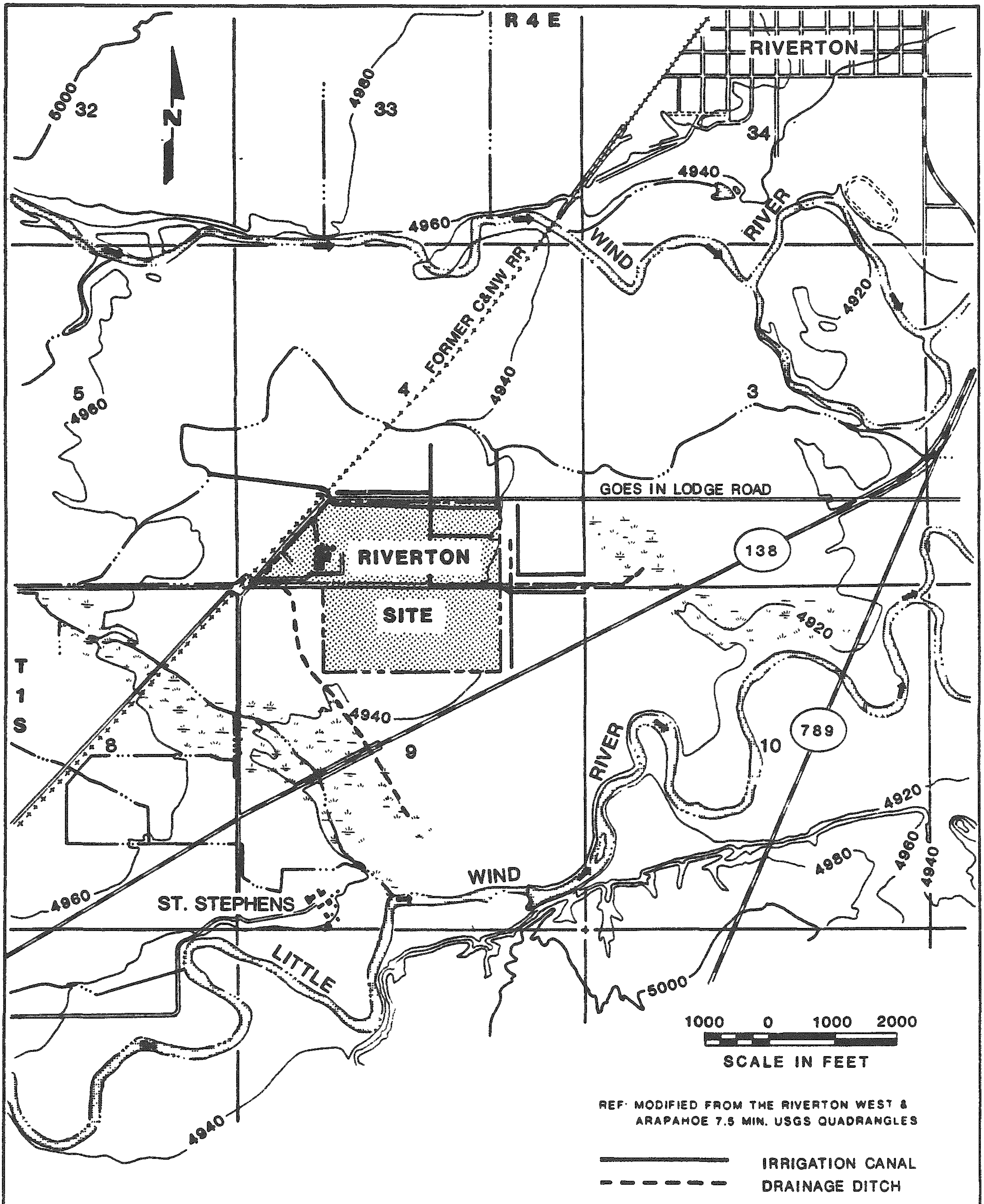


FIGURE 3.8
EXISTING DRAINAGE CONDITIONS, RIVERTON SITE

(FBD, 1983a). The U.S. Geological Survey (USGS) maintains gauging stations on each river between the tailings site and the confluence of the rivers. A maximum flow of 13,300 cubic feet per second (cfs) was recorded in 1935 for the Wind River (period of record, 1913 through 1983), and a maximum of 14,700 cfs was recorded in 1963 for the Little Wind River (period of record, 1942 through 1983) (USGS, 1984a).

Evidence of extensive channel migration by the Wind and Little Wind Rivers can be seen by viewing historical sets of aerial photographs. These photographs show paleo-channels from the Wind River on or near the tailings site and meander scars from the Little Wind River within 0.42 mile of the site. The thalweg of the largest paleo-channel from the Wind River (hereafter referred to as the meander scar) is 2,100 feet southwest of the site (SHB, 1985).

The Wind River has a mixed load channel typical of rivers in which the bed load forms a significant part of the total load. It has an irregular, single-phase, meandering pattern that locally is semi-confined by the valley sides. Common bars and islands result from cutoff meander loops. In contrast, the Little Wind River has a suspended load channel typical of rivers in which the bed load forms a small part of the total load. The single-phase, meandering channel is more deeply incised than the Wind River (SHB, 1985).

The Wind River is the main source of water for Riverton's municipal uses during the spring and summer (April through October). During the fall and winter, the city's only source of water is its well system which taps the confined aquifer of the Wind River Formation (Scott, 1987). The waters of both the Wind and Little Wind Rivers are used locally for irrigation and livestock watering.

The USGS has monitored water quality from 1950 to the present at the gauging stations on the Wind and Little Wind Rivers downstream of the Riverton site (USGS, 1984b). The Wind River gauging station is 1.4 miles upstream from the confluence of the two rivers, and the Little Wind River gauging station is 1.8 miles upstream from the rivers' confluence. The levels of sulfate in the Little Wind River exceeded the Federal secondary standard of 250 mg/l during periods of low flow (40 CFR Parts 141 and 143). The USGS monitoring data (USGS, 1984b) show no increases of contaminants in either river due to the presence of the tailings pile during periods of normal or high flow; however, these data indicate that the concentration of sulfate in the Little Wind River may be slightly increased during periods of low flow due to the discharge of contaminated ground water. More recent water-quality data indicate no perceptible contamination of the Little Wind River due to the discharge of contaminated ground water (Section C.1.3.1 of Appendix C, Water).

A radiological survey of the tailings site showed slightly increased levels of radium-226 (Ra-226) downstream of the tailings pile in the irrigation canal along the northern edge of the pile;

however, samples taken from the drainage ditch west of the tailings pile showed no significant increase in Ra-226 downstream of the pile (FBDU, 1981). None of the samples contained Ra-226 concentrations that exceeded the State of Wyoming's allowable limit of 5 picoCuries per liter (pCi/l) (WDEQ, 1983b).

Dry Cheyenne alternate disposal site

The Dry Cheyenne alternate disposal site is within the Wind River basin on an east-facing slope at the head of a small, ephemeral tributary to Dry Cheyenne Creek (Figure 3.3). The site is 11 miles east of the confluence of the Wind and Little Wind Rivers. Surface-water flows occur only during rainfall and snowmelt. No data on historical flows or water quality are available.

Borrow sites

Surface-water information for the Little Wind borrow site is the same as that provided for the tailings site. Small ephemeral tributaries of the Little Wind River drain the borrow site, but flows occur only during rainfall and snowmelt. No data on historical flows or water quality are available for this borrow site.

Borrow site 2 is immediately north of the tailings pile. Surface-water information for this borrow site is the same as that provided for the tailings site.

Borrow site 10 is near the head of a small ephemeral tributary to Kirby Draw. Surface-water flows occur only during rainfall and snowmelt, and earthen dams have been built across the small drainages northeast and southeast of the borrow site to impound the ephemeral flows for livestock and wildlife. No data on historical flows or water quality are available for borrow site 10.

The Boulder Flats borrow site is on a terrace north of and above the North Popo Agie River. The Reynolds Ditch taps the river west of the site and courses generally due east to dead-end south of the site. This ditch provides irrigation water for small agricultural plots, pastures, and gardens during the spring and summer. The flows in the Reynolds Ditch are intermittent, and water-quality data are not available.

Floodplains

The 500-year flood flows in the Wind and Little Wind Rivers would have upper limits of 18,164 cfs and 24,233 cfs, respectively (USGS, 1984c). These flow rates were used in the HEC-2 computer model (COE, 1982) to determine the surface-water elevations of the 500-year floods. The HEC-2 analysis was performed separately for each river because interflow between the rivers at these upper limits does not occur until downstream of the tailings site near the present confluence of the rivers.

The 500-year flood flow in the Wind River has estimated surface-water elevations in the vicinity of the tailings site ranging from 4,940 to 4,944.5 feet above mean sea level. These elevations are not high enough for flow over the escarpment directly north of the road that runs along the northern boundary of the tailings site nor are they high enough for flow to enter the old meander scar southwest of the site. The flow levels would approach within 2,000 feet of the edge of the tailings pile and within 800 feet of the northern boundary of the tailings site. The 500-year flood flow in the Little Wind River has a computed surface-water elevation in the vicinity of the site of 4,930 feet above sea level. At this elevation, the flow level would be 3,500 feet from the boundary of the tailings site. The analysis revealed that the tailings site (including borrow site 2) and the adjacent areas of windblown tailings are not located within the 500-year floodplain of either river.

The Dry Cheyenne alternate disposal site and borrow site 10 are not near any floodplains, and visual inspections of the sites did not reveal the presence of any floodplains. The Little Wind borrow site is 60 to 80 feet above the Little Wind River, and calculation of the 500-year flood elevation for the Little Wind River revealed that the borrow site is not within the floodplain of the river. The Boulder Flats borrow site is above the floodplain of the North Popo Agie River (Gooley, 1985).

3.6.2 Ground water

Existing ground-water conditions at the Riverton tailings site, Dry Cheyenne alternate disposal site, and the proposed borrow sites are summarized in this section. Ground-water data for the sites and detailed analyses of these data are presented in Section C.2 of Appendix C, Water.

Riverton tailings site

Ground water occurs under unconfined and confined conditions within the alluvial deposits and the sedimentary strata of the Wind River Formation in the Riverton area. Two ground-water systems have been identified in the vicinity of the tailings site. An unconfined system exists in the shallow, alluvial deposits and the hydrologically connected, upper sandstone unit of the Wind River Formation. A confined system exists in the deeper sandstone strata of the Wind River Formation.

The stratigraphy of the unconfined aquifer at the Riverton site varies (Section C.2.4.1 of Appendix C, Water). Directly beneath the entire tailings pile, the discontinuous, fine-grained foundation materials consist of brown and gray layers of silty sands from zero to 3 feet thick. These foundation materials are underlain by a deposit of cobbly alluvium, and, under the eastern side of the pile, the cobbly alluvium and foundation materials are separated by sandy gravel (CSU, 1983a). The alluvial deposit beneath the pile is 20 feet thick with a saturated thickness of 14 feet (i.e., the water table is 6 feet below the natural ground surface). The pile and foundation material are underlain by 6 to 10 feet of shale, sandy shale, or claystone (FBD, 1983a). Between the tailings pile and the inactive mill facilities, the alluvium is 14.5 feet thick and is underlain by 12 to 14 feet of saturated sandstone.

The ground-water flow direction in the unconfined aquifer is predominantly to the south-southeast toward the Little Wind River. The hydraulic gradient is 12 feet per mile or 0.0023. Recharge to the aquifer is from precipitation, snowmelt, and irrigation seepage. The ground water discharges into the Little Wind River 2,800 feet downgradient from the tailings site (LBL, 1984). A pump test in the entire saturated thickness of the unconfined aquifer had a sustained yield of 5 gallons per minute (gpm) for 24 hours with a total drawdown of 4.08 feet at the pump well.

Beneath the saturated sandstone of the unconfined aquifer lie 12 to 24 feet of saturated siltstones and shales. These strata act as an aquitard between the unconfined and confined aquifers, and cores from these strata revealed no evidence of fracturing in the 12- to 24-foot interval. Below the saturated siltstones and shales lie 13.5 to 16 feet of sandstone which represents the top of the confined ground-water system. Within the confined aquifer, interbedded layers and lenses of shale, siltstone, and mudstone confine the ground water in the sandstone beds; however, the entire sequence can behave as a single aquifer in response to long-term stresses (FBDU, 1981).

Intensive use of the confined aquifer by the city of Riverton has formed a cone of depression around the city well field which is located in an area 1.5 to 9 miles north and northeast of the tailings site. This has reversed the confined hydraulic gradients to the northeast (CSU, 1983b), and USGS Map HA-270 (Whitcomb and Lowry, 1968) shows a hydraulic gradient of 0.0455. Recharge occurs along outcrops of the Wind River Formation sandstones and apparently is insufficient to replace the water withdrawn from municipal and other privately owned wells (Anderson and Kelly, 1976). The water levels in 500- to 800-foot deep municipal wells have dropped 60 to 70 feet during the last 50 years (FBDU, 1981).

Communication between the unconfined aquifer and the first two confined sandstone units was assessed by conducting pump tests and analyzing water samples for radiogenic tritium. Two 24-hour pump tests did not reveal any appreciable changes in water levels in the unstressed system while pumping either the unconfined or confined system. However, studies conducted by the State of Wyoming show that communication does exist between the unconfined aquifer and the first confined sandstone units (Askew, 1987).

The concentrations of three constituents were consistently higher than background concentrations in the unconfined aquifer beneath and downgradient of the tailings pile. Measured concentrations of sulfate, uranium, and molybdenum were as high as 5,510, 2.4, and 3.7 mg/l, respectively. The maximum sulfate concentration is greater than the Federal secondary standard and the Wyoming Class I (domestic), II (agriculture), and II (livestock) standards. The maximum uranium concentration is within the Wyoming Class I, II, and III standards but exceeds the recommended health advisory level (Cothern et al., 1983). There are no Federal or Wyoming standards for molybdenum in ground water (40 CFR Parts 141 and 143; WDEQ, 1980). In addition, concentrations of arsenic, chromium, thorium230, radium, iron, selenium, and manganese were higher than background concentrations in some samples from the unconfined aquifer. The area of contamination in the unconfined aquifer is between the former mill and ore storage areas and the Little Wind River (Figures 3.9 through 3.11).

The concentrations of uranium and sulfate in the unconfined aquifer are greater at the Little Wind River than beneath the tailings site. This indicates that the contamination in the unconfined aquifer is due primarily to percolating leachate generated by the natural dewatering of the tailings during and after the uranium milling. Lesser but continuing ground-water contamination is caused by precipitation filtering through the tailings pile and possibly by the shallow ground water rising into the lower portions of the pile.

Water samples from the confined aquifer were taken from on-site monitor wells and local domestic wells. Concentrations of total dissolved solids (TDS) were generally greater than the Wyoming Class I standard but within the Class II and III standards. The Federal standards and the Wyoming Class I standards are almost identical (Section C.2.4.4 of Appendix C, Water). Sulfate concentrations in the on-site monitor wells were greater than the Wyoming Class I and II standards but within the Class III standard. Sulfate concentrations in the domestic wells varied; however, all were greater than the Wyoming Class I and II standards but within the Class III standard. Uranium concentrations in all of the wells were within the Wyoming Class I standard, but the concentrations in the on-site monitor wells were higher than those in the domestic wells (WDEQ, 1974).

Presently, the unconfined aquifer is not used downgradient of the tailings site. Some shallow wells upgradient of the site and beyond the Little Wind River are used for stock watering, and the Little Wind River is used for irrigation (Scott, 1987).

The city of Riverton is the principal user of the confined aquifer in the area. The city's eleven wells are located upgradient in an area 1.5 to 9 miles north and northeast of the tailings site. The wells have a combined annual yield in the range of 475 to 500 million gallons (Scott, 1987). The major non-municipal usage occurs at the sulfuric acid plant at the tailings site and approximates 42 million gallons per year (Larson, 1987). A golf course west of Riverton uses two wells for irrigation with an estimated annual pumpage of 13 million gallons (McFarland, 1987), and an estimated 15 to 25 million additional gallons per year (based on discharge rates) are withdrawn from privately owned, domestic wells in suburban areas (Anderson and Kelly, 1976).

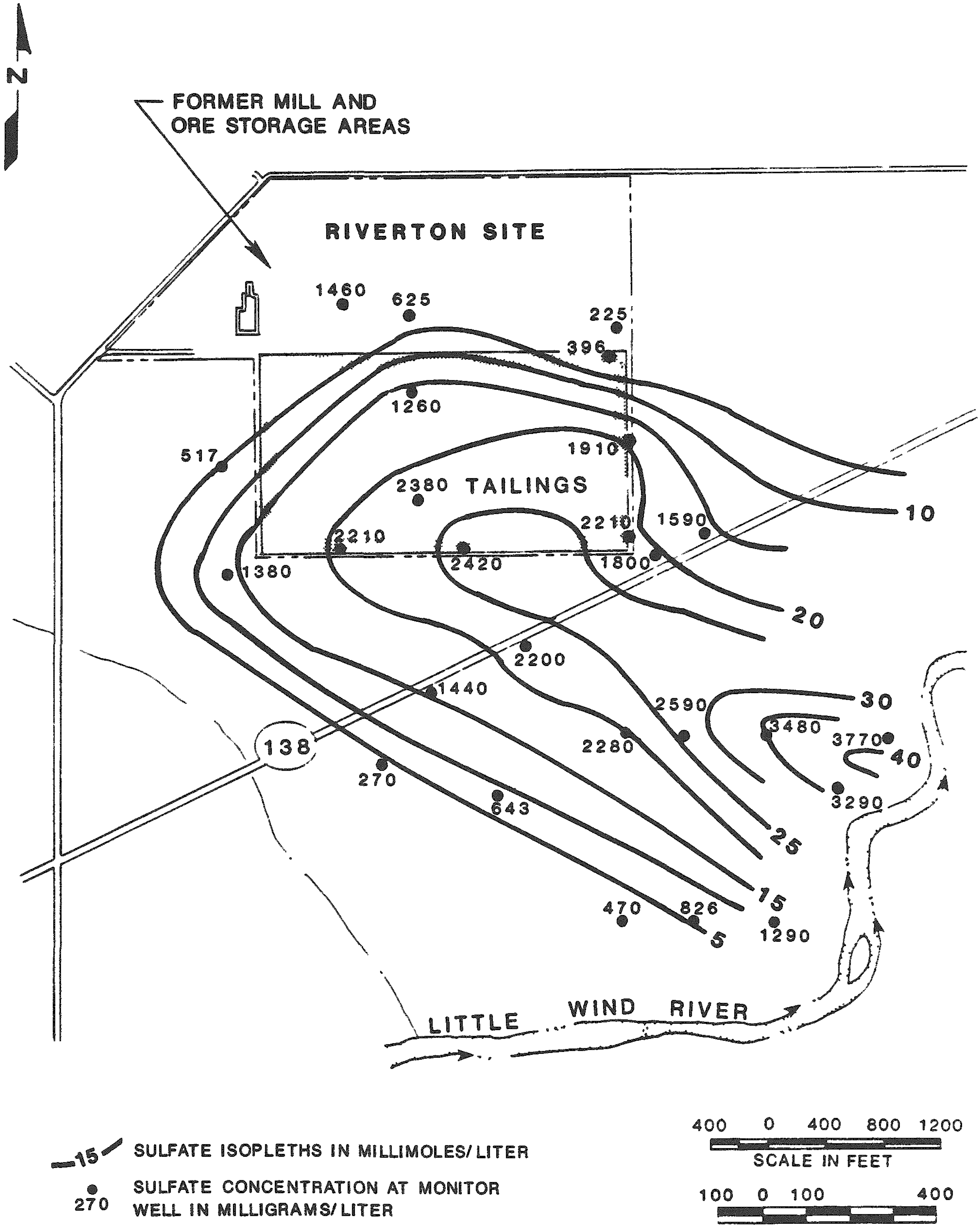


FIGURE 3.9
SULFATE PLUME AT THE RIVERTON SITE

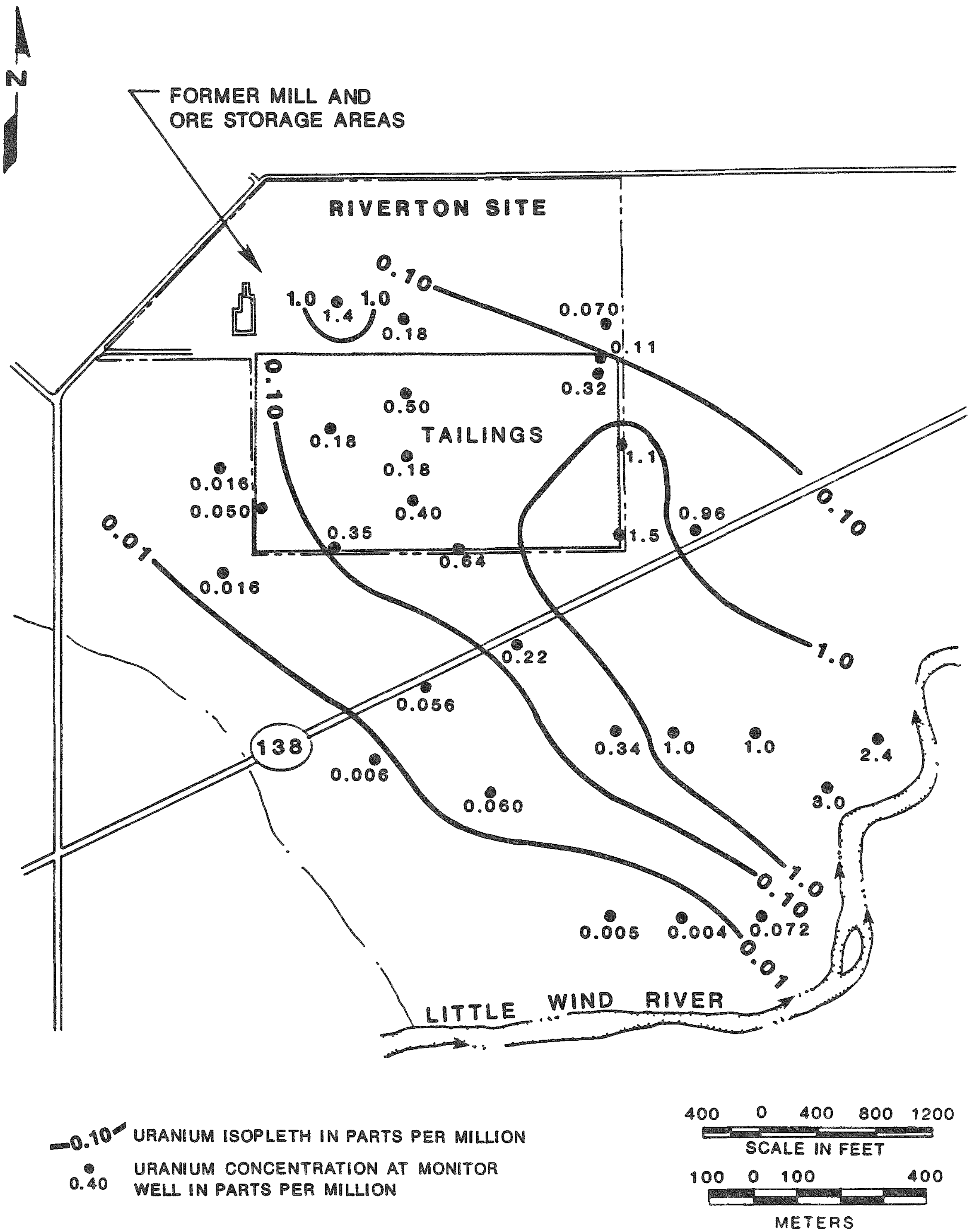


FIGURE 3.10
URANIUM PLUME AT THE RIVERTON SITE

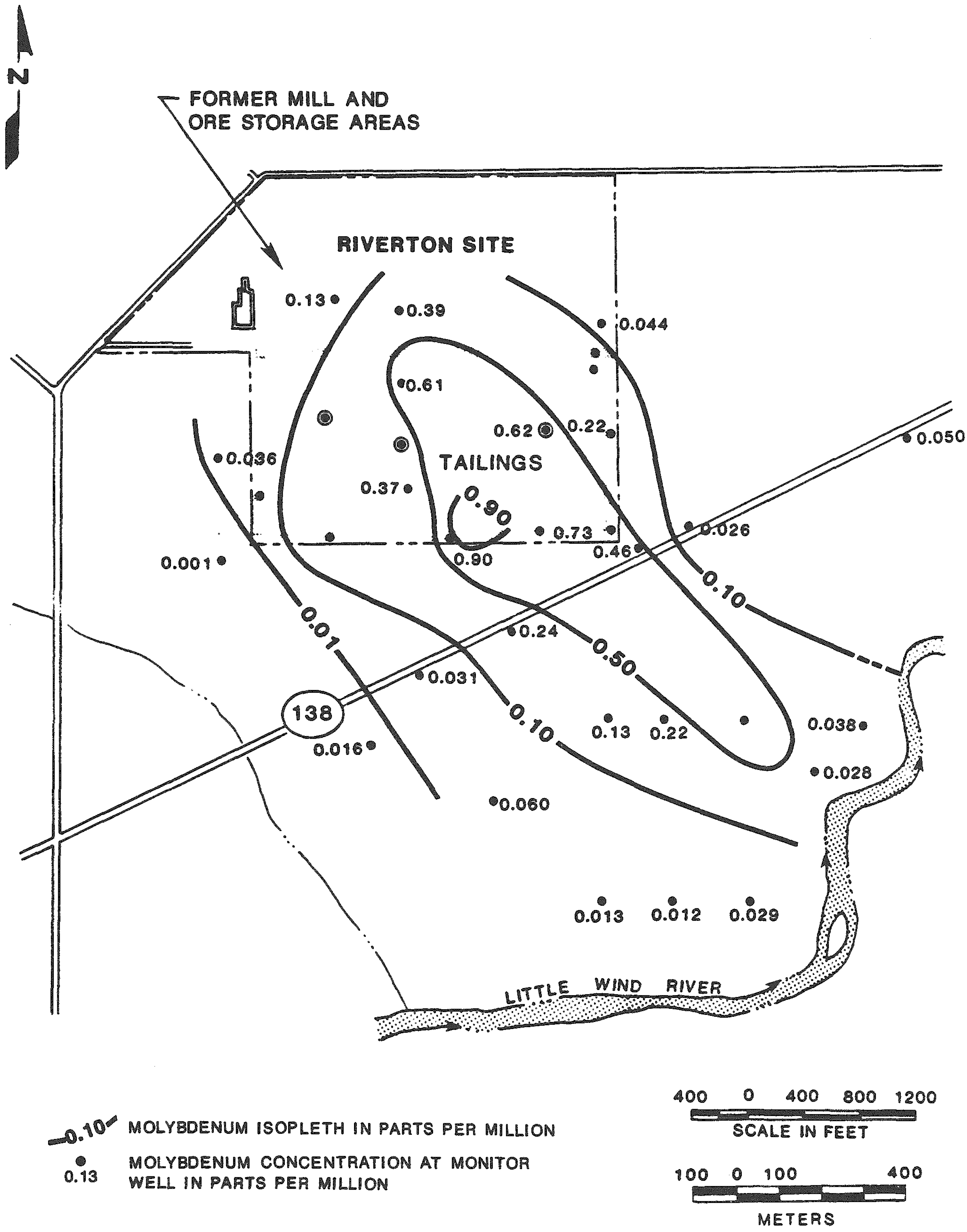


FIGURE 3.11
MOLYBDENUM PLUME AT THE RIVERTON SITE

Dry Cheyenne alternate disposal site

No ground-water data have been collected at the Dry Cheyenne site; however, one well was drilled approximately 1 mile south of the site. This well was dry; no additional well information is available (Packer, 1984). Four other water wells were drilled 5 to 8 miles southeast and southwest of the site. The water producing zones in these wells are from 55 to 402 feet below the ground surface, and yields range from 1 to 50 gpm. Two of the wells had TDS concentrations of 4,130 and 5,500 mg/l (Kelly, 1984). The Wyoming Class III standard for TDS is 5,000 mg/l (WDEQ, 1980).

Borrow sites

No test pits or borings were completed at the Little Wind borrow site so the depth to ground water at the site is unknown. There is no other available ground-water information for this borrow site. The ground-water conditions at borrow site 2 would be the same as those described for the tailings site.

Test pits and borings at borrow site 10 reached a maximum depth of 31 feet. No ground water was encountered in these pits and borings, and there is no other available ground-water information for this site.

The Boulder Flats borrow site is just north of an active gravel pit operated by the Wyoming Highway Department. This pit is 15 to 18 feet deep, and no ground water has been encountered. The Wyoming Highway Department has conducted an exploratory drilling program at the Boulder Flats borrow site. The boreholes penetrated shale bedrock at a depth of 40 feet and indicated that ground water could be encountered at depths of 20 to 40 feet (Darr, 1985). There is no other ground-water information for this borrow site.

3.7 ECOSYSTEMS

The Riverton tailings site, Gas Hills, and Dry Cheyenne alternate disposal site have a semi-arid to arid, high-desert environment. Vegetation includes typical low desert shrubs, grasses, and forbs. The riparian zones along the Wind and Little Wind Rivers contain dense populations of cottonwood, Russian olive, and willow trees. Appendix D, Ecosystems, contains detailed listings of the plant and animal species that could be found at or in the vicinity of the Riverton, Dry Cheyenne, and borrow sites.

Riverton tailings site

The tailings site, including the large empty fields north of the tailings pile, has been severely disturbed. As a result, 30 percent of the plant species at the site are of the primary succession type that invade disturbed areas, such as Russian knapweed and Swainson's pea. Typical native species include wheatgrass, sand dropseed, big sagebrush, and rabbitbrush (FBD, 1983a).

There are no wildlife data for the area around the tailings site as no surveys or inventories have been conducted. Human activity in and around the area discourages use of the area by wildlife; however, the marshy areas nearby contain pheasant, chukar, hawk, owl, blackbird, small game, and ground-dwelling rodent populations (Baldes, 1984). Mule deer and white-tailed deer are confined mainly to the riparian zone along the Wind River and brushy drainages approximately 1 mile from the site (WGFD, 1983).

Reptiles found in the area are the short-horned lizard and the fence lizard. The garter snake is likely to occur in the marshy areas adjacent to the site. Depending on seasonal weather conditions and runoff, the marshes contain water intermittently and could provide breeding habitats for amphibians such as the leopard frog and spadefoot toad (Behler and King, 1979).

A large variety of waterfowl, including many riparian species, are found along the rivers and adjacent marshy areas. Canadian geese and snow geese as well as many duck and shorebird species are common in these areas (WGFD, 1983).

The Wind and Little Wind Rivers contain rainbow, brown, and brook trout, three species of suckers, carp, flathead chub, and the longnose dace (BLM, 1984). Any of these fishes could be found in the canals and ditches adjacent to the tailings site depending on the availability and source of the water in these drainage courses.

Dry Cheyenne alternate disposal site

This site is relatively undisturbed and supports a diverse population of plants, almost all of which are native. Low desert shrubs cover about 50 percent of the ground surface and include big sagebrush, black sagebrush, fringed sagewort, rubber rabbitbrush, Douglas rabbitbrush, and several small, mat-forming species. Grasses found in the area include blue grama, galleta, and Indian ricegrass. A few small forbs common to the area are vetch, fleabane, aster, and phlox. Patches of prickly pear cactus are abundant in some areas. Species such as snakeweed and Patagonia Indian wheat are present and indicate overgrazing (FBD, 1983a).

Some of the more common small mammals to be found are the kangaroo rat, white-tailed jackrabbit, pocket gopher, cottontail rabbit, and ground squirrel. Common birds include the American kestrel, mourning dove, meadowlark, red-tailed hawk, raven, and blackbird. Reptiles include the bullsnake, prairie rattlesnake, short-horned lizard, and sagebrush lizard. No waterfowl or amphibians are likely to be present due to the lack of standing water (BLM, 1984).

Although not confirmed by field studies, the habitat in the area of the disposal site may be important winter range for pronghorn antelope which use mainly black sagebrush and big sagebrush as forage. There is also a possibility that mule deer may use surface drainages in the area as winter range (Welch, 1984).

Sage grouse have been found in the area around the alternate disposal site. This game bird species breeds exclusively in sagebrush-shrubland habitat and is a year-round resident. Nesting usually occurs within 2 miles of a lek (a mating and display area). Some of the surface drainages near the site may provide suitable habitat for these leks; however, none have been identified (FBD, 1983a). During a September, 1984, reconnaissance of the site, sage grouse scat were found at a few locations, but no grouse were observed (Peel, 1984).

Borrow sites

The plants and animals at the Little Wind borrow site and borrow site 2 are the same as those described for the Riverton tailings site. Borrow site 10 is ecologically quite similar to the Dry Cheyenne alternate disposal site, and the plant and animal species present at this site are also very similar. This site is not important winter range for pronghorn antelope or mule deer. The site includes habitat suitable for use as leks by sage grouse (Welch, 1984).

The Boulder Flats borrow site is located in a transition zone between the sagebrush-shrubland habitat of the Sand Hills to the northeast and the riparian habitat of the North Popo Agie River to the southwest. The Boulder Flats borrow site could therefore have a mixture of plant and animal species common to both types of habitat (i.e., common to the Riverton tailings site and the Dry Cheyenne disposal site) (Baldes, 1985; Hockley, 1985).

Wetlands

Consultations with the U.S. Army Corps of Engineers (COE) and the U.S. Fish and Wildlife Service (FWS) have confirmed that there are no wetlands at or in the vicinity of the Riverton tailings site, borrow sites 2 and 10, and the Boulder Flats borrow site (Anderson, 1985a,b, 1984; Gooley, 1985; Miller, 1984). Therefore, species commonly associated with wetlands or riparian habitats would not be found at the borrow sites as permanent residents. Earthen dams have been built across the small drainages northeast and southeast of borrow site 10 to impound the ephemeral surface-water flows and provide important sources of water for wildlife and livestock (Anderson, 1984). The Little Wind borrow site (Figure 3.4) is adjacent to the riparian zone along the Little Wind River that contains dense populations of cottonwood, Russian olive, and willow trees; the FWS has indicated that wetlands or riparian habitats would not exist more than 300 feet from the river (Street, 1987). The Dry Cheyenne alternate disposal site is not near any wetlands or riparian areas, and no riparian species were observed during an inspection of the site (Peel, 1984).

Threatened and endangered species

Both the Dry Cheyenne alternate disposal site and borrow site 10 contain habitat possibly suitable for Artemisia porteri (Porter sagebrush) and Cryptantha subcapitata (no common name). Porter sagebrush was proposed for listing as threatened in the Federal Register (40 FR 27887) of July 1, 1975 (Clark and Dorn, 1979). The species is, however, more abundant than was previously believed and is not subject to any identifiable threat (FWS, 1985). The forb Cryptantha subcapitata is currently under review by the FWS as a Category 2 species (current information indicates, but does not adequately support, the probably appropriate listing as threatened or endangered) (FWS, 1985), and the species is considered rare in Wyoming (Clark and Dorn, 1979).

The bald eagle (Haliaeetus leucocephalus) and peregrine falcon (Falco peregrinus anatum) are listed as endangered species by the FWS (Harms, 1984; FWS, 1983). The FWS and the Wyoming Game and Fish Department report no nesting sites for these species in the Riverton area; however, both agencies agree that these birds could occur in the area as transients or migrants. Bald eagles are known to winter along the Wind River approximately 35 miles northwest of Riverton, but the closest known nesting sites are on the Big Horn River in the northern part of the state (Harms, 1984; Oakleaf, 1984; WGFD, 1983). No bald eagle nests were found during a September, 1984, reconnaissance of the tailings site, Dry Cheyenne alternate disposal site, and borrow sites 2 and 10 (Peel, 1984). The closest peregrine falcon nesting sites are in the Wind River Canyon area 35 miles north of Riverton (Harms, 1984; Oakleaf, 1984; WGFD, 1983).

Bald eagles and peregrine falcons could occur at or around the Boulder Flats borrow site (Taylor, 1985). However, this area does not have significant habitat for these species, and any occurrences of these species would be as transients or migrants. Some bald eagles may winter in the area surrounding the borrow site, but there is no documentation of any sightings or significant populations of either species in the area (Oakleaf, 1985).

The black-footed ferret (Mustela nigripes) is listed as an endangered species by the FWS (Taylor, 1985; Harms, 1984; FWS, 1983). The black-footed ferret occurs only in or near prairie dog towns. The presence of prairie dogs at or around the Riverton tailings site is unlikely due to the presence of human activity, and none have been found at the site. The Dry Cheyenne alternate disposal site and borrow site 10 contain habitat suitable for prairie dogs, but none have been sighted at either site (Peel, 1984). The presence of the black-footed ferret at any of these sites is unlikely due to the lack of prairie dog towns.

The black-footed ferret could occur at or around the Boulder Flats borrow site (Taylor, 1985). There is no information on the presence of prairie dog towns or black-footed ferrets at the Boulder Flats borrow site.

There are no data on the presence of threatened and endangered species at the Little Wind borrow site and in the area adjacent to the transportation route to Gas Hills Wyoming State Highway 136. Due to the locations of the borrow site and highway, it is expected that the above discussions for threatened and endangered species at the Riverton and Dry Cheyenne sites would apply to this borrow site and highway.

3.8 RADIATION

The existing radiation levels at the Riverton tailings site, Gas Hills, and the Dry Cheyenne alternate disposal site are discussed below. Section F.1 of Appendix F, Radiation, contains detailed discussions of radiation and radiation measurements.

3.8.1 Background radiation

Radioactive elements occur naturally throughout the air, water, soil, and rock of the earth. The concentrations of these elements vary greatly throughout the United States, and the concentrations in the Riverton area are generally higher than the averages for other areas because of local mineralization.

The background gamma radiation exposure rate was measured at three locations 10 to 20 miles from the Riverton tailings site. The average background gamma exposure rate from both terrestrial and cosmic sources, measured at 3 feet above the ground, is 13 microroentgens per hour (microR/hr) with a range of 12 to 13 microR/hr (ORNL, 1980). Cosmic rays (radiation from the sun and other sources external to the earth) contribute approximately 7.7 microR/hr (55 percent) of the 13 microR/hr background gamma exposure rate in the Riverton area (EG&G, 1983).

The average outdoor background radon concentration in the Riverton area is 1.1 pCi/l based on measurements at two locations southwest and north of Riverton. The range of radon concentrations for these 24-hour samples was 0.8 to 1.3 pCi/l (FBDU, 1977; Mound, 1985, 1984).

The average background concentration of radioactive particulates in air has not been measured in the Riverton area. Due to the lack of any sources for emissions of radioactive particulates, it can be assumed that the average background concentration would be essentially zero.

The average background levels of radiation in ground and surface waters in the Riverton area can be estimated from the concentrations of Ra-226 in water samples taken upgradient of the tailings pile. The maximum Ra-226 concentrations in upgradient domestic water wells completed in the confined aquifer of the Wind River Formation were measured to be less than 1.0 pCi/l (Section C.2.4 of Appendix C, Water). Two surface-water samples taken from a drainage ditch northeast and immediately upstream of the tailings pile had Ra-226 concentrations of 0.141 and 0.206 pCi/l (GECR, 1983). Samples taken from the Little Wind River upstream of the tailings site had Ra-226 concentrations of 0.4 pCi/l (Section C.1.3 of Appendix C, Water).

Background soil radioactivity levels typical of the Riverton area and not influenced by the Riverton tailings pile have been established as 0.9 picoCurie per gram (pCi/g) for Ra-226. These levels were determined from samples taken at the same three locations used to measure the background gamma radiation exposure rate (ORNL, 1980).

3.8.2 Radiation levels

Riverton tailings site

The average Ra-226 content of the tailings pile and the existing earthen cover is 342 pCi/g (Section F.3 of Appendix F, Radiation). The Ra-226 concentrations ranged from 180 to 1,200 pCi/g (BFEC, 1983a). The thorium-230 (Th-230) concentrations of the tailings pile were not measured; however, if the Ra-226 is in equilibrium with the Th-230, the average Th-230 concentration would be approximately 342 pCi/g. The uranium-238 (U-238) content of the tailings pile is 25 pCi/g (MSRD, 1982).

Gamma radiation exposure rates have been measured around the Riverton tailings site by many organizations (EG&G, 1983; BFEC, 1983b; ORNL, 1980; EPA, 1977), and all reported rates are in general agreement. Over the eastern half of the mill site, the gamma exposure ranges from 180 to 360 microR/hr. Over the western half of the pile and around the edges of the ore storage area, the exposure rates range from 90 to 180 microR/hr. Along a band about 200 feet wide ringing the entire site, the exposure rate is about 60 to 90 microR/hr. To the southeast of the pile, extending about 2,000 feet, is an area of windblown contamination producing an exposure rate of 20 to 60 microR/hr. Background gamma exposure rates are reached within about 1,000 feet of the pile in all other directions.

Radon flux through the cover of the existing pile ranges from 51 to 81 picoCuries per square meter per second (pCi/m^2s), with an area averaged flux of 65 pCi/m^2s (FBDU, 1977). The radon flux source term was calculated using the RAECOM model (NRC, 1984). The calculation resulted in an annual average radon flux of 210 pCi/m^2s from the bare tailings based upon an average Ra-226 concentration of 342 pCi/g. Using a tailings pile surface area of 70 acres, the radon flux of 210 pCi/m^2s is equivalent to a radon source term of 1,880 Curies per year.

The soil beneath the tailings pile exceeds the EPA standard of 15 pCi/g of Ra-226 to an average depth of about 3 feet. The Ra-226 concentration in this material ranges from 4 to 1,300 pCi/g based on data from the analyses of interface samples collected by Mountain States Research and Development (MSRD, 1982).

Dispersion of the tailings by wind and water erosion has contaminated soils adjacent to the tailings pile. A field survey of the designated tailings site and the area surrounding it was conducted to determine the areal extent of the displaced tailings (BFEC, 1983b). Figure 3.12 shows the areas contaminated by dispersion of the tailings (96 acres) as well as the contaminated ore storage and mill areas (22 acres) within the designated tailings site.

Along the eastern half of the ore storage area, contaminated material is relatively shallow, less than 1 foot deep. Along the western half of the ore storage area, and over most of the mill area, the contaminated material ranges from 2 to 4 feet in depth.

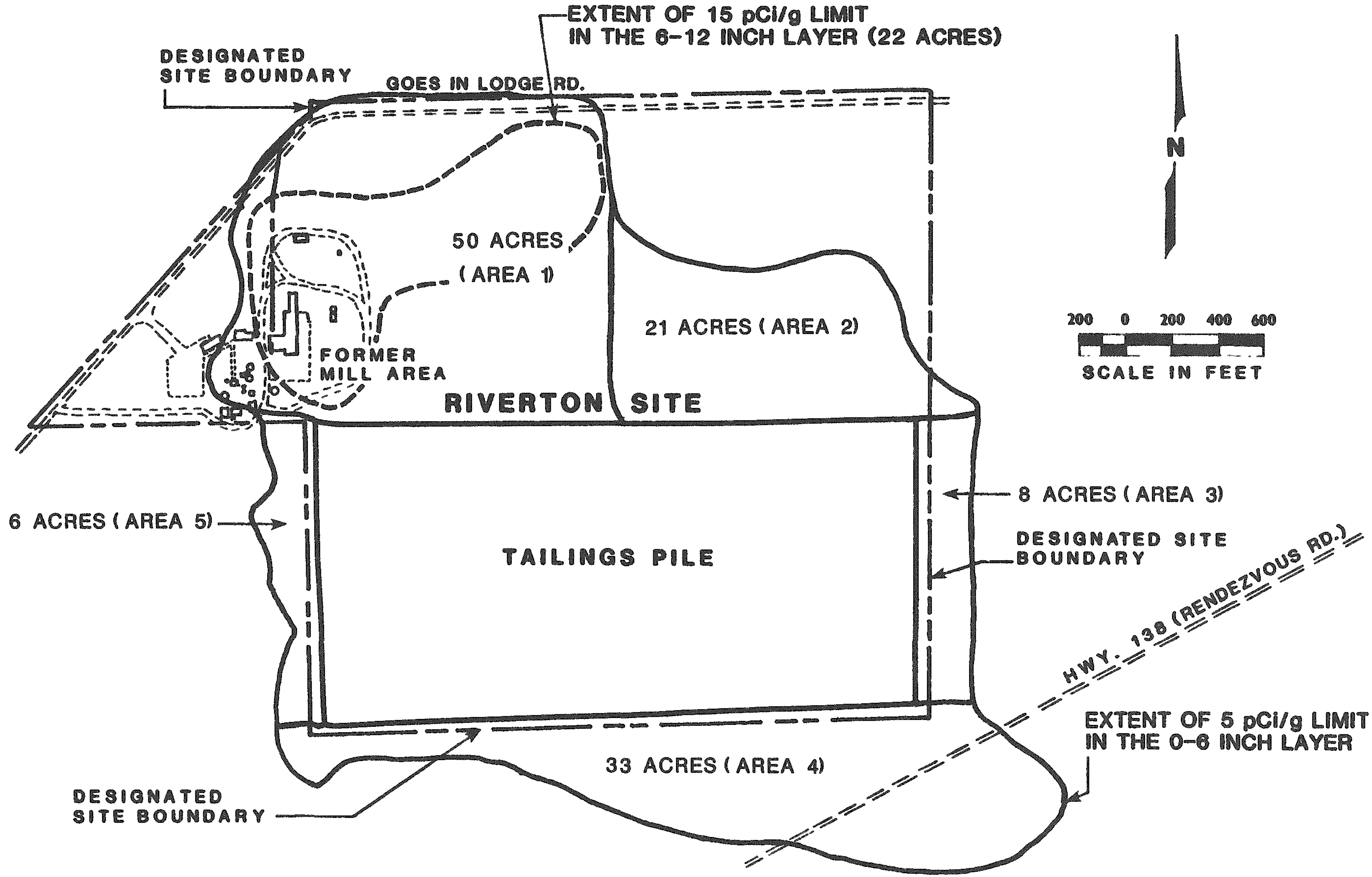


FIGURE 3.12
LIMITS OF EXCAVATION FOR THE WINDBLOWN AREA, RIVERTON SITE

Contamination in these areas is slightly elevated above the EPA standard for radium in soil with isolated spots of higher activity. Windblown contamination around the tailings pile consists of diluted tailings and is generally slightly elevated above the EPA standard. The total number of acres of off-pile contamination is approximately 118 acres (BFEC, 1983b).

Dry Cheyenne alternate disposal site

No data exist on the background gamma exposure rate and Ra-226 concentration in soil at the Dry Cheyenne alternate disposal site. The site is believed to have radiation levels typical of non-mineralized areas near Riverton. These are 13 microR/hr for gamma exposure at 3 feet above the ground surface and 0.9 pCi/g for Ra-226 (ORNL, 1980). The background radon concentration at the site was measured from July through October of 1984 and averaged 1.26 pCi/l (Mound, 1984).

3.9 LAND USE

Over 90 percent of the total acreage of Fremont County (9 million acres) is in agricultural use, with over 5 million acres being nonirrigated rangeland used for grazing purposes. Roughly 216,000 acres are in irrigated agricultural use, with about 10 percent of this total used as cropland and the remaining 90 percent used for pasture and hay production (Fremont County Planning Commission, 1978).

Nearly 1 million acres in Fremont County are managed by the U.S. Forest Service. Of this total, 321,000 acres are classified as commercial forest by the U.S. Forest Service. The nearly 1.9 million-acre Wind River Indian Reservation lies mostly in Fremont County, with some acreage extending into Hot Springs County (FBD, 1983a).

As of 1978, the six incorporated municipalities in Fremont County encompassed 8,475 acres, with this total expanding yearly due to annexations of surrounding areas by the municipalities. Approximately 49 percent of this urban acreage is undeveloped land within the municipalities' boundaries (Fremont County Planning Commission, 1978).

The predominant land use in the immediate vicinity of the existing tailings site is agricultural (Figure 3.13), with hay the primary crop. The active sulfuric acid plant is immediately adjacent to the former mill area northwest of the tailings pile. A number of residences exist along the tailing site's northern and southern boundaries and residential development is just northwest of the site. The St. Stephen's Mission School, a contract school for the Bureau of Indian Affairs (BIA), is 0.6 mile from the site. The lands surrounding the tailings site are generally owned by the Arapahoe and Shoshone Indian Tribes, although there are scattered sections of fee land as well.

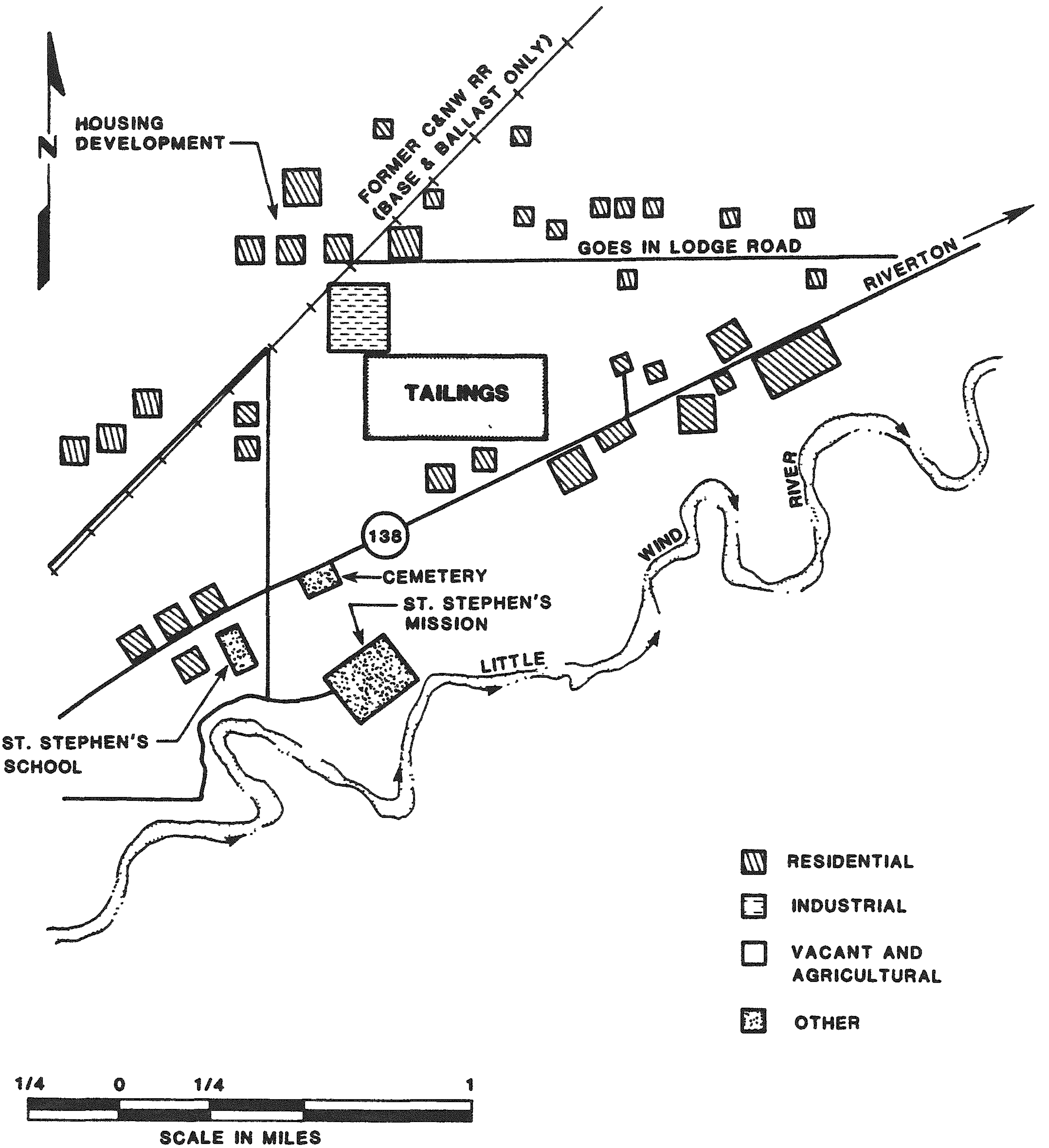


FIGURE 3.13
LAND USE AROUND THE RIVERTON SITE

There are both Indian tribal lands (administered by the Arapahoe-Shoshone Joint Business Council) and Indian allotted lands (reserved for use by individual Indians or allottees) in the vicinity of the existing tailings site. Reportedly, most of the allottees are living on the allotted lands rather than leasing them for other purposes such as grazing. In terms of land use plans and policies for the area around the tailings site, the controlling factor is a tribal zoning ordinance administered by the Arapahoe-Shoshone Joint Business Council. This ordinance governs virtually all types of development activity (e.g., trader permits, concessions, and residential development) within the boundaries of the Wind River Indian Reservation, and it effectively halted the residential development on fee land northwest of the tailings site (Price, 1985; Robertson, 1985a).

Gas Hills is an area that contains several active uranium mill tailings sites in the Gas Hills Uranium Mining District. Uranium mining and milling have occurred extensively in the district, but the land is also used for low-density livestock grazing. The district is sparsely populated, the closest urban center being Jeffrey City approximately 30 miles to the south. Gas Hills is 45 to 60 miles east of the Riverton tailings site via Wyoming State Highway 136. The majority of the lands along this highway are managed by the BLM and used primarily for lowdensity livestock grazing and oil and gas exploration and development.

The Dry Cheyenne alternate disposal site is managed by the BLM, with the area in use for low-density grazing. There is oil and gas exploration and development activity in the vicinity, and the site is within a current oil and gas lease (Weber, 1987). However, there is no apparent oil and gas activity on the site at present, and the nearest producing wells are approximately 3 miles from the site. The nearest residence to the site is approximately 4 miles to the northeast.

The Little Wind borrow site and borrow site 2 are privately owned, and land use in the area around these borrow sites is as described above for the tailings site. The primary land use at and near borrow site 10 is low-density grazing. The site is managed by the BLM. There is an active oil and gas lease that covers part of the site, but there is no oil and gas activity on the site at present. There are ongoing oil and gas exploration and production in the general area but not in the immediate site vicinity. There are two natural gas pipelines in the vicinity of borrow site 10, one running parallel to Wyoming State Highway 135 less than 1 mile southwest of the site and the other running diagonally through the borrow site in a northeasterly direction. There are no residences in the immediate area. There is a county landfill on the other side of Wyoming State Highway 135 across from the site (Weber, 1987).

In terms of land use plans and policies for the areas around the Dry Cheyenne alternate disposal site and borrow site 10, both sites and the surrounding areas are managed by the BLM as stated above. According to the BLM, there are no existing or proposed special use lands (e.g., recreational facilities, wilderness areas, and the like) in close proximity to either site, and there are no plans for uses other than those currently in effect (grazing and oil and gas leasing). While land use plans for the areas may change, it is not expected that such changes would involve any new or special uses. More than likely, such changes would consist of shifting the emphasis from one current land use to the other based on the current BLM evaluation of the surface and mineral resources. For example, lands previously promoted for grazing may be promoted for oil and gas leasing (Weber, 1987; Womack, 1985).

The Boulder Flats borrow site is on private land within the Wind River Indian Reservation. The North Popo Agie River runs generally west to east approximately 0.5 mile south of the site and marks the southern boundary of the Reservation. The lands to the east, north, and west of the site are checkerboard Indian tribal and allotted lands and, as with the Riverton tailings site, the controlling factor for land use plans and policies for the area is the tribal zoning ordinance administered by the Arapahoe-Shoshone Joint Business Council. In the vicinity of the borrow site, the land is used primarily for rural residences with some small farms and pasture lands. There is a small commercial campground north of the site, and the Wyoming Highway Department operates a gravel pit just south of the site. U.S. Highway 287 (north-south) passes just west of the site, and the small, rural town of Milford is 1 mile south of the site, across the North Popo Agie River and off of the Wind River Indian Reservation (Robertson, 1985b).

3.10 NOISE LEVELS

A background noise survey was performed in the vicinity of the Riverton tailings site (FBD, 1983a). Noise levels at and around the tailings pile ranged from 50 to 65 decibels (dBA) as recorded on the A-weighted scale which most closely approximates the human ear. Three sensitive noise receptors (residences) are located from 900 to 2,700 feet from the tailings pile. Noise measurements recorded at these three residential areas were 51, 54, and 56 dBA. The highest noise level recorded, 65 dBA, occurred at the intersection of Wyoming State Highways 789 and 138 (Figure 3.2).

Noise measurements were not taken along the transportation route to Gas Hills (Wyoming State Highway 136) and at the Dry Cheyenne alternate disposal site, borrow site 10, and the Little Wind and Boulder Flats borrow sites; however, it is likely that noise levels along this highway and at these sites would generally be lower than those at the Riverton site since they are removed from population centers and major transportation routes. Based on the National Academy of Sciences' method of relating noise levels to population densities, noise levels along Wyoming State Highway 136 and at the Dry Cheyenne site and borrow site 10 (undeveloped rural areas) would be equivalent to an average day-night noise level (Ldn) of 35 dBA (NAS, 1977). The Ldn is a noise rating system which assigns a 10-dBA penalty to the nighttime period to account for the heightened perception to noise during that time. The Little Wind borrow site is 0.5 mile from the St. Stephens Mission, and the Boulder Flats borrow site is 1 mile from the small, rural town of Milford. Using Figure 3.14, it is estimated that the noise level at either of these borrow sites would be 50 dBA.

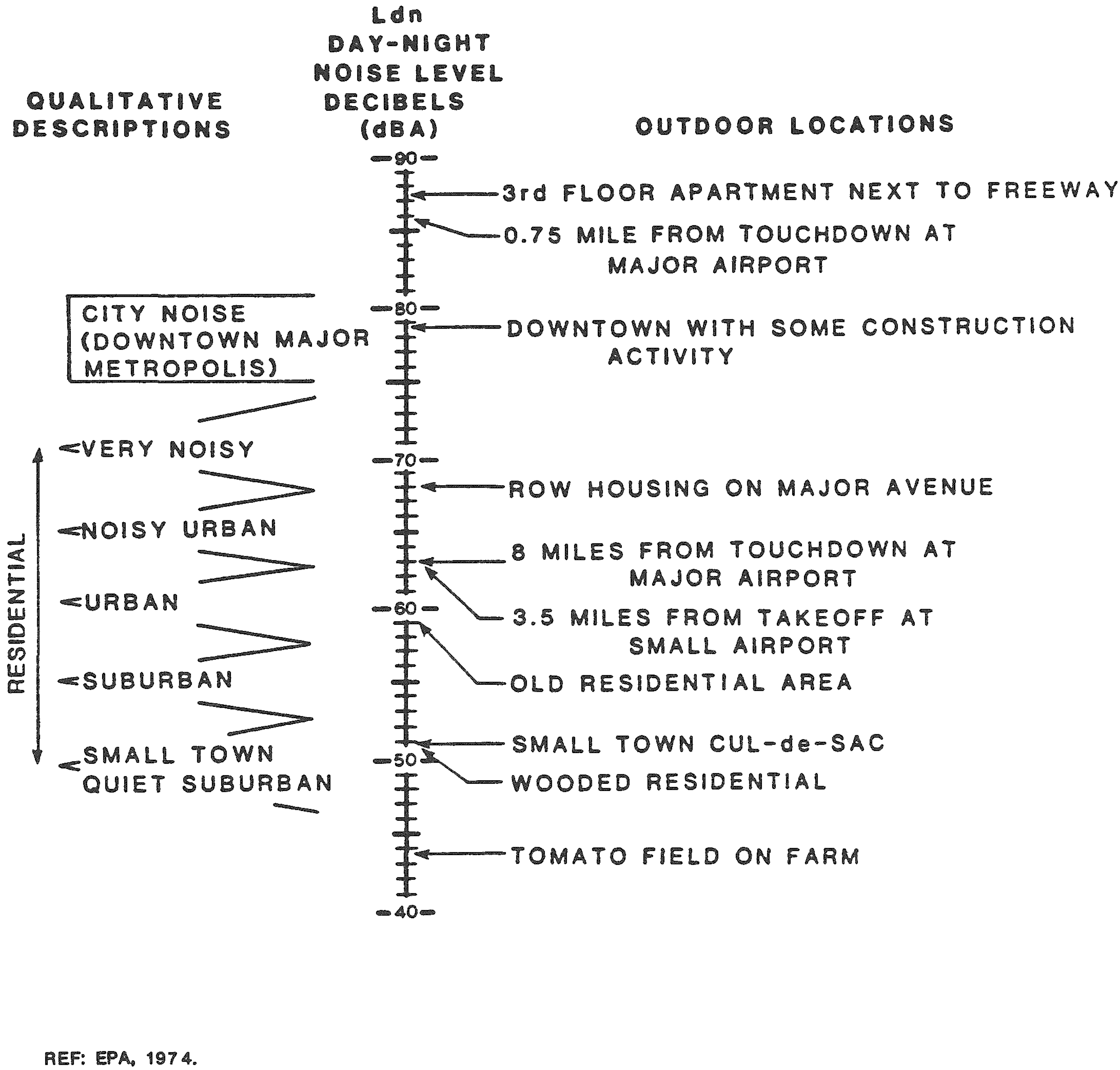


FIGURE 3.14
TYPICAL NOISE LEVELS

3.11 SCENIC AND CULTURAL RESOURCES

3.11.1 Scenic resources

The scenic resources of the Riverton tailings site, Little Wind borrow site, and borrow site 2 are characterized by a combination of suburban and pastoral views with distant vistas of the Wind River Mountains to the west. Noticeable features in the immediate vicinity include the active sulfuric acid plant, the mill building and water tower, St. Stephen's Mission (0.6 mile south of the tailings site), farm lands, pastures, low-density residential areas, and clusters of cottonwood trees. The tailings pile is not visible from the city of Riverton, but it can be seen from nearby residences and the roadway and highways passing by the tailings site.

Scenic resources along the transportation route to Gas Hills (Wyoming State Highway 136) and at the Dry Cheyenne alternate disposal site and borrow site 10 consist primarily of views of hills covered with grass and sagebrush and distant mountains. The scenic resources at the Boulder Flats borrow site are characterized by nearby views of the rural surroundings and the valley of the North Popo Agie River. The grass- and sagebrush-covered foothills of the Wind River Mountains are visible to the west; however, the most noticeable feature in the area is the distant vista of the lofty peaks of the Wind River Mountains.

3.11.2 Cultural resources

Cultural resources include historic, archaeological, and ethnographic resources. Class III cultural resource surveys are field examinations conducted to identify historic and archaeological resources and to determine if the identified resources are potentially eligible for listing in the National Register of Historic Places (NRHP). Ethnographic surveys include field examinations and interviews with local residents and other concerned parties (e.g., the Arapahoe and Shoshone Indians).

Historic resources

The history of the Wind River basin reflects many activities including mineral prospecting and mining, ranching, and farming.

Fur trappers, including John Colter, intermittently used the area in the early 1800s. Several rendezvous (mountain man gatherings) are believed to have been held at the confluence of the Wind and Little Wind Rivers at a location called Double Dives 2.5 miles east of the tailings site (Snakespeare, 1971).

The Shoshone Indians have occupied the region since before recorded history, and the Northern Arapahoe Indian Tribe was relocated to the area by the Federal Government in 1878. The Shoshone and Arapahoe Indians jointly occupy the Wind River Indian Reservation which surrounds the tailings site and the city of Riverton (Shakespeare, 1971). In 1884, a Jesuit priest from Buffalo, New York, established the St. Stephen's Indian Mission (Brown, 1984).

In 1904, the Federal Government initiated an irrigation project that encompassed the area north and west of the Wind River. This project led to the establishment of the city of Riverton in 1906 (SCS, 1974).

Uranium processing at the Riverton tailings site began in 1958 after the mill was built by Fremont Minerals, Inc., later known as Susquehanna-Western, Inc. The milling operations continued until 1963 when the mill was closed.

A Class III cultural resource survey of the tailings site and surrounding area (including borrow site 2) identified one concentration of historic homestead materials. Additional data from this concentration are required before a determination of eligibility for listing in the NRHP can be made. A Class III cultural resource survey of borrow site 10 did not identify any historic resources (Reher et al., 1986). The Dry Cheyenne alternate disposal site and the Little Wind and Boulder Flats borrow sites have not been surveyed for cultural resources. There is no information available as to the presence of historic resources at these sites.

Archaeological resources

The Riverton area lies within the Northwestern Plains Culture Area (Frison, 1978). Distinct cultural traditions of big game hunting and foraging by small, nomadic groups persisted until the area was settled by Euro-Americans. The earliest known habitation of some locations within the Wind River basin has been correlated with the Paleo-Indian Period approximately 10,000 years before the present (Zier and Zier, 1980). The latest of prehistoric occupations of the basin involved primarily the Shoshone Indians who were present when the first Euro-American trappers arrived in the early 1800s (Frison, 1978).

A Class III cultural resource survey of 340 acres at and around the tailings site (including borrow site 2) identified two small lithic scatters. These two scatters are not eligible for listing in the NRHP. A Class III cultural resource survey of 370 acres at borrow site 10 and its haul road identified four large lithic scatters. These lithic scatters are extensive in nature and are considered eligible for listing in the NRHP (Reher et al., 1986).

The Dry Cheyenne alternate disposal site and the Little Wind and Boulder Flats borrow sites have not been surveyed for cultural resources. There is no information available on the presence of archaeological resources at these sites.

Ethnographic resources

An ethnographic survey of the area within a one-mile radius around the Riverton tailings site was conducted in conjunction with the Class III cultural resource survey. This survey was conducted to identify any religious, sacred, or herb gathering sites or landmarks important to either the Arapahoe or Snoshone Indians. Only one site of concern, an Arapahoe Indian historic site associated with the early 1900s, was identified within the area to be affected by remedial action (i.e., the tailings site and adjacent areas of windblown contamination). Other sites identified by the survey are outside the area to be affected, the primary site being St. Stephen's Mission which is listed in the NRHP (Reher et al., 1986).

3.12 SOCIOECONOMIC CHARACTERISTICS

The following is a brief description of the socioeconomic characteristics of the Riverton area. This description summarizes the more detailed data presented in Section E.1 of Appendix E, Socioeconomics.

The 1983 populations of Fremont County and the city of Riverton were 41,071 and 10,438, respectively (Fremont County Planning Commission, 1984). These values represented increases from 1980 census levels of 38,992 (county) and 9,588 (city). In 1980, the city of Riverton housing stock totaled 3,653 units plus over 500 motel-type rooms. The total 1980 county-wide housing stock was 14,570 units. Vacancy rates for rental units in Riverton were 7.3 percent, while county-wide rental vacancy rates were 8.5 percent (DOC, 1982).

The Fremont County employment base included over 13,300 workers in 1982, with services and retail trade the largest sectors in terms of employment. Mining (iron and uranium) has been an important part of the local economy in recent years, but depressed conditions in the mining industries have reduced county mining employment to less than half of the 1979 levels (Fremont County Planning Commission, 1984). The average county unemployment rate for 1983 was 10.8 percent which is considerably higher than the statewide average of 8.4 percent (WESC, 1984). The U.S. Department of Labor has classified Fremont County as a labor surplus area; it is the only Wyoming county so classified (Askew, 1987).

Assessed valuations in 1983 for Fremont County and the city of Riverton were $512.0 million and $23.7 million, respectively. The total 1983 tax levy for Riverton was 84.97 mills per $1,000 in assessed valuation, or $20,146.50 (WDRT, 1983). Sales tax collections in Fremont County in fiscal year 1982 were $10,369,648. Under State of Wyoming law, 2 percent of sales tax collections are returned to the city or county of origin (WDRT, 1982).

Riverton's city police force has 20 sworn officers; the Fremont County Sheriff also maintains nine officers in Riverton to serve unincorporated areas in the vicinity. Fire protection is provided by a 52-person volunteer force which is housed in two stations. There are seven public schools and one junior college in Riverton. Total enrollment at these institutions exceeds 4,100 pupils. The seven public schools could accommodate an additional 300 pupils (FBD, 1983a).

Riverton obtains its water supply from wells and from the nearby Wind River. The water system has a current capacity of 4 million gallons per day (gpd) which could be doubled with development of additional water lines. The city's sewage system was expanded in 1986 and now has a capacity of 5 million gpd. Flows into the system range from 1.85 million gpd during the winter to 3 million gpd during the summer (Scott, 1987).

The Riverton area is served by the Chicago and Northwestern Railroad (C&NWRR) and a regional airport with commercial service. In the past, the C&NWRR passed by the Riverton tailings site and continued on to the southwest; the railroad terminates in Riverton just north of the Wind River (Figure 3.2). Major transportation routes include U.S. Highway 26 (east-west) and Wyoming State Highway 789 (north-south).

In addition to the roadway in the immediate vicinity of the existing tailings site (Goes In Lodge Road), the roadways affected by the remedial action alternatives would be Wyoming State Highways 789, 135, and 136 (Figure 3.1). Average daily traffic volumes on these routes in 1985 were 4,470 trips per day on Wyoming State Highway 789, 520 trips per day on Wyoming State Highway 135, and 270 trips per day on Wyoming State Highway 136 (Taylor, 1987). No traffic data are available for Goes In Lodge Road.

Wyoming State Highways 789, 135, and 136 are generally two-lane roadways in the areas that would be affected by the remedial action alternatives. The design capacity (Level of Service "E") of a two-lane roadway is 2200 vehicles per hour. When flows approach 1,400 vehicles per hour (Level of Service "C"), the Wyoming Highway Department believes that the threshold has been reached where some corrective action should be taken. The desired capacities at which an acceptable level of service is maintained must be adjusted to take into account factors such as the amount of truck traffic and roadway grades and width. Considering these factors, the desired maximum capacities at which adequate service is still maintained are 950 vehicles per hour for Wyoming State Highways 789 and 136, and 820 vehicles per hour for Wyoming State Highway 135. Up to 15 percent of daily traffic flows occur in the peak hour; therefore, current, peak hourly flows approximate 670 vehicles per hour on Wyoming State Highway 789, 80 vehicles per hour on Wyoming State Highway 135, and 40 vehicles per hour on Wyoming State Highway 136. Thus, each of the above roadways are currently operating at levels of service considerably above Level of Service "C" (Lane, 1985).

REFERENCES FOR SECTION 3.0

ANL (Argonne National Laboratory), 1979. Descriptions of United States Uranium Resource Areas, NUREG/CR-0597, ANL/ES-75, prepared by ANL, Argonne, Illinois, for the U.S. Nuclear Regulatory Commission, Washington, D.C.

Anderson, Arthur, 1985a. Personal communication with Arthur Anderson, U.S. Fish and Wildlife Service, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated February 6, 1985.

Anderson, Arthur, 1985b. Personal communication with Arthur Anderson, U.S. Fish and Wildlife Service, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 4, 1985.

Anderson, Arthur, 1984. Personal communication with Artnur Anderson, U.S. Fish and Wildlife Service, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated August 27, 1984.

Anderson and Kelly (Anderson and Kelly, Consultants in Engineering and Geology), 1976. "Water Supply Study, City of Riverton, Wyoming," Riverton, Wyoming.

Askew, D. Lynn, 1987. Personal communication with D. Lynn Askew, Wyoming Department of Environmental Quality, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 14, 1987.

BFEC (Bendix Field Engineering Corporation), 1983a. "Radium-226 Analysis for Riverton Site Tailings Samples," prepared by BFEC, Grand Junction, Colorado, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

BFEC (Bendix Field Engineering Corporation), 1983b. Radiologic Characterization of the Riverton, Wyoming, Uranium Mill Tailings Remedial Action Site, GJ-12(83), prepared by BFEC, Grand Junction, Colorado, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

BLM (Bureau of Land Management), 1984. "Moneta, URA Step II," File No. 4773, Lander Resource Area, Lander, Wyoming.

Baldes, Dick, 1985. Personal communication witn Dick Baldes, U.S. Fish and Wildlife Service, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 8, 1985.

Baldes, Dick, 1984. Personal communication with Dick Baldes, U.S. Fish and Wildlife Service, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated June 5, 1984.

Behler, John L., and F. W. King, 1979. The Audubon Society Field Guide to North American Reptiles and Amphibians, Random House, Inc., New York, New York.

Birk, Roger, 1987. Personal communication with Roger Birk, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated February 27, 1987.

Brown, Kathryn, 1984. Personal communication with Kathryn Brown, St. Stephen's Indian Mission, Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated July 17, 1984.

COE (U.S. Army Corps of Engineers), 1982. HEC-2 Water Surface Profiles, User's Manual, Computer Program 723-X6-L202A, Water Resources Support Center, Hydrology Engineering Center, Davis, California.

CSU (Colorado State University), 1983a. "Characterization of Inactive Uranium Mill Tailings Sites: Riverton, Wyoming," draft report prepared by CSU, Fort Collins, Colorado, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

CSU (Colorado State University), 1983b. "CSU/HGCC Report, Interim Draft," draft report prepared by CSU, Fort Collins, Colorado, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Clark, Tim W., and Robert D. Dorn, 1979. Rare and Endangered Vascular Plants and Vertebrates of Wyoming, Cheyenne, Wyoming.

Cothern et al. (C.R. Cothern, W. L. Lappenbusch, and J.A. Cotruvo), 1983. "Health Effects Guidance for Uranium in Drinking Water," in Radiobiology of Radium and the Actinides in Man," Health Physics, Volume 44, Supplement No. 1, Pergammon Press, New York, New York.

DOC (U.S. Department of Commerce), 1982. 1980 Census of Housing, General Housing Characteristics, Wyoming, Washington, D.C.

DOC (U.S. Department of Commerce), 1976. Annual Wind Direction Versus Wind Speed Summary for Riverton, Wyoming, 1967-1971, prepared by the National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina, Job No. 14094.

DOC (U.S. Department of Commerce), 1970. Climatological Summary of Riverton, Wyoming, Climatography of the United States, No. 20-48, Asheville, North Carolina.

Dailey, Bernard, 1987. Personal communication with Bernard Dailey, Wyoming Department of Environmental Quality, Cheyenne, Wyoming, and the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 15, 1987.

Darr, Paul, 1985. Memorandum from Paul Darr, Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico; Subject: Trip Report - Riprap Reconnaissance - Riverton; dated February 28, 1985.

EG&G, 1983. An Aerial Radiological Survey of the Area Surrounding the Riverton Mill Site, Riverton, Wyoming, EG&G Survey Report NE-U-007, Las Vegas, Nevada.

EPA (U.S. Environmental Protection Agency), 1977. Radiological Survey at the Inactive Uranium Mill Site Near Riverton, Wyoming, Technical Note ORP/LV-77-2, Office of Radiation Programs, Washington, D.C.

EPA (U.S. Environmental Protection Agency), 1974. Information on Levels of Environmental Noise Requirements to Protect the Public Health and Welfare with an Adequate Margin of Safety, EPA-550/9-74-004, Washington, D.C.

FBD (Ford, Bacon & Davis, Inc.), 1983a. "Environmental Assessment of Remedial Actions on the Uranium Mill Tailings at the Riverton Site, Fremont County, Wyoming," unpublished preliminary draft prepared by FBD, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

FBD (Ford, Bacon & Davis, Inc.), 1983b. "Evaluation of Alternate Disposal Sites for the Riverton, Wyoming, UMTRA Site," UC-451-320, UMTRA-SNL/68 8605, unpublished report prepared by FBD, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

FBDU (Ford, Bacon & Davis Utah Inc.), 1981. Engineering Assessment of Inactive Uranium Mill Tailings, Riverton Site, Riverton, Wyoming, DOE/UMT-0106, FBDU-360-19, UC 70, prepared by FBDU, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

FBDU (Ford, Bacon & Davis Utah Inc.), 1977. Phase II, Title I Engineering Assessment of Inactive Uranium Mill Tailings, Riverton Site, Riverton, Wyoming, GJT-19, prepared by FBDU, Salt Lake City, Utah, for the U.S. Department of Energy, Grand Junction, Colorado.

FWS (U.S. Fish and Wildlife Service), 1985. "Endangered and Threatened Wildlife and Plants: Review of Plant Taxa for Listing as Endangered or Threatened Species," Federal Register, Vol. 50, No. 188.

FWS (U.S. Fish and Wildlife Service), 1983. "Republication of the Lists of Endangered and Threatened Species," Federal Register, Vol. 48, No. 145.

Fremont County Planning Commission, 1984. Socioeconomic Profiles and Projections, Fremont County, Wyoming (Progress Draft), Lander, Wyoming.

Fremont County Planning Commission, 1978. Fremont County Land Use Plan, Lander, Wyoming.

Frison, George C., 1978. Prehistoric Hunters of the High Plains, Academic Press, New York, New York.

GECR (Geochemistry and Environmental Chemistry Research, Inc.), 1983. Geochemical Investigation of UMTRAP Designated Site at Riverton, Wyoming, UMTRA-DOE/AL-0229, prepared by GECR, Rapid City, South Dakota, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Gooley, Edward, 1985. Personal communication with Edward Gooley, U.S. Army Corps of Engineers, Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 1, 1985.

Harms, Dale, 1984. Personal communication with Dale Harms, U.S. Fish and Wildlife Service, Helena, Montana, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated July 17, 1984.

Hausel, W. D., and G. S. Holden, 1978. Mineral Resources of the Wind River Basin and Adjacent Precambrian Uplifts, Wyoming Geological Association, 30th Annual Field Conference, Casper, Wyoming.

Hockley, Marvin, 1985. Personal communication with Marvin Hockley, Wyoming Game and Fish Department, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 4, 1985.

Iiams, Jack, 1987. Personal communication with Jack Iiams, Soil Conservation Service, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated February 27, 1987.

Iiams, Jack, 1985. Personal communication with Jack Iiams, Soil Conservation Service, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 12, 1985.

Iiams, Jack, 1984. Personal communication with Jack Iiams, Soil Conservation Service, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated June 21, 1984.

Kelly, Jack, 1984. Personal communication with Jack Kelly, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated August 1, 1984.

LBL (Lawrence Berkeley Laboratory, University of California), 1984. "Hydrology and Geochemistry of the Uranium Mill Tailings Pile at Riverton, Wyoming," draft report prepared by LBL, Berkeley, California, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Lane, John, 1985. Personal communication with John Lane, Wyoming Highway Department, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated February 1, 1985.

Larson, Kyle, 1987. Personal communication with Kyle Larson, Chemical Marketing Services, Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 14, 1987.

MSRD (Mountain States Research and Development), 1982. Economic Evaluation of Inactive Uranium Mill Tailings, Riverton Site, Riverton, Wyoming, UMTRA-DOE/ALO-178, prepared by MSRD, Tucson, Arizona, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

McFarland, Charles, 1987. Personal communication with Charles McFarland, Riverton Country Club, Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 15, 1987.

Miller, Ralph, 1984. Personal communication with Ralph Miller, Department of the Army, Omaha District Corps of Engineers, Omaha, Nebraska, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated July 10, 1984.

Mound (Monsanto Research Corporation-Mound), 1985. "Radon Monitoring at Riverton, Wyoming, July 1984 through April 1985," unpublished report prepared by Mound, Miamisburg, Ohio, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Mound (Monsanto Research Corporation-Mound), 1984. "Radon Monitoring at Riverton, Wyoming, July 1984 to October 1984," unpublished report prepared by Mound, Miamisburg, Ohio, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

NAS (National Academy of Sciences), 1977. Guidelines for Preparing Environmental Impact Statements on Noise, Committee on Bioacoustics and Biomechanics, Working Group Number 69, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission), 1984. Radon Attenuation Handbook for Uranium Mill Tailings Cover Design, NUREG/CR-3533, Washington, D.C.

Nation, Ray, 1987. Personal communication with Ray Nation, Bureau of Indian Affairs, Wind River Agency, Fort Washakie, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated February 27, 1987.

ORNL (Oak Ridge National Laboratory), 1980. Radiological Survey of the Inactive Uranium Mill Tailings at Riverton, Wyoming, ORNL-5461, prepared by ORNL, Oak Ridge, Tennessee, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Oakleaf, Robert, 1985. Personal communication with Robert Oakleaf, Wyoming Game and Fish Department, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 4, 1985.

Oakleaf, Robert, 1984. Personal communication with Robert Oakleaf, Wyoming Game and Fish Department, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated August 7, 1984.

Packer, Ray, 1984. Personal communication with Ray Packer, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated June 14, 1984.

Peel, Robert C., 1984. Memorandum from Robert C. Peel, Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico; Subject: Field Inspection of Riverton Site, Alternate Disposal Site, and Borrow Sites (No. 2 and 10); dated September 11, 1984.

Pettingill, Harry, 1987. Personal communication with Harry Pettingill, U.S. Nuclear Regulatory Commission, Uranium Recovery Field Office, Denver, Colorado, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 30, 1987.

Price, Ray, 1985. Personal communication with Ray Price, Fremont County Planner's Office, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated February 4, 1985.

Reher et al. (C. Reher, T. Fisher, and D. Whiting), 1986. "Cultural Resource Survey in the Central Wind River Basin: The Riverton Uranium Tailings Project Survey," draft report prepared by Reher et al., Laramie, Wyoming, for the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico.

Robertson, Bob, 1985a. Personal communication with Bob Robertson, Bureau of Indian Affairs, Wind River Agency, Fort Washakie, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated February 1, 1985.

Robertson, Bob, 1985b. Personal communication with Bob Robertson, Bureau of Indian Affairs, Wind River Agency, Fort Washakie, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 4, 1985.

SCS (Soil Conservation Service), 1974. Soil Survey of Riverton Area, Wyoming, prepared by the U.S. Department of Agriculture, Washington, D.C.

SHB (Sergent, Hauskins & Beckwith), 1985. "Geomorphic Evaluation, Riverton Uranium Mill Tailings Site, Uranium Mill Tailings Remedial Action Project," unpublished report prepared by SHB, Albuquerque, New Mexico, for the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico.

SHB (Sergent, Hauskins & Beckwith), 1983. "Evaluation of Potential Earthquake Effects, Riverton Site, Fremont County, Wyoming, Uranium Mill Tailings Remedial Action Project," unpublished report prepared by SHB, Albuquerque, New Mexico, for the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico.

Scott, Bernard, 1987. Personal communications with Bernard Scott, City of Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated March 26 and April 15, 1987.

Shakespeare, Tom, 1971. The Sky People, Vantage Press, Inc., New York, New York.

Street, Phillip E., 1987. Personal communication with Phillip E. Street, U.S. Fish and Wildlife Service, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 20, 1987.

Taylor, Carol, 1985. Personal communication with Carol Taylor, U.S. Fish and Wildlife Service, Helena, Montana, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 4, 1985.

Taylor, Eric, 1987. Personal communication with Eric Taylor, Wyoming Highway Department, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 15, 1987.

USGS (U.S. Geological Survey), 1984a. WATSTORE Data Retrieval, May, 1984. Water Resources Division, New Mexico District Office, Albuquerque, New Mexico.

USGS (U.S. Geological Survey), 1984b. WATSTORE Data Retrieval, June, 1984. Water Resources Division, New Mexico District Office, Albuquerque, New Mexico.

USGS (U.S. Geological Survey), 1984c. WATSTORE Data Retrieval, August 1984. Water Resources Division, New Mexico District Office, Albuquerque, New Mexico.

WDEQ (Wyoming Department of Environmental Quality), 1985. Ambient Air Monitoring Data for 1984, Cheyenne, Wyoming.

WDEQ (Wyoming Department of Environmental Quality), 1983a. Wyoming's Air Quality, Ambient Monitoring Data - 1982, Cheyenne, Wyoming.

WDEQ (Wyoming Department of Environmental Quality), 1983b. "Quality Standards for Wyoming Surface Waters," Water Quality Rules and Regulations, State of Wyoming, Cheyenne, Wyoming.

WDEQ (Wyoming Department of Environmental Quality), 1980. "Quality Standards for Wyoming Ground Waters," Water Quality Rules and Regulations, State of Wyoming, Chapter VIII, Cheyenne, Wyoming.

WDRT (Wyoming Department of Revenue and Taxation), 1983. State of Wyoming Annual Report, Ad Valorem Tax Division, Cheyenne, Wyoming.

WDRT (Wyoming Department of Revenue and Taxation), 1982. State of Wyoming Tax Revenue Report, Cheyenne, Wyoming.

WESC (Wyoming Employment Security Commission), 1984. Wyoming Labor Force Trends, Vol. 21, No. 1, Casper, Wyoming.

WGFD (Wyoming Game and Fish Department), 1983. "Riverton Valley Project, Level III Terrestrial Wildlife Impact Report," Pinedale, Wyoming.

Weber, Ed, 1987. Personal communication with Ed Weber, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 15, 1987.

Welch, Jack, 1984. Personal communication with Jack Welch, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated June 1, 1984.

Whitcomb, H.A., and M.E. Lowry, 1968. Ground-Water Resources and Geology of the Wind River Basin Area, Central Wyoming, U.S. Geological Survey Hydrologic Investigations Atlas HA-270, U.S. Department of the Interior, Washington, D.C.

Womack, Edward, 1985. Personal communication with Edward Womack, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated February 1, 1985.

Womack, Edward, 1984. Personal communication with Edward Womack, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated June 1, 1984.

Zier, Anne H., and Christian J. Zier, 1980. "Final Report of Archaeological Surveys and Test Excavations at the Copper Mountain Development Project, Fremont County, Wyoming, Federal and State Lands," Powers Elevation Company, Denver, Colorado.

4.0 ENVIRONMENTAL IMPACTS

The environmental impacts of the remedial action alternatives presented in this environmental assessment (EA) are based on conservative assumptions and impact assessment procedures and thereby represent a realistic upper limit on the severity of the impacts that may occur. The actual impacts that would occur would probably be less severe than those identified in this EA. The environmental impacts presented in this EA are also based on continuous remedial action schedules (i.e., remedial action would be conducted throughout the year). In reality, inclement weather during the winter months would probably necessitate the cessation of remedial action, and the associated impacts would cease or decrease accordingly. This section and the appendices to this EA contain descriptions of the impacts assessment assumptions and procedures.

The proposed remedial action for the inactive (Title I) Riverton tailings site is relocation to Gas Hills. Gas Hills is an area that contains several active (Title II) uranium mill tailings sites in the Gas Hills Uranium Mining District. The specific active site for disposal of the inactive Riverton tailings and contaminated materials would be selected by competitive bidding from owners and operators of active tailings sites in the Gas Hills District.

For the impacts analyses in this EA, it was assumed that the selected active tailings site in Gas Hills is 45 to 60 road miles east of the Riverton site. Therefore, the impacts identified for relocation to Gas Hills are conservative and represent a realistic upper limit on the severity of the impacts that may occur. The impacts identified for relocation to Gas Hills are the impacts of remedial action at the Riverton site and, when appropriate, the impacts along the transportation route to Gas Hills (i.e., impacts on gamma radiation levels, air quality, surface water, noise levels, traffic volumes, and traffic accident injuries and fatalities).

The remedial action at the selected active tailings site in Gas Hills would be consistent with the U.S. Environmental Protection Agency (EPA) standards for active sites, Title 40, Code of Federal Regulations, Part 192, Subparts D and E (40 CFR Part 192, Subparts D and E) and would be performed in accordance with a remedial action plan prepared by the owner and operator of the selected active site and to be approved by the U.S. Nuclear Regulatory Commission (NRC). The generic impacts of the EPA standards were addressed in an environmental impact statement (EIS) published by the EPA (EPA, 1983). The short- and long-term impacts of remedial action at the selected active site would be assessed by the NRC for its compliance with the National Environmental Policy Act (NEPA), Public Law 91-190 (Pettingill, 1987). It should be noted that the Riverton tailings and contaminated materials (1.5 million cubic yards) are only 31 percent of the smallest active tailings pile (4.8 million cubic yards) in Gas Hills that could be selected as the final disposal site (Garcia, 1987).

The borrow sites included in this EA were selected as the sources of the necessary borrow materials for impacts analyses purposes; the borrow sites to be used for the remedial action will be selected during the final design. The impacts identified for the borrow sites included in this EA are conservative and represent a realistic upper limit on the severity of the impacts that may occur.

All of the remedial action alternatives except no action include remedial action at the estimated 25 off-site vicinity properties. However, only those impacts of remedial action at the vicinity properties that make an appreciable contribution to the impacts of the overall remedial action are included in this

EA (e.g., excess health effects to the general public and remedial action workers and impacts on soils). The impacts of remedial action at the vicinity properties were previously assessed in a programmatic environmental report (DOE, 1985).

4.1 RADIATION

4.1.1 Exposure pathways

There are five principal radiological pathways by which individuals could be exposed during the remedial action (Figure 4.1). These are: (1) inhalation of radon and radon daughters; (2) direct exposure to gamma radiation emitted; (3) inhalation and ingestion of, and submersion in, airborne radioactive particulates; (4) ingestion of surface or ground water contaminated with radioactive materials; and (5) ingestion of contaminated foods produced in areas contaminated by tailings. For the calculation of excess health effects, only those pathways that would result in the largest radiological doses to the general public were considered in detail (i.e., inhalation of radon and radon daughters, direct exposure to gamma radiation, and inhalation and ingestion of airborne radioactive particulates), and the general public included the workers at the active sulfuric acid plant at the Riverton tailings site. Section F.3 of Appendix F, Radiation, contains calculations that estimate the radiation exposures and excess health effects to the general public from the water ingestion pathway and to a maximally exposed individual from the contaminated foods ingestion pathway.

Radon is an inert gas (i.e., does not react chemically with other elements) produced from the radioactive decay of radium-226 (Ra-226) in the uranium-238 (U-238) decay series. As a gas, radon can diffuse through the tailings and into the atmosphere where it is transported by atmospheric winds over a large area. In the atmosphere, radon decays into its solid daughter products that attach to airborne dust particles and are inhaled by humans. These dust particles, with the radon daughter products attached, may adhere to the lining of the lungs and decay with the release of alpha radiation directly to the lungs.

Gamma radiation is also emitted by many members of the U-238 decay series. Gamma radiation behaves independently of atmospheric conditions and travels in a straight line until it impacts with matter. Gamma radiation emitted from the tailings delivers an external exposure to the whole body. Gamma radiation levels emitted from the tailings become negligible beyond 0.3 mile from the perimeter of the tailings due to the interaction of the gamma rays with matter in the air.

The general public is presently being exposed to radon daughters and direct gamma radiation from the partially stabilized tailings pile. Radon is diffusing into the ambient atmosphere where it is being dispersed by winds over a large area (i.e., radon inhalation pathway). Gamma radiation is being emitted and is exposing any person living or working within 0.3 mile of the tailings (i.e., direct gamma exposure pathway). Currently, there are no

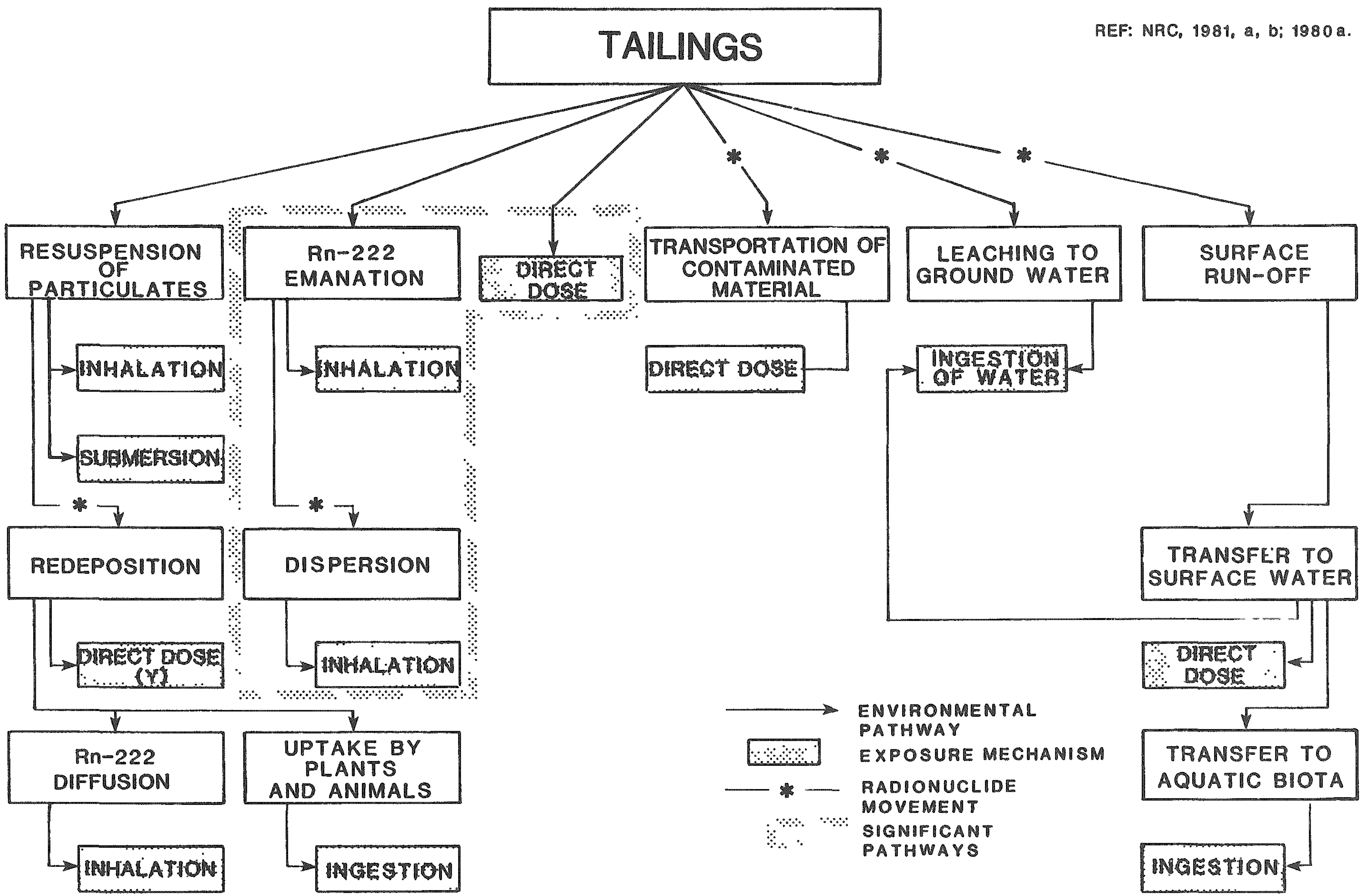


FIGURE 4.1
POTENTIAL RADIATION EXPOSURE PATHWAYS TO THE GENERAL PUBLIC AND REMEDIAL ACTION WORKERS

effective barriers to prevent continued dispersion and unauthorized removal and use of the tailings that could increase the general public's exposure to radon daughters and gamma radiation.

During implementation of any of the action alternatives, the exposures to the general public from these two pathways and from the airborne radioactive particulates pathway would increase as the tailings are disturbed on the site or as the tailings are transported to another disposal site. Remedial action workers would also be exposed to these three pathways during remedial action.

After relocation to Gas Hills, there would be no exposure above that allowed by the EPA standards (40 CFR Part 192, Subparts A, B, and C) to radon and radon daughters or direct gamma radiation at or in the vicinity of the Riverton tailings site because the tailings and contaminated materials would have been removed. Following stabilization in place or disposal at the Dry Cheyenne site, there would be no exposure to direct gamma radiation at the Riverton or Dry Cheyenne site since both of these alternatives include the construction of a compacted, earthen radon barrier that gamma radiation could not penetrate. However, there would continue to be a small public exposure to radon and radon daughters following remedial action because the earthen radon barrier for these alternatives would substantially reduce but not eliminate the release of radon. This would result in a small lung dose to the nearby population with the excess health effects proportional to the size of the population. The earthen radon barrier for these action alternatives would have a very low permeability and thereby slow the rate of radon diffusion through the barrier. Most of the radon would decay into its solid daughter products before it could diffuse through the barrier and enter the atmosphere. The rate of radon emanation would be no greater than the allowable levels contained in the EPA standards (40 CFR Part 192, Subpart A).

The following sections discuss the excess health effects that would result during and after the implementation of each remedial action alternative and the excess health effects of construction related accidents that might occur. Exposure to gamma radiation may cause genetic health effects in addition to somatic health effects (e.g., cancer). The genetic risk is approximately two-thirds of the somatic risk for gamma radiation, and a genetic health effect in general may be considered less severe. Measures taken to reduce the somatic health effects would also reduce the genetic effects. The discussions in the following sections and the excess health effects calculations in Section F.3 of Appendix F, Radiation, reflect only the somatic health effects.

4.1.2 Health effects during remedial action

The estimates of excess health effects (i.e., fatal cancers) in this section are based on the procedures discussed in Sections F.2 and F.3 of Appendix F, Radiation. These procedures are based on realistic but conservative assumptions to estimate the levels of excess health effects. Table 4.1 lists the estimated excess

Table 4.1 Excess health effects during remedial action[a]

Remedial action alternative[b]	General public radon daughters health effects	General public gamma health effects	General public transportation gamma health effects	General public radioactive particulates health effects	Remedial action worker radon daughters health effects	Remedial action worker gamma health effects	Remedial action worker radioactive particulates health effects	Total excess health effects
Relocation to Gas Hills[c]	0.025	0.00037	Negligible[d]	0.00063	0.0056	0.0026	0.00047	0.03
Stabilization in place	0.033	0.00024	0.00000	0.00086	0.0060	0.0028	0.00090	0.04
Disposal at Dry Cheyenne site	0.021	0.00032	Negligible[d]	0.0016	0.0090	0.0042	0.0019	0.04

[a]Sections F.2 and F.3 of Appendix F, Radiation, contain detailed discussions of the methods and assumptions used to estimate these excess health effects.

[b]The no action alternative would result in 0.02 total excess health effects per year (0.023 general public radon daughters health effects and 0.00016 general public gamma health effects).

[c]The estimated excess health effects for relocation to Gas Hills do not include the excess health effects during remedial action at the selected active uranium mill tailings site in Gas Hills. The health effects at the selected active site in Gas Hills would be assessed by the NRC for its compliance with the NEPA, Public Law 91-190 (Pettingill, 1987).

[d]0.000000020 excess health effects.

health effects that would occur for each remedial action alternative during remedial action.

As presented in Section F.3 of Appendix F, Radiation, the percentage increase in radon released from the tailings due to remedial action activities would be small relative to the radon released prior to remedial action because there is a large radon flux from the existing tailings pile under no action conditions. During remedial action, increases in gamma exposure rates and airborne radioactive particulates concentrations would be larger than the radon concentration increases compared to levels prior to remedial action. Gamma exposure rates would increase as the pile is reshaped and the existing cover is removed or disturbed because more tailings would be exposed; airborne radioactive particulates concentrations would also increase from near zero background levels to measurable levels due to disturbance of the tailings.

The elevated gamma exposure rates would increase the excess health effects primarily to the remedial action workers at the tailings site. Inhalation of radon daughters would be the dominant exposure pathway in the excess health effects for the general public. The inhalation of airborne radioactive particulates would have almost equal effects on the general public and remedial action workers for any of the action alternatives.

The excess health effects to the general public during remedial action are principally dependent on the amount of tailings and contaminated materials to be moved and the number of people who live and work nearby. The excess health effects estimated for each of the remedial action alternatives are very small in comparison to the natural incidence of cancer. In the United States, an individual has a 16 percent chance or approximately one chance in six of contracting cancer (NAS, 1980).

As a comparison, the excess radon daughters health effects to an individual in the general public during remedial action for stabilization in place were estimated to be 0.00025 percent (determined by dividing 0.032 excess health effects by an exposed population of 13,001 people) or one chance in 400,000 of contracting fatal cancer from exposure to radon daughters. The excess health effects for the remedial action alternatives are, therefore, a very small fraction of the normal cancer incidence rate of 16 percent (approximately one chance in six).

Relocation to Gas Hills would result in 0.03 total excess health effects during remedial action. This is due primarily to the length of the time required to remove the tailings and contaminated materials from the Riverton site (28 months) which increases the general public's exposure to radon and radon daughters. The excess gamma health effects to the general public due to transportation of the tailings and contaminated materials would be negligible (0.000000020 excess health effects).

The no action alternative would result in 0.02 total excess health effects per year. This number of total excess health effects is not directly comparable to the total excess health effects listed in Table 4.1 because the total excess health effects for the remedial action alternatives are for the duration of the remedial action: 31 months for relocation to Gas Hills, 24 months for stabilization in place, and 30 months for the Dry Cheyenne alternative. In addition, the total excess health effects for the no action alternative do not consider any dispersion or unauthorized removal and misuse of the tailings. Continued dispersion and unauthorized removal and use of the tailings could result in greater excess health effects than those calculated.

Stabilization in place would result in 0.04 total excess health effects during remedial action. All of the tailings and contaminated materials would remain at the Riverton site resulting in increased exposure to radon and radon daughters for the general public (Table 4.1).

During remedial action, the Dry Cheyenne alternative would result in 0.04 total excess health effects. The increased health effects to remedial action workers (Table 4.1) would be due to the number of workers (an average of 81 workers) while the decreased health effects to the general public would be due to the time required to remove the tailings and contaminated materials from the Riverton site (24 months). The excess gamma health effects to the general public due to transportation of the tailings and contaminated materials to the Dry Cheyenne site would be also negligible (0.000000020).

4.1.3 Hypothetical accidents

The Riverton tailings contain radioactive elements in low concentrations that emit low levels of radiation. A long exposure time is required to produce excess health effects. For any action alternative, a spillage of tailings resulting from a traffic accident involving a truck loaded with tailings would be cleaned up immediately and would therefore cause a short exposure time to persons living or working near the spill. Contractors would be required to establish approved procedures for cleaning up spills.

The only spill which could not be cleaned up would be one that occurs as a truck crosses a river or flowing watercourse. The probability of such an accident would be very low. Relocation of the tailings to either Gas Hills or the Dry Cheyenne alternate disposal site would have the possibility of this occurring since the transportation route would cross the Little Wind River. In this case, much of the tailings could not be recovered; however, the concentrations of radioactive elements would be rapidly diluted by the flowing waters, and little or no excess health effects would occur (Section F.3.3 Appendix F, Radiation). All reasonable mitigative measures would be taken if such an event occurred.

4.1.4 Health effects after remedial action

The procedures used to calculate the excess health effects after remedial action for each of the alternatives are discussed in Section F.3.5 of Appendix F, Radiation. These procedures are based on realistic but conservative assumptions to estimate the levels of excess health effects. Table 4.2 lists the estimated yearly excess health effects for each of the alternatives after remedial action.

As stated previously in Section 4.1.1, there would be no exposure above that allowed by the EPA standards (40 CFR Part 192, Subparts A, B, and C) to radon and radon daughters or direct gamma radiation at or in the vicinity of the Riverton site after the tailings and contaminated materials were relocated to Gas Hills. Therefore, there would be no general public excess health effects at or in the vicinity of the Riverton site after this alternative. There would be no exposure to direct gamma radiation after stabilization in place or disposal at the Dry Cheyenne site because these alternatives include the use of an earthen radon barrier for the tailings which would also attenuate gamma radiation to approximately background levels. This radon barrier would ensure that the radon releases for these alternatives, after remedial action, would be no greater than allowed by the EPA standards. The no action alternative would result in continued exposures due to elevated gamma exposure rates and radon emanation from the unaltered tailings pile.

The no action alternative would result in the greatest yearly excess health effects to the general public (0.02 total excess effects per year) which is 10 times greater than after stabilization in place. These effects would occur because the tailings would not have a radon barrier to inhibit radon emanation and gamma radiation. The excess health effects to the general public resulting from radon emanation would exceed those from gamma radiation by a factor of almost 145 for the no action alternative.

The excess health effects calculations for the no action alternative assume that the tailings would not be dispersed in the future by natural erosion or removal and use by man because there is no way to accurately predict the level or rate of dispersion. However, without remedial action, dispersion would occur over time, and the actual total excess health effects of the no action alternative might be greater than the 0.02 per year shown in Table 4.2.

Stabilization in place would result in 0.002 total general public excess health effects per year after remedial action. These effects would occur because the tailings would remain near the city of Riverton. The Dry Cheyenne alternative would result in 0.0000004 total excess health effects per year to the general public after remedial action. The alternate disposal site is relatively remote and located in a sparsely populated area, resulting in minimal excess health effects following remedial action.

Table 4.3 lists the estimated total excess health effects for each alternative that would occur over 5, 10, 100, 200, and 1,000 years following remedial action. This table adds the total excess health effects that would occur during remedial action to the integrated yearly excess health effects that would occur after remedial action. The data in Table 4.3 reflect a stable population, and

Table 4.2 Yearly excess health effects after remedial action[a]

Remedial action alternative	General public radon daughters health effects per year	General public gamma health effects per year	Total excess health effects per year
Relocation to Gas Hills[b]	0.00	0.00	0.00
Stabilization in place	0.0020	0.00	0.002
No action	0.023	0.00016	0.02
Disposal at Dry Cheyenne site	0.00000039	0.00	0.0000004

[a]Sections F.2 and F.3.5 of Appendix F, Radiation, contain discussions of the methods and assumptions used to estimate these excess health effects.

[b]The estimated excess health effects for relocation to Gas Hills do not include the excess health effects after remedial action at the selected active uranium mill tailings site in Gas Hills. The health effects at the selected active site in Gas Hills would be assessed by the NRC for its compliance with the NEPA, Public Law 91-190 (Pettingill, 1987).

Table 4.3 Total excess health effects 5, 10, 100, 200, and 1,000 years after remedial action

Remedial action alternative[a]	Number of years after remedial action				
	5 years	10 years	100 years	200 years	1,000 years
Relocation to Gas Hills[b]	0.03	0.03	0.03	0.03	0.03
Stabilization in place	0.05	0.06	0.2	0.4	2
No action[c]	0.1	0.2	2	4	20
Disposal at Dry Cheyenne site[b]	0.04	0.04	0.04	0.04	0.04

[a]These estimates assume that the population in the vicinity of each site remains constant and include the total excess health effects during remedial action.

[b]The total excess health effects for the Gas Hills and Dry Cheyenne relocation alternatives appear to be constant throughout the time intervals shown because the total excess health effects per year after remedial action (Table 4.2) are very small (e.g., 0.0000004 for the Dry Cheyenne alternative) even when multiplied by the maximum time interval (e.g., 0.0000004 total excess health effects per year multiplied by 1,000 years equals 0.0004 total excess health effects). Hence, the total excess health effects shown for these alternatives are those that would occur during remedial action (0.03 and 0.4 from Table 4.1, respectively).

[c]The calculations for no action assume that the tailings would not be dispersed by natural forces or by man because there is no way to accurately predict the level or rate of dispersion. However, if the dispersion could be predicted and were factored into the above estimates, the total excess health effects for the no action alternative would greatly increase.

the total excess health effects would increase if the nearby population increased.

4.1.5 Health effects at vicinity properties

All of the remedial action alternatives except no action would include the cleanup of the estimated 25 off-site vicinity properties. This cleanup would involve the removal and transportation of contaminated materials from the vicinity properties to the existing tailings site. The contaminated materials would be consolidated with the stabilized tailings. Conservative estimates of the excess health effects during the 24-month vicinity property cleanup period are 0.066 total excess health effects to the general public and 0.00060 total excess health effects to the remedial action workers.

The no action alternative would consist of taking no remedial action at the estimated 25 off-site vicinity properties. The tailings and contaminated materials at the properties would not be cleaned up and would continue to pose potential public health hazards. The no action alternative would result in 0.03 total excess health effects per year to the general public, and the exposure of the general public would continue for thousands of years. Since there would be no remedial action, there would be no excess health effects to remedial action workers.

4.2 AIR QUALITY

Air quality impacts were estimated for relocation to Gas Hills, stabilization in place, and disposal at the Dry Cheyenne site. For relocation to Gas Hills, only the air quality impacts at the Riverton tailings site and Little Wind borrow site and along the transportation route to Gas Hills (Wyoming State Highway 136) were estimated. The impacts assessment consisted of a detailed emissions inventory and translation of these emissions into ambient air pollutant concentrations through the use of computer simulation techniques. The modeling is conservative in nature and thus overpredicts potential impacts. Additional details concerning the air quality assessment (e.g., description of the computer model used) are presented in Sections B.3 and B.4 of Appendix B, Weather and Air Quality.

Air emissions inventory

The emissions inventory includes estimates of combustion emissions from construction equipment and fugitive dust emissions for relocation to Gas Hills, stabilization in place, and disposal at the Dry Cheyenne site. Emissions were calculated for hydrocarbons (HC), nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), and total suspended particulates (TSP). The estimates include emissions from activities occurring at the Riverton and Dry Cheyenne sites, from vehicles traveling on paved roads and gravelled haul roads, and from equipment operating at the Little Wind borrow site and borrow site 10.

Combustion emissions were calculated based on emissions factors for construction equipment (EPA, 1979). Fugitive dust emissions were based on emissions factors from a variety of sources (Section B.3 of Appendix B, Weather and Air Quality), with the most frequently used values being those recommended by the Wyoming Department of Environmental Quality (WDEQ, 1979). It was assumed that sources of fugitive dust would be controlled through the application of water at each of the sites and chemical suppressants on gravelled haul roads. Total emissions for each case were based on fuel consumption rates, vehicle-miles traveled, vehicle speed, soil composition, the size of the area of disturbance, and the volumes of materials moved.

Combustion and fugitive dust emissions were not calculated for the borrow activities at the Boulder Flats borrow site because the activities at this borrow site would be very small in comparison to the activities at the Riverton tailings site, Dry Cheyenne disposal site, Little Wind borrow site, and borrow site 10. For example, the activities at borrow site 10 would disturb 59 acres to obtain 783,000 cubic yards of earth while the activities at the Boulder Flats borrow site would disturb 15 acres to obtain 195,000 cubic yards of gravel and rock. The Boulder Flats borrow activities would involve much less equipment, most of which would be haulage trucks operating over a wide area between the borrow site and the tailings site (27 road miles), and therefore much lower combustion emissions. The Boulder Flats borrow activities would also produce considerably less fugitive dust because the much smaller amount of material to be moved would consist primarily of rock. The combustion and fugitive dust emissions from the activities at the Boulder Flats borrow site would be minor compared to the emissions at the other sites.

Table 4.4 provides a summary of emissions for relocation to Gas Hills, stabilization in place, and disposal at the Dry Cheyenne site. Fugitive dust emissions would well exceed combustion emissions for each alternative. Relocation to Gas Hills would generate 380 tons of fugitive dust. A total of 458 tons of fugitive dust emissions would result from stabilization in place, while disposal at the Dry Cheyenne site would generate 1,700 tons of fugitive dust. The no action alternative would not create emissions of hydrocarbons, nitrogen oxides, sulfur oxides, and carbon monoxide; however, it would contribute suspended particulates to the ambient atmosphere due to dispersion of the tailings by winds. This contribution of particulates was not quantified but would be somewhat greater than that from undisturbed rangeland due to the sparse vegetative cover on the existing tailings pile.

As shown in Table 4.4, combustion emissions would be substantially higher for relocation to Gas Hills than for the other two action alternatives. This would be attributable to the relatively long haulage distance involved (45 to 60 road miles), and the major portion of these emissions would be distributed over the transportation route (Wyoming State Highway 136) from the Riverton tailings site to Gas Hills. Emissions of NO_x and CO would be the highest of the combustion emissions; HC, SO_x, and TSP emissions would be similar in magnitude and the lowest of the combustion emissions. The emissions in Table 4.4 for relocation to Gas Hills do not include the combustion and fugitive dust emissions at Gas Hills. For the other action alternatives, NO_x emissions would be the highest of the combustion emissions followed by CO emissions; emissions of HC, SO_x, and TSP would be similar in magnitude and the lowest of the combustion emissions. The combustion emissions for stabilization in place would be

Table 4.4 Summary of emissions for remedial action alternatives

Remedial action alternative[a]	Source	Emissions (tons)				
		HC	NO_x	SO_x	CO	TSP
Relocation to Gas Hills	Combustion emissions	48	283	34	294	17
	Fugitive dust	--	--	--	--	380
	Totals	48	283	34	294	397
Stabilization in place	Combustion emissions	10	102	10	55	6
	Fugitive dust	--	--	--	--	458
	Totals	10	102	10	55	464
Disposal at Dry Cheyenne site	Combustion emissions	25	209	21	137	12
	Fugitive dust	--	--	--	--	1,700
	Totals	25	209	21	137	1,712

[a]The no action alternative would not create emissions of hydrocarbons, nitrogen oxides, sulfur oxides, and carbon monoxide; however, it would contribute suspended particulates to the ambient atmosphere due to dispersion of the tailings by winds. This contribution of particulates was not quantified but would be somewhat greater than that from undisturbed rangeland due to the sparse vegetative cover on the existing tailings pile.

substantially lower than those for the relocation alternatives because the tailings and contaminated materials would not be transported by truck to another site.

The NO_x emissions for all of the action alternatives would exceed the EPA significant level of 40 tons per years, and the CO emissions for relocation to Gas Hills would exceed the EPA significance level of 100 tons per year. However, the prevention of significant deterioration regulations do not apply to temporary emissions sources such as those in the remedial action alternatives (40 CFR Part 51; WDEQ, 1984).

Air pollutant concentrations

Ambient air pollutant concentrations were estimated through the use of EPA-approved computer simulation models. These models translate air pollutant emissions into ambient air pollutant concentrations under conservative meteorological conditions.

Emphasis was placed upon the modeling of fugitive dust emissions because these emissions would be much higher than combustion emissions (Table 4.4). Further, TSP is the only pollutant type for which the Riverton area either exceeds or approaches the limits of applicable air quality standards, and preliminary calculations indicated that only the 24-hour TSP concentrations would approach or exceed applicable standards.

Modeling of 24-hour TSP increments due to remedial action was based on the use of the Industrial Source Complex Dispersion Model for short-term application (ISCST). This model is described in further detail in Section B.4 of Appendix B, Weather and Air Quality. The ISCST model is particularly appropriate for an application of this type since it considers particulate deposition and can also accommodate large area emission sources and line emission sources such as trucks traveling on haul roads. The emissions used as inputs to the model are presented in Section B.4 of Appendix B, Weather and Air Quality, and correspond to the project phase in which the maximum emissions rates occur.

Modeling was performed for the following cases: (1) impacts at the Riverton tailings site resulting from tailings removal activities under the Gas Hills relocation and Dry Cheyenne disposal alternatives; (2) stabilization in place at the Riverton site; (3) disposal at the Dry Cheyenne alternate disposal site; and (4) activities occurring at the Little Wind borrow site and borrow site 10. Also included in the emissions modeling, where appropriate, were fugitive dust emissions from trucks traveling on the gravelled haul roads. The modeled 24-hour TSP concentrations associated with the remedial action were added to the maximum 24-hour TSP concentration measured in the area (111 micrograms per cubic meter) to determine if the TSP standards would be exceeded.

Table 4.5 presents the maximum 24-hour TSP increments as well as the estimated total 24-hour TSP concentrations for the remedial action alternatives. Relocation to Gas Hills would result in an increase of 61 micrograms per cubic meter (microg/m^3) in the 24-hour TSP concentration at the Riverton tailings site. This would be slightly lower than the same increase for stabilization in place but slightly higher than that for

Table 4.5 Estimated incremental and total 24-hour TSP concentrations for the remedial action alternatives

Remedial action alternative[a]	Location	24-hr TSP increment[b] (microg/m^3)	Total 24-hr TSP concentration[c] (microg/m^3)	Federal secondary 24-hour standard[d] (microg/m^3)	Federal primary 24-hour standard[d] (microg/m^3)
Relocation to Gas Hills	Riverton site	61	172	150	260
	Little Wind borrow site	72	183	150	260
Stabilization in place	Riverton site	70	181	150	260
	Borrow site 10	59	170	150	260
Disposal at Dry Cheyenne site	Dry Cheyenne	132	243	150	260
	Riverton site	50	161	150	260

[a]The no action alternative would not create emissions of hydrocarbons, nitrogen oxides, sulfur oxides, and carbon monoxide; however, it would contribute suspended particulates to the ambient atmosphere due to dispersion of the tailings by winds. This contribution of particulates was not quantified but would be somewhat greater than that from undisturbed rangeland due to the sparse vegetative cover on the existing tailings pile.

[b]Based on emission inputs and meteorological conditions specified in Section B.4 of Appendix B, Weather and Air Quality.

[c]Based on the addition of 24-hour TSP increments to the maximum recorded TSP concentration in the area (111 microg/m^3).

[d]Ref. 40 CFR Part 50. The State of Wyoming 24-hour TSP standard is the same as the Federal secondary 24-hour standard (WDEQ, 1985).

disposal at the Dry Cheyenne site. There would also be an increase of 72 microg/m^3 at the Little Wind borrow site. Total, estimated 24-hour TSP concentrations would be 172 and 183 microg/m^3 at the Riverton site and Little Wind borrow site, respectively. Both of these concentrations would exceed the Federal secondary and State of Wyoming 24-hour TSP standards of 150 microg/m^3 but would be less than the Federal primary 24-hour TSP standard of 260 microg/m^3. The Federal secondary standard defines the level of air quality deemed necessary to protect the public welfare from any known or anticipated adverse effects of the pollutant while the Federal primary standard defines the level of air quality deemed necessary, with an adequate margin of safety, to protect the public health (40 CFR Part 50).

Stabilization of the tailings in place would result in increases of the 24-hour TSP concentrations of approximately 70 and 59 microg/m^3 at the Riverton site and borrow site 10, respectively. Total estimated 24-hour TSP concentrations would be 181 microg/m^3 at the Riverton site and 170 microg/m^3 at borrow site 10. Both concentrations would exceed the Federal secondary and State of Wyoming 24-hour TSP standards of 150 microg/m^3 but would be less than the Federal primary standard of 260 microg/m^3.

The modeled 24-hour TSP increments resulting from disposal at the Dry Cheyenne site would be 132 microg/m^3 at the Dry Cheyenne site and 50 microg/m^3 at the Riverton site. The latter increment would result from the removal of the tailings from the Riverton site. Total estimated 24-hour TSP concentrations for the Dry Cheyenne disposal alternative would be 243 microg/m^3 at the Dry Cheyenne site and 161 microg/m^3 at the Riverton site. Both concentrations would exceed the Federal secondary and State of Wyoming 24-hour TSP standards of 150 microg/m^3 but would be less than the Federal primary standard of 260 microg/m^3. It should be noted that the maximum TSP concentration to which project increments were added to determine total TSP concentrations was that for the Riverton area (111 microg/m^3) since no data exist for the Dry Cheyenne site. Actual TSP concentrations in the Dry Cheyenne area may be considerably less than at Riverton due to the absence of emission sources (e.g., construction activities, farming, and travel on dirt and gravelled roads) unrelated to remedial action.

The annual emission rates and ambient TSP data for Riverton are such that it is expected that any of the action alternatives could result in similar, minor exceedances of the Federal annual TSP standards. The Federal secondary annual TSP standard is 60 microg/m^3, and the Federal primary annual TSP standard is 75 microg/m^3 (40 CFR Part 50). It should be noted that the modeling uses a conservative approach which assumes simultaneous occurrence of maximum emission rates and conservative meteorological conditions (i.e., light winds blowing persistently from a single direction under stable mixing conditions); therefore, the modeled values should be viewed as relative rather than absolute concentrations. All predicted maximum increments are localized, occurring at or near the boundary of each of the sites.

4.3 SOILS

Each of the action alternatives would result in both the temporary disturbance and permanent loss of soils. These impacts would result from surface disturbances caused by the excavation of contaminated soils and borrow materials and the construction of haul roads, staging and stockpile areas, and the Dry Cheyenne alternate tailings disposal site. The cleanup of the off-site vicinity properties would also result in soil disturbances and losses. For impacts assessment purposes, all contaminated soils, except those beneath the existing tailings pile, that are consolidated and stabilized with the tailings are lost. Soils that are stockpiled and then replaced or used to restore disturbed areas are temporarily disturbed.

Relocation to Gas Hills

Relocation of the tailings and contaminated materials to Gas Hills would result in the loss of 118 acres of soils (approximately 113,000 cubic yards) at the Riverton tailings site for the cleanup of the former ore storage and mill areas (22 acres) and the windblown tailings (96 acres). These contaminated soils would be consolidated with the tailings and relocated to Gas Hills. Approximately 12 acres of soils at the Riverton site would be temporarily disturbed for on-site access roads (4 acres) and the off-site construction staging area (5 acres) and waste-water retention pond (3 acres). After remedial action, all of the areas disturbed at the Riverton site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, and revegetated as necessary.

Relocation to Gas Hills would require the use of the Little Wind borrow site to provide earthen materials for restoring the disturbed areas at the Riverton tailings site. Approximately 160 acres (430,000 cubic yards) of soils would be removed from the borrow site and backfilled into the disturbed areas at the Riverton site. After remedial action, the disturbed acreage at the Little Wind borrow site would be reclaimed according to the requirements of the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licences, and Approvals).

No action

The no action alternative would not involve remedial action; therefore, no new disturbance or loss of soils would occur. Contamination (with Ra-226) of soils adjacent to the tailings site due to dispersion of the tailings by water and wind erosion would continue. The rate of this continuing contamination cannot be accurately quantified, but 96 acres of soils have been contaminated to date.

Stabilization in place

Stabilization in place would result in the permanent loss of 118 acres of soils (approximately 113,000 cubic yards) during the cleanup of the areas contaminated by the former ore storage and mill facilities (22 acres) and the windblown tailings (96 acres). These contaminated soils would be consolidated with the tailings pile. The areas disturbed during the cleanup of the contaminated soils within and adjacent to the tailings site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, and revegetated as necessary.

Stabilization in place would require the use of borrow site 10 and the Boulder Flats borrow site. Borrow site 10 would be the source of earthen materials for covering the consolidated tailings and contaminated materials and restoring the areas disturbed during cleanup of the contaminated soils. Nine acres would be disturbed to construct 1 mile of haul road to the site, and 50 acres would be disturbed for the borrow activities. Prior to surface disturbance, the soils from these acreages would be scraped to a depth of 6 inches and stockpiled near the borrow site for reclamation of the site and haul road according to the requirements of the free use permit (Appendix G, Permits, Licenses, and Approvals) issued by the Bureau of Land Management (BLM).

The Boulder Flats borrow site would be the source of gravel and rock for graveling the haul roads to the borrow sites and armoring the stabilized tailings pile against erosion. Fifteen acres would be disturbed to construct 0.5 mile of haul road to the site and to excavate the required quantities of gravel and rock. The disturbed acreage would be reclaimed according to the requirements of the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals).

Disposal at the Dry Cheyenne site

Disposal of the tailings and contaminated materials at the Dry Cheyenne site would result in the disturbance of 77 acres of soils at the alternate disposal site. Seventeen (17) acres would be disturbed by the construction of 2 miles of haul road to the site, and 13 acres would be disturbed for a construction staging area at the site. Excavation of the partially below-grade disposal area would disturb another 47 acres. Soils from the haul road and staging area would be scraped to a depth of 6 inches and stockpiled with the surface materials excavated from the disposal area. The stockpiled materials would be used later to cover the tailings and contaminated materials and to restore the construction staging area at the disposal site and the disturbed areas at the Riverton tailings site.

At the Riverton tailings site, 118 acres of soils (approximately 113,000 cubic yards) would be lost in the cleanup of the former ore storage and mill areas (22 acres) and the windblown tailings (96 acres). These contaminated soils would be consolidated with the tailings and relocated to the Dry Cheyenne site. The areas disturbed during the cleanup, consolidation, and removal of the tailings and contaminated materials would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, and revegetated as necessary. The materials for this restoration would be obtained from the surface materials excavated and stockpiled at the Dry Cheyenne site.

Disposal of the tailings at the Dry Cheyenne site would require the use of only borrow site 2, and the 15 acres that would be disturbed by the borrow activities at this site would have already been disturbed by the cleanup of the windblown tailings. The 15 acres of borrow site 2 would be restored in accordance with the requirements of the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals).

Vicinity properties

Assuming that an average of 0.25 acre of soils would be removed during the cleanup of each vicinity property, approximately 6 acres (approximately 5,000 cubic yards) of soils would be lost during remedial action at the 25 properties. These contaminated materials would be consolidated with the tailings. Restoration at the vicinity properties would be achieved by backfilling the disturbed areas with uncontaminated soil to levels compatible with the surrounding terrain, adding topsoil, and revegetating the areas as necessary.

4.4 MINERAL RESOURCES

All of the remedial action alternatives, except no action, would result in the consumption of borrow materials (earth, gravel, and rock). The consumption of borrow materials from the proposed local sources would have a negligible impact on the availability and cost of these resources in the area as all of these materials are commercially available in large quantities throughout the Riverton area. None of the alternatives would have an impact on other mineral resources in the area. The existing tailings site, the Dry Cheyenne alternate disposal site, borrow site 10, and the Little Wind and Boulder Flats borrow sites are underlain by the Wind River Formation. Although mineralized in some areas, this formation is not known to contain economic mineral reserves in the vicinity of Riverton.

The use of the Riverton or Dry Cheyenne site for stabilization of the tailings would not necessarily preclude future development of any mineral or oil and gas resources beneath the site. Public Law 95-604 requires that the mineral rights be transferred to the Federal Government along with the disposal site. Public Law 95-604 also authorizes the Secretary of the Interior, with the concurrence of the Secretary of Energy and the Nuclear Regulatory Commission, to dispose "of any subsurface mineral rights by sale or lease... if the Secretary of the Interior takes such action as the Commission deems necessary pursuant to a license issued by the Commission to assure that the residual radioactive materials will not be disturbed by reason of any activity carried on following such disposition." Any recovery of mineral, oil, or gas resources from beneath the site would be governed by license conditions to prevent any disturbance of the stabilized tailings pile. If the cost of avoiding disturbance of the pile were too high, resource recovery would be precluded.

Relocation to Gas Hills

The in-place volumes of uncontaminated borrow materials that would be required for relocation to Gas Hills are 430,000 cubic yards (cy) of earth for restoration at the Riverton tailings site and 8,000 cy of gravel for road construction at the tailings site. The earthen borrow materials would be obtained from the Little Wind borrow site, and the gravel would be purchased from a local, commercial source. Relocating the tailings to Gas Hills would allow access to the sand and gravel deposits beneath the existing tailings pile.

No action

The no action alternative would not require the consumption of borrow materials because there would be no remedial action. Access to the sand and gravel deposits beneath the existing tailings pile would be restricted, but this would not be expected to affect the availability or cost of these resources in the area.

Stabilization in place

The in-place volumes of uncontaminated borrow materials that would be required for stabilization in place are 958,000 cy of earth, gravel, and rock for construction of the radon and erosion protection barriers and restoration at the tailings site and 20,000 cy of gravel for road construction to borrow site 10. These borrow materials would be obtained from borrow site 10 (earth) and the Boulder Flats borrow site (gravel and rock). Access to the sand and gravel deposits beneath and around the stabilized tailings pile would be restricted; however, this would not be expected to affect the availability or cost of these resources in the area. Oil and gas exploration and development could occur immediately adjacent to the stabilized tailings pile without affecting the stability of the pile.

Disposal at the Dry Cheyenne site

The in-place volumes of uncontaminated borrow materials that would be required for disposal at the Dry Cheyenne site are 919,000 cy of earth, gravel, and rock for the radon and erosion protection barriers and restoration at the existing tailings site and 52,000 cy of gravel for road construction to the disposal site. These borrow materials would be obtained from excavation of the partially below-grade disposal site (earth) and borrow site 2 (gravel and rock). Relocating the tailings to the Dry Cheyenne site would allow access to the sand and gravel deposits beneath the existing tailings pile but would preclude access to any borrow materials beneath and around the alternate disposal site. Oil and gas exploration and development could occur immediately adjacent to the stabilized tailings pile without affecting the stability of the pile.

Borrow sites

The mineral rights for the Little Wind borrow site are privately owned, and the site is therefore not subject to mining claims or mineral leasing. The temporary borrow activities at the site would not permanently preclude future borrow or oil and gas activities because the site would be reclaimed in accordance with applicable regulations (Appendix G, Permits, Licenses, and Approvals).

The mineral rights for borrow site 2 are privately owned, and the site is not subject to mining claims or mineral leasing. It is possible that oil or gas is present below the site (Womack, 1984). The temporary borrow activities at the site for the Dry Cheyenne alternative would not permanently preclude future borrow or oil and gas activities because the area disturbed by the borrow activities would be reclaimeD in accordance with the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals). If the tailings were stabilized in place, the Federal Government would acquire the mineral rights for the portion of the designated tailings site north of the stabilized tailings pile to restrict future borrow activities on the north side of the tailings pile. The geomorphic evaluation of the tailings site area recommended such a restriction to protect the stabilized tailings pile against erosion from river meander (SHB, 1985).

There are no mining claims on file for borrow site 10; however, a small portion of the site is within an existing oil and gas lease (Weber, 1987). The temporary borrow activities at the site would not permanently preclude future borrow or oil and gas activities because the site would be reclaimed in accordance with the free use permit issued by the BLM (Appendix G, Permits, Licenses, and Approvals).

The mineral rights for the Boulder Flats borrow site are privately owned, and the site is not subject to mining claims or mineral leasing. The temporary borrow activities at the site would not permanently preclude future borrow or oil and gas activities because the site would be reclaimed in accordance with the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals).

4.5 WATER

Section 4.5.1 describes the potential surface-water impacts from each remedial action alternative. Section 4.5.2 summarizes the predicted ground-water impacts for the remedial action alternatives and discusses restoration of the unconfined aquifer at the Riverton tailings site. The predicted ground-water impacts are based on ground-water data and modeling techniques that are detailed in Section C.2 of Appendix C, Water. The amount of water consumed during remedial action and the resulting impacts on water sources are described in Section 4.14.

4.5.1 Surface water

Relocation to Gas Hills

During remedial action, the cleanup and consolidation of the tailings and contaminated materials would result in surface disturbances, and runoff from the disturbed areas could likewise be contaminated. Also, contaminated waste water would be generated by activities such as the washing of equipment. The remedial action design includes the construction of drainage controls and a waste-water retention pond during site preparation to prevent the discharge of contaminated water from the site. The drainage controls and waste-water retention pond would be constructed according to applicable regulations (Appendix G, Permits, Licenses, and Approvals). The contaminated water would be retained for evaporation or used for dust control on the tailings and contaminated materials; any sediments from the pond would be relocated with the tailings and contaminated materials to the Gas Hills disposal site.

The cleanup of the windblown tailings north of the tailings pile may require the temporary rerouting of the irrigation canal that courses west to east along the northern edge of the tailings pile. This reroute would be conducted according to applicable regulations and coordinated with users of the canal to minimize or avoid any interference with use of the canal.

No action

The no action alternative would result in the continued exposure of the tailings pile to erosion from surface runoff. The existing earthen cover on the pile is not adequate to provide protection against sheet and gully erosion created by severe rainfall events. Eventual erosion of the existing cover would result in the transport of contaminants from the tailings pile into local surface waters.

The existing earthen cover on the tailings pile is also not adequate to provide protection against erosion caused by flooding or river meander. As indicated by the flood analysis and geomorphic evaluation, the tailings site is potentially subject to both of these events. Without properly designed protection, the pile would be subject to severe erosion resulting from flooding or river meander.

Stabilization in place

As with relocation to Gas Hills, contaminated surface runoff and waste water would be generated by activities such as the cleanup and consolidation of the tailings and contaminated materials and the washing of equipment. The remedial action design includes the construction of drainage controls and a waste-water retention pond during site preparation to prevent the discharge of contaminated water from the site. The drainage controls and wastewater retention pond would be constructed according to applicable regulations (Appendix G, Permits, Licenses, and Approvals). The contaminated water would be retained for evaporation or use in the compaction of the tailings and contaminated materials and any sediments from the pond would be consolidated with the tailings during the final reshaping of the tailings pile.

As with relocation to Gas Hills, the irrigation canal along the northern edge of the tailings pile may be temporarily rerouted during the cleanup of the windblown tailings north of the pile. This reroute would be conducted according to applicable regulations and coordinated with users of the canal to minimize or avoid any interference with use of the canal.

Several control features were incorporated into the remedial action design to prevent erosion of the stabilized pile and subsequent contamination of adjacent surface waters. The sideslopes of the pile would be limited to 5 horizontal to 1 vertical (20 percent), and the top of the pile would be gently crowned (2 percent). These shallow slopes would promote drainage from the pile with non-erosive flow velocities. The area around the pile would be graded to direct surface runoff around and away from the pile. The rock erosion protection barrier placed on the top (1 foot thick) and sideslopes (2 feet thick) of the pile is designed to withstand the erosive forces of severe rainfall events such as a

Probable Maximum Precipitation (PMP). For the Riverton site, the PMP was calculated to be 8.3 inches of rain in 1 hour with a maximum intensity of 25 inches per hour for a 5-minute period; this PMP would generate sheet flow rates ranging from 0.4 to 1.2 cubic feet per second per foot of slope width on the pile (Section A.3.5 of Appendix A, Conceptual Designs, and Section C.1.2 of Appendix C, Water).

Due to the location of the tailings site with respect to the Wind and Little Wind Rivers, there are two design concerns related to flooding. If the pile were inundated or surrounded by flood flows, there would be a possibility that high flow velocities could damage the rock erosion protection barrier or cause rapid channel shifts or localized scour that would undercut and erode the pile.

The flood analysis for the tailings site area (Section A.3.5 of Appendix A, Conceptual Designs, and Section C.1.2 of Appendix C, Water), indicated that a Probable Maximum Flood (PMF) would result in the stabilized tailings pile being surrounded by water depths less than 10 feet around the sides of the pile with flow velocities less than 15 feet per second (fps). The 5-foot thick, 32-foot wide, tapered, riprap apron around the base of the stabilized pile is designed to protect the pile from water depths of 10 feet with flow velocities of 15 fps and would also protect the pile against any river channel shifts caused by flooding.

A geomorphic evaluation of the tailings site area (SHB, 1985) has been performed to assess the possibility that the channels of the Wind and Little Wind Rivers could move toward the site. Geologic evidence indicates that the Wind River could migrate laterally across its floodplain within a 2,000-year period. The extent of possible channel migration is unpredictable, but the rate of migration could exceed 0.5 mile per 1,000 years. The present Wind River channel is about 1 mile north of the site. It also appears that aggradation (channel filling) or large-scale flooding could result in avulsion, or rapid channel shift, of the Wind River across the floodplain. The Little Wind River is more stable and more deeply incised, and the potential for its migration toward the site is much less.

The stabilized tailings pile would be surrounded with a riprap apron to protect the pile against erosion that could result from a Probable Maximum Flood. This riprap apron would also protect the pile against erosion that could result from river meander or sudden shifts in the channels of the Wind and Little Wind Rivers.

Disposal at the Dry Cheyenne site

Both during and after remedial action, the Dry Cheyenne disposal alternative would incorporate the same erosion protection measures as stabilization in place to prevent the release of contaminants from the sites and to assure the long-term stability of the stabilized tailings pile. These measures would include construction of drainage controls and waste-water retention ponds at both the tailings and disposal sites, placement of a rock erosion protection barrier over the stabilized pile, and grading of the area around the stabilized pile to divert surface runoff around and away from the pile. As with stabilization in place, the irrigation canal along the northern edge of the tailings pile may be temporarily rerouted during the cleanup of the windblown tailings north of the pile. This reroute would be conducted according to applicable regulations and coordinated with users of the canal to minimize or avoid any interference with use of the canal.

Flooding and river meander are not stability considerations for the Dry Cheyenne disposal alternative because of the disposal site's distance from (11 miles) and elevation above (approximately 600 feet) the confluence of the Wind and Little Wind Rivers. The Dry Cheyenne site is located at the head of a small, ephemeral drainage, and the only surface-water flows are those from runoff from the site itself; therefore, flash flooding would not be a hazard to the stabilized tailings pile. The small drainages west of the disposal site could advance toward the site; however, the potential for this advancement has not been evaluated. If the Dry Cheyenne alternative were to be selected, the potential for advancement of these drainages would be evaluated, and the remedial action design would be revised, if necessary, to include adequate protection against erosion resulting from the advancement.

Borrow sites

During remedial action, appropriate drainage controls would be used at the borrow sites to minimize or prevent erosion and any corresponding surface-water impacts. The controls used at borrow site 2 during the Dry Cheyenne disposal alternative would be the same as those implemented for the Riverton tailings site. At borrow site 10, the earthen dams across the small drainages northeast and southeast of the site would not be disturbed by the borrow activities. After remedial action, the borrow sites would be reclaimed in accordance with the requirements of the applicable permit to mine issued by the State of Wyoming or free use permit issued by the BLM (Appendix G, Permits, Licenses, and Approvals). Generally, these requirements consist of grading and revegetation measures to control erosion and return the site to a condition compatible with the surrounding terrain.

Floodplains determination

Calculations of the surface-water elevations of the 500-year flood flows in the Wind and Little Wind Rivers have shown that the designated Riverton tailings site (including borrow site 2) and the adjacent areas of windblown tailings do not lie within the 500-year floodplain of either river. The calculation for the Little Wind River also showed that the Little Wind borrow site is not within the 500-year floodplain of the river. According to the U.S. Army Corps of Engineers (COE), the Boulder Flats borrow site is above the floodplain of the North Popo Agie River (Gooley, 1985). Therefore, remedial action would not affect any floodplains at these sites.

The Dry Cheyenne alternate disposal site and borrow site 10 are not near any floodplains, and visual inspections of the sites did not reveal the presence of any floodplains. Prior to any surface disturbance at either of these sites, the COE would be consulted regarding the presence of any floodplains at or near the site to be affected.

4.5.2 Ground water

Relocation to Gas Hills

During relocation to Gas Hills, the consolidation and excavation of the tailings and contaminated materials at the Riverton site could increase drainage from the tailings pile. This could cause a small increase in contamination of the unconfined aquifer; however, this increase would be only for a short duration until all of the tailings and contaminated materials were removed.

After remedial action, the impact to ground water would consist of the reduction of the existing contamination in the unconfined aquifer. Relocation of the tailings and contaminated materials to Gas Hills would remove the source of any future ground-water contamination. Existing contamination, including any additional contamination generated by the remedial action, would continue to migrate downgradient and discharge into the Little Wind River until the existing concentrations of contaminants in the aquifer had returned to background levels. The time required for this natural reduction in the contamination is estimated to be 45 years.

The depth to ground water at the Little Wind borrow site is not known. However, the borrow activities at this site would not be expected to penetrate any water-bearing formations, and, therefore, no ground-water impacts would be anticipated at the borrow site during and after remedial action.

No action

Implementation of the no action alternative would result in the continued infiltration of water through the tailings pile and the associated leaching of contaminants from the tailings into the unconfined aquifer. The contaminated ground water would continue to move downgradient and discharge into the Little Wind River.

Both processes would continue until the tailings pile was effectively leached of all transportable contaminants and the concentrations of contaminants in the unconfined aquifer were reduced to background levels. The time required for these natural processes to be completed is estimated at 65 years. The potential for downward migration of the contamination in the unconfined aquifer to the deeper, usable units of the confined aquifer exists, but it is estimated that this migration would take 1,700 years. However, studies conducted by the State of Wyoming show that the effects of communication between the aquifers would occur much sooner than 1,700 years (Askew, 1987).

Stabilization in place

During stabilization in place, consolidation and compaction of the tailings and contaminated materials could increase drainage from the tailings pile. This could cause a small increase in contamination of the unconfined aquifer directly beneath the tailings pile; however, this increase would be for only a short duration. After remedial action, there would be a substantial decrease in the contamination of the unconfined aquifer. Sloping of the top and sides of the stabilized tailings pile would promote the drainage of precipitation off of the pile, and the compacted, earthen radon barrier over the pile would inhibit the filtration of precipitation through the pile. These measures would minimize the leaching of contaminants into the underlying unconfined aquifer.

With the substantial decrease in the generation and migration of contamination from the tailings pile, the natural movement and discharge of the unconfined ground water into the Little Wind River would eventually reduce the existing concentrations of the contaminants to background levels. It is estimated that this natural reduction in the contamination of the unconfined aquifer would take 65 years. Although there is a potential for downward migration of the contamination in the unconfined aquifer to the confined aquifer, this migration would be slowed by the various low-permeability strata (shale, siltstone, and claystone) of the Wind River Formation. It is estimated that downward migration of the contamination to the deeper, usable units of the confined aquifer would take 1,700 years. However, studies conducted by the State of Wyoming show that downward migration would occur much sooner than 1,700 years (Askew, 1987).

There is no ground water within 30 feet of the land surface at borrow site 10, and no ground water has been encountered within 15 to 18 feet of the land surface at the Boulder Flats borrow site. The borrow activities at these sites would not extend beyond these depths; therefore, no ground-water impacts are anticipated during and after remedial action.

Disposal at the Dry Cheyenne site

During relocation of the tailings and contaminated materials to the Dry Cheyenne site, there would be no impacts on the ground-water regime at the Dry Cheyenne site. The partially belowgrade disposal area for the tailings and contaminated materials would be excavated to an average depth of 16 feet and would not encounter any water-bearing formations. It should be noted that no field investigations have been conducted at the Dry Cheyenne site, and the exact depth to the uppermost water-bearing formation is not known. However, information for water wells in the surrounding area indicates that the depth to ground water far exceeds the proposed depth of the disposal area (Sections C.2.2.3 and C.2.4.4 of Appendix C, Water).

After remedial action, the impacts to the ground water at the Dry Cheyenne site would be minimal. Sloping of the top and sides of the stabilized tailings pile would promote the drainage of precipitation off of the pile, and the compacted, earthen radon barrier over the pile would inhibit the filtration of precipitation through the pile. These measures would minimize water infiltration through the tailings and thereby minimize the leaching of contaminants into the underlying strata. Although the exact depth to ground water at the Dry Cheyenne site is not known, information for the surrounding area indicates that the minor seepage of contaminants from the stabilized tailings would not enter any water-bearing formations.

During disposal at the Dry Cheyenne site, impacts at the Riverton tailings site would be very similar to those for relocation to Gas Hills. Consolidation and excavation of the tailings and other contaminated materials could increase contamination of the unconfined aquifer; however, this increase would be only for a short duration until all of the tailings and contaminated materials were removed. The borrow activities at borrow site 2 could require some dewatering of the unconfined aquifer. This dewatering would be minimal and for a short duration, and the water removed would be used for compaction and dust control or evaporated. The impact to ground water after remedial action would be the same as that for relocation to Gas Hills.

Aquifer restoration

Relocation of the tailings and contaminated materials to Gas Hills or the Dry Cheyenne alternate disposal site would remove the source of any future ground-water contamination. Stabilization in place would minimize contamination of the unconfined aquifer at the Riverton tailings site by effectively reducing the generation and migration of contaminants from the tailings pile. With any remedial action alternative, the natural movement and discharge of the ground water in the unconfined aquifer would eventually reduce the existing concentrations of the contaminants to background levels. The time required for this natural reduction of the contamination is estimated to be 45 years for the relocation alternatives and 65 years for no action and stabilization in place. Aquifer restoration, the removal and treatment of contaminated ground water, is a potential method for accelerating this natural process.

Aquifer restoration is generally very costly in comparison to ground-water protection techniques such as physical containment. The selection of an optimum restoration method must consider the criteria of technical feasibility, effectiveness, and cost; these criteria are governed by the volume of the contaminated ground water and the ability to remove and treat that volume of water. The evaluation of aquifer restoration must also consider the present and future uses of the contaminated ground water, the possible development of other water sources to replace the contaminated ground water, and the potential health hazards associated with consumption of the contaminated ground water.

A possible method of restoring the contaminated unconfined aquifer includes:

- Installation of eight wells, each well capable of withdrawing 30 gallons per minute for 20 years.

- Transfer of all withdrawn water to a central treatment facility with subsequent treatment of the water to meet applicable water-quality standards.

- Discharge of all treated water into the Little Wind River.

This method of aquifer restoration could be effective for the removal of mobile contaminants such as sulfate but less effective for less mobile contaminants such as molybdenum.

A cost-benefit evaluation of the aquifer restoration method described above was performed by dividing the estimated cost of the restoration process by the estimated value of the ground water to be restored. The value of the ground water to be restored is limited by the areal extent of the contaminated ground water and the restricted present and future use of the ground water (livestock watering and irrigation). The evaluation resulted in an estimated cost-benefit ratio of 28. Several alternative water supplies are readily available, including the Wind and Little Wind Rivers and the deeper sandstone units of the Wind River Formation, and the potential health hazards associated with consumption of the contaminated ground water are low (Section F.3.2 of Appendix F, Radiation). Combining these factors with the high cost-benefit ratio for the aquifer restoration process indicates that aquifer restoration is not warranted at the Riverton tailings site.

Regardless, when the EPA issues revisions to the water protection standards (40 CFR Part 192.20 (a) (2)-(3)) that were remanded by the U.S. Tenth Circuit Court of Appeals, the DOE will re-evaluate the ground-water issues at the Riverton site to assure that the revised standards are met. Performing remedial action to stabilize the tailings prior to the EPA issuing new standards will not affect the measures that are ultimately required to meet the revised EPA water protection standards. The DOE has characterized the conditions at the Riverton site and does not anticipate that any substantial changes to the remedial action would be required. However, after the EPA re-issues the water protection standards, the DOE will determine the need for institutional controls, aquifer restoration, or other controls and will take appropriate action so as to comply with the re-issued standards.

4.6 ECOSYSTEMS

The temporary and permanent losses of vegetation and wildlife habitat would be the primary biological impacts from remedial action. These impacts would result from surface disturbances caused by the excavation of contaminated soils and borrow materials; the construction of haul roads and staging and stockpile areas; and remedial action at the Dry Cheyenne alternate tailings disposal site.

Relocation to Gas Hills

Relocating the tailings and contaminated materials to Gas Hills would result in the disturbance of 200 acres at and around the Riverton tailings site and, consequently, the loss of the vegetation on that acreage. Seventy (70) acres would be disturbed with the excavation of the tailings, and 71 acres would be disturbed during the cleanup of the on-site windblown contamination and mill and ore storage areas. The cleanup of the off-site windblown contamination would disturb 47 acres, and another 12 acres would be disturbed for on-site access roads (4 acres), the off-site construction staging area (5 acres), and waste-water retention pond (3 acres). After remedial action, these 200 acres would be restored to a level compatible with the surrounding terrain and revegetated as necessary.

The remedial action activities would result in the displacement of wildlife (mammals, birds, reptiles, and amphibians) inhabiting the disturbed areas at and around the tailings site. Most of the wildlife would relocate to the similar, surrounding habitat although a few individuals unable to relocate would not survive. Following remedial action, restoration and revegetation of 200 acres at and around the tailings site would provide suitable habitat for many of the displaced species. During the trucking of the tailings and contaminated materials from the Riverton tailings site to Gas Hills, there could also be a limited, temporary increase in wildlife mortality along the transportation route (Wyoming State Highway 136).

Relocation to Gas Hills would require the disturbance of 160 acres of land and its vegetation at the Little Wind borrow site. This disturbed acreage would be reclaimed according to the reclamation requirements of the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals). The borrow activities would result in the displacement of wildlife inhabiting the borrow site. While there is habitat for the displaced species in the surrounding area, some individuals unable to relocate would not survive, and truck transportation of the borrow materials to the tailings site could cause a limited, temporary increase in wildlife mortality along the transportation route. Reclamation of the borrow site would re-establish suitable habitat for any displaced wildlife.

No action

The no action alternative would not involve any remedial action and, therefore, would not create any surface disturbance. There would not be any impacts on vegetation, wildlife, or wildlife habitat.

Stabilization in place

Stabilizing the tailings pile in place would result in the disturbance of 188 acres at and around the tailings site and, consequently, the loss of the vegetation on that acreage. Seventy (70) acres would be disturbed with the consolidation of the tailings, and 71 acres would be disturbed during the cleanup of the on-site windblown contamination and mill and ore storage areas. The cleanup of the off-site windblown contamination would disturb another 47 acres.

Following remedial action, 108 of the 188 acres disturbed at and around the tailings site would be restored to a level compatible with the surrounding terrain and revegetated as necessary. The 80 acres containing the rock-covered stabilized tailings pile would not be revegetated.

The remedial action activities would result in the displacement of wildlife (mammals, birds, reptiles, and amphibians) inhabiting the disturbed areas at and around the tailings site. Most of the wildlife would relocate to the similar, surrounding habitat although a few individuals unable to relocate would not survive. Following remedial action, restoration and revegetation of 108 acres at and around the tailings site would provide suitable habitat for many of the displaced species. The 80 acres containing the rock-covered tailings pile would not be suitable for wildlife habitat.

Stabilization in place would require the disturbance of 74 acres of land and its vegetation at the borrow sites. At borrow site 10, 9 acres would be disturbed by the construction of a 1-mile haul road to the site, and 50 acres would be disturbed by the borrow excavation. The 59 acres disturbed would be reclaimed according to the reclamation requirements of the free use permit issued by the BLM (Appendix G, Permits, Licenses, and Approvals). At the Boulder Flats borrow site, 15 acres would be disturbed by the construction of a 0.5-mile haul road to the site and the borrow excavation. The 15 acres disturbed would be reclaimed according to the reclamation requirements of the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals).

The borrow activities would result in the displacement of any small wildlife species inhabiting the borrow sites. While there is habitat for the displaced species in the surrounding areas, some individuals unable to relocate would not survive. Borrow site 10 and the Boulder Flats borrow site contain suitable habitat for pronghorn antelope, mule deer, and sage grouse, and the borrow activities could therefore result in the displacement of these large mammals and the disruption of the breeding and nesting of the sage grouse. However, the surrounding areas contain adequate habitat for these species. Truck transportation of the borrow materials from the borrow sites to the tailings site could cause limited, temporary increases in wildlife mortality along the transportation routes.

Reclamation of the haul roads and borrow areas at borrow site 10 (59 acres) and the Boulder Flats borrow site, (15 acres) would re-establish suitable habitat for any displaced wildlife. The earthen dams northeast and southeast of borrow site 10 that impound ephemeral surface-water flows for wildlife and livestock would not be disturbed by the borrow activities in accordance with the free use permit issued by the BLM (Appendix G, Permits, Licenses, and Approvals).

Disposal at the Dry Cheyenne site

At the Dry Cheyenne disposal site, 87 acres would be disturbed by the construction of 2 miles of haul road to the site (17 acres), preparation of a staging area (13 acres), stockpiling of the surface materials excavated from the partially below-grade disposal area (10 acres), and construction of the enclosed, stabilized tailings pile (47 acres). The vegetation on these 87 acres would be destroyed by these surface disturbing activities. Following remedial action, 23 of the 87 acres disturbed would be reclaimed. The 64 acres containing the haul road to the site and the enclosed, stabilized tailings pile would not be revegetated.

The surface disturbing activities at the Dry Cheyenne site would result in the displacement of the small wildlife species (mammals, birds, and reptiles) inhabiting the site. Most of these species would relocate to suitable habitat in the surrounding area, but a few individuals unable to relocate would not survive. The Dry Cheyenne site contains suitable habitat for pronghorn antelope, mule deer, and sage grouse, and may be part of the pronghorn antelope's important winter range (Welch, 1984). The surface disturbances at the site could result in the displacement of these large mammals and the disruption of the breeding and nesting activities of the sage grouse; however, the surrounding area contains adequate habitat for these species.

Following remedial action, 23 acres at the disposal site would be reclaimed and made suitable for wildlife habitat. The 64 acres covered by the haul road to the site and the rock-covered tailings pile would not be revegetated and would not be suitable for wildlife habitat.

Relocating the tailings and contaminated materials to the Dry Cheyenne site would result in the disturbance of 188 acres at and around the Riverton tailings site. The individual surface disturbances and resulting impacts on vegetation would be the same as those for stabilization in place. Following remedial action, all of the 188 acres disturbed would be restored and revegetated as necessary.

The Dry Cheyenne alternative would have the same impacts on wildlife at and around the Riverton tailings site as stabilization in place. During the trucking of the tailings and contaminated materials from the tailings site to the Dry Cheyenne site, there could also be a limited, temporary increase in wildlife mortality along the transportation route (Wyoming State Highway 136).

Relocating the tailings and contaminated materials to the Dry Cheyenne site would require the disturbance of 15 acres at borrow site 2. This acreage would have been previously disturbed during the cleanup of the windblown contamination so the borrow activities would not create any additional impacts on the vegetation and wildlife at the site. Following remedial action, borrow site 2 would be restored and revegetated as necessary with the other disturbed areas at the tailings site and therefore would be suitable for wildlife habitat. There would be no borrow activities at borrow site 10 because the earthen radon barrier for the tailings pile would be obtained from the surface materials excavated from the partially below-grade disposal area.

Vicinity properties

All of the remedial action alternatives except no action include remedial action at the estimated 25 off-site vicinity properties in the Riverton area. These vicinity properties include personal residences, commercial structures, and vacant lots. Assuming that the remedial action at each property would affect 0.25 acre, approximately 6 acres would be disturbed by the cleanup of contaminated materials at the vicinity properties. These cleanup activities could result in the loss of any vegetation and wildlife associated with each micro-environment. After remedial action, the disturbed areas at the vicinity properties would be restored and revegetated as necessary.

Wetlands determination

According to the COE and the U.S. Fish and Wildlife Service (FWS), there are no wetlands or riparian areas within the designated Riverton tailings site (including borrow site 2) and the adjacent areas of wind-blown contamination, borrow site 10, and the Boulder Flats borrow site (Anderson, 1985a,b; 1984; Gooley, 1985; Miller, 1984). Therefore, remedial action activities at these sites would not affect any species commonly associated with wetlands or riparian habitats. The Little Wind borrow site is adjacent to the riparian zone along the Little Wind River, and the FWS has recommended that a 300-foot minimum buffer zone be maintained between the borrow site and the river for the protection of wetlands, riparian habitats, and the river. The FWS also recommended that the borrow activities be conducted to avoid disturbance of any riparian habitats (Street, 1987).

The Dry Cheyenne alternate disposal site is not near any wetlands or riparian areas, and no riparian species were observed during an inspection of the site (Peel, 1984). Prior to any surface disturbance at the site, the COE and FWS would be consulted regarding the presence of wetlands or riparian areas at or near the site.

Threatened and endangered species

The Dry Cheyenne alternate disposal site and borrow site 10 contain habitat suitable for the Federal candidate plant species *Cryptantha subcapitata* (no common name). Prior to any surface disturbance at either of these sites, a field survey would be conducted to determine the presence or absence of this species.

None of the sites that would be affected by remedial action contain habitat suitable for nesting of the endangered bald eagle (*Haliaeetus leucocephalus*) or peregrine falcon (*Falco peregrinus anatum*), and the presence of these species in the areas around the sites as transients or migrants would be rare (Harms, 1984; Oakleaf, 1985, 1984; Peel, 1984; WGFD, 1983). Therefore, the remedial action would have no impact on the endangered bald eagle or peregrine falcon (BLM, 1984).

The Riverton tailings site, Dry Cheyenne alternate disposal site, borrow site 10, and the Little Wind and Boulder Flats borrow sites contain habitat suitable for the occurrence of prairie dog towns and hence the possible presence of the endangered black-footed ferret (*Mustela nigripes*) (Harms, 1984; Taylor, 1985). No prairie dog towns have been observed at the tailings site, alternate disposal site, or borrow site 10 (Peel, 1984); therefore, the presence of the black-footed ferret at these sites would not be expected. The Little Wind and Boulder Flats borrow sites have not been examined for the presence of prairie dog towns. Prior to surface disturbing activities at either borrow site, the site would be examined for prairie dog towns. If it were determined that prairie dog towns of sufficient size were present, a black-footed ferret survey would be conducted.

4.7 LAND USE

Relocation to Gas Hills

The Gas Hills alternative would result in relocation of the Riverton tailings and contaminated materials to a selected active uranium mill tailings site, thereby precluding the construction of a new tailings disposal site. The Riverton tailings site would be released for use consistent with existing land use controls. The existing tailings site, in the valley between the Wind and Little Wind Rivers, would be more valuable land than the selected active tailings site in the remote Gas Hills area in terms of foreseeable future land uses.

Relocation to Gas Hills would involve the temporary disturbance of 188 acres at and adjacent to the Riverton tailings site for cleanup of the tailings, the former ore storage and mill areas, and the areas contaminated by windblown tailings. Another 12 acres would be temporarily disturbed at the Riverton site for on-site access roads and the off-site construction staging area and waste-water retention pond. These areas would be restored as necessary and released for any use consistent with existing land use controls. Part of the active sulfuric acid plant is located within an area contaminated by windblown tailings, and portions of the scale and pump houses used in the acid plant operations have been contaminated. Cleanup of the windblown tailings and decontamination of the scale and pump houses may interfere with the acid plant operations. The cleanup and decontamination activities would be conducted to minimize interference with the acid plant operations.

One hundred sixty acres would be disturbed at the Little Wind borrow site. This acreage would be reclaimed in accordance with the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals).

No action

The no action alternative would allow the tailings pile to continue to affect existing land use patterns. The acreage presently occupied by the pile (70 acres) would not be available for alternative uses. In addition, dispersion of the tailings by water and wind erosion would continue to contaminate lands adjacent to the pile. The existing cover on the pile was not designed to provide protection against erosion from severe weather, and erosion of the tailings has contaminated 96 acres of land adjacent to the pile.

Stabilization in place

The final restricted area containing the stabilized tailings pile (69 acres) would encompass 80 acres, and other uses of these 80 acres at the Riverton tailings site would be permanently precluded. The stabilized tailings site would be under the control of the Federal Government and would be permanently restricted from public access and development. However, the remaining contaminated and uncontaminated acreage at and around the site (140 acres) would be decontaminated, restored as necessary, and released for use consistent with existing land use controls.

Stabilization in place would involve the temporary disturbance of 118 acres at and adjacent to the tailings site for cleanup of the former ore storage and mill areas and the areas contaminated by windblown tailings. These areas would be restored as necessary and released for use consistent with existing land use controls. As with relocation to Gas Hills, the cleanup activities and decontamination of the scale and pump houses would be conducted to minimize interference with the acid plant operations.

Fifty-nine additional acres would be disturbed at borrow site 10. This acreage would be reclaimed in accordance with the free use permit issued by the BLM (Appendix G, Permits, Licenses, and Approvals) and released for use consistent with existing land use controls. The proposed activities at borrow site 10 could affect the natural gas pipeline that traverses the site; however, the borrow activities would be planned and conducted to avoid impacts to the pipeline in accordance with the free use permit. The borrow activities at the Boulder Flats borrow site would disturb 15 acres. This acreage would be reclaimed in accordance with the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals).

The stabilized tailings pile would not have an appreciable effect on land use in the surrounding area. Studies of unstabilized tailings piles have indicated that the development and values of adjacent lands were not affected by the piles. At the tailings site near Salt Lake City, Utah, a study revealed that land values at and adjacent to the pile were dependent primarily on the current and planned uses of these lands (DOE, 1984). In Grand Junction, Colorado, residential and commercial developments adjacent to the tailings site have increased over the last 10 years. During that time, a sawmill and lumber yard, several warehouses and businesses, and 50 to 60 housing units have been located near the tailings site (Metzner, 1984).

Disposal at the Dry Cheyenne site

The final restricted area containing the stabilized tailings pile (40 acres) would encompass 47 acres, and other use of this acreage at the Dry Cheyenne site would be permanently precluded. This acreage represents a very small portion of the lands available for grazing in the general area (approximately 5 million acres in Fremont County). The access road to the disposal site (17 acres) would be available for public use and would provide access into the area for the existing land uses (grazing and oil and gas exploration and development). Relocation of the tailings to the Dry Cheyenne site would allow release of the existing tailings site for use consistent with existing land use controls. The existing tailings site, located in the valley between the Wind and Little Wind Rivers, would almost certainly be considered more valuable land than the remote Dry Cheyenne site in terms of foreseeable future land uses.

As was described above for relocation to Gas Hills, the Dry Cheyenne alternative would involve the temporary disturbance of 188 acres at and adjacent to the tailings site for cleanup of the tailings, the former ore storage and mill areas, and the areas contaminated by windblown tailings and for the borrow activities at borrow site 2. These areas would be restored as necessary and released for use consistent with existing land use controls. Borrow site 2 would be reclaimed in accordance with the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals). As with the Gas Hills alternative, the cleanup activities and decontamination of the scale and pump houses would be conducted to minimize interference with the acid plant operations.

Relocation of the tailings to the Dry Cheyenne alternate disposal site also would require the disturbance of 23 acres at that site for a construction staging area and stockpiling of surface materials. This disturbed land would be reclaimed and released for use consistent with existing land use controls in accordance with the applicable permits issued by the BLM.

4.8 NOISE LEVELS

Noise impacts were estimated for the action alternatives. The major noise producing sources would be the construction equipment used at the sites and the trucks used to haul tailings and borrow materials. Typical sound levels generated by the types of equipment that would be used in the alternatives are presented in Table 4.6. The no action alternative would not involve any remedial action, and, consequently, there would be no increased noise levels.

Table 4.6 Noise levels for equipment used for remedial action

Type of equipment	Maximum noise level at 50 feet (decibels)
Bulldozer	88
Front-end loader	85
Scraper	87
Water truck	89
Haulage truck	86
Compactor	87
Grader	83

Ref. Kessler et al., 1978.

A noise prediction model (Kessler et al., 1978) was used to estimate the maximum A-weighted sound level in decibels (dBA) emitted from each of the sites during the remedial action. The model is based on the numbers and types of equipment operating on the site, usage factors for operation in the noisiest modes, and the distance from the activity to the nearest noise-sensitive receptors (residences). The model tends to overestimate noise levels since it assumes a clustering of equipment. In reality, the equipment would be located over a number of acres.

The estimated maximum noise level at the Riverton tailings site during relocation to Gas Hills is 93 dBA at a location 50 feet from the center of activity. The residences closest to the Riverton site are 900 feet away. The maximum noise level would be attenuated by 25 dBA over this distance, resulting in a noise level of 68 dBA at the closest residence. The estimated maximum noise level from activities at the Little Wind borrow site is 90 dBA. This maximum noise level would be attenuated by 30 dBA over the 1,700 feet to the nearest residence in St. Stephens, resulting in a noise level of 60 dBA. The noise levels at the residences closest to the sites exceed the EPA's recommended 55-dBA level for annoyance from outdoor activity but are less than the 70-dBA level established for the protection of hearing (EPA, 1974). These noise levels would occur only during normal daytime working hours.

The maximum noise level estimated for the Riverton site during stabilization in place is 94 dBA 50 feet from the center of activity. This noise level would be attenuated by 25 dBA over 900 feet resulting in a 69-dBA noise level at the nearest residence. This noise level is greater than the EPA's recommended annoyance level (55 dBA) but less than the level established for the protection of hearing (70 dBA). This noise level would occur only during normal daytime working hours.

Estimated maximum noise levels from activities at the Dry Cheyenne alternate disposal site and borrow site 10 are 94 dBA and 90 dBA, respectively. There are no residences near enough to either site (within 4 miles) to be affected by the elevated noise levels. The estimated maximum noise level from activities at the Boulder Flats borrow site is 90 dBA. The nearest residence is estimated to be 1,000 feet from the borrow site. The maximum noise level would be attenuated by 25 dBA over this distance, resulting in a 65-dBA noise level at the nearest residence. This noise level is greater than the recommended 55-dBA annoyance level but less than the 70-dBA level established for the protection of hearing. The noise levels at the Dry Cheyenne site, borrow site 10, and the Boulder Flats borrow site would occur only during normal daytime working hours.

Finally, there would also be noise produced by the haulage trucks traveling between the various sites. Noise produced by the trucks could be expected to be 84 dBA at a location 50 feet from the transportation route. Such levels would prove annoying to residents along the transportation routes, but the elevated noise levels would be extremely brief in duration at any single location as the trucks passed by and would occur only during normal daytime working hours.

4.9 SCENIC AND CULTURAL RESOURCES

4.9.1 Scenic resources

Relocation to Gas Hills

Relocation to Gas Hills would have a minor impact on scenic resources. The immediate view around the Riverton tailings site would be permanently changed due to the removal of the tailings and contaminated materials and possible demolition of the existing mill structures. Demolition of the mill building would remove an obstruction to the distant view of the Wind River Mountains for residents north and east of the tailings site, but the active sulfuric acid plant and water tower would remain to partially block this view. The permanent changes in the views would be subordinate to the regional view, and all of the disturbed areas at the Riverton site would be restored to a level compatible with the surrounding terrain.

The removal of vegetation and borrow materials at the Little Wind borrow site would temporarily alter the elements of color, contrast, and texture at the site. The site would be reclaimed according to the reclamation requirements specified in the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals). These requirements typically include grading and revegetation measures to return a site to a condition compatible with the surrounding terrain.

No action

The no action alternative would not involve any remedial action and, therefore, would have no effect on existing scenic resources.

Stabilization in place

Stabilization in place would have a minor impact on scenic resources. The new shape and height of the stabilized tailings pile and the possible demolition of the existing mill structures would cause a permanent but slight change in the immediate view around the tailings pile. During the decontamination activities, the removal of vegetation and surficial materials would temporarily alter the foreground views around the pile until restoration of these areas to a level compatible with the surrounding terrain was complete. The stabilized tailings pile could block, at least partially, the distant view of the Wind River Mountains for residents north and east of the tailings site. Demolition of the mill building would remove an obstruction to the same view, but the active sulfuric acid plant and water tower would remain to partially block this view. Both the permanent and temporary changes in the views would be subordinate to the regional view.

During stabilization in place, the removal of vegetation and borrow materials at borrow site 10 and the Boulder Flats borrow site would temporarily alter the elements of color, contrast, and texture at the sites. The sites would be reclaimed according to the reclamation requirements specified in the free use permit issued by the BLM and the permit to mine issued by the State of Wyoming, respectively (Appendix G, Permits, Licenses, and Approvals). These requirements typically include grading and revegetation measures to return a site to a condition compatible with the surrounding terrain.

Disposal at the Dry Cheyenne site

Disposal of the tailings at the Dry Cheyenne site would cause the views across the alternate disposal site to be changed due to the truncated pyramid appearance of the stabilized tailings pile. The rock layers covering the pile would contrast slightly with the surrounding terrain in texture and color. These changes would be minor because the visual sensitivity at the site is low due to its location outside the view of any land users (residents). The impacts to scenic resources at the Riverton tailings site would be the same as those described for relocation to Gas Hills except for the below-grade excavation at borrow site 2. All of the disturbed areas at the Riverton site would be restored to a level compatible with the surrounding terrain.

4.9.2 Cultural resources

Historic resources

No sites currently listed in the National Register of Historic Places (NRHP) would be affected by any of the remedial action alternatives, including remedial action at the vicinity properties. Prior to remedial action, the list of vicinity properties would be checked to determine if any of the structures involved are more than 50 years old and of such architecture and construction to be eligible for listing in the NRHP. This assessment cannot be completed until the specific vicinity properties warranting remedial action have been determined.

Additional data are required to determine the eligibility to the NRHP for a concentration of historic homestead materials identified near the Riverton tailings site (Reher et al., 1986). If this site is determined to be eligible and if the site would be affected by remedial action, a data recovery plan would be developed and implemented in consultation with the Bureau of Indian Affairs (BIA), the Arapahoe and Shoshone Indians, and the State Historic Preservation Officer (SHPO) as appropriate.

The Dry Cheyenne alternate disposal site and the Little Wind and Boulder Flats borrow sites have not been surveyed for cultural resources. Prior to surface disturbance at any of these sites, a Class III cultural resource survey of the sites would be conducted to determine the presence of historic resources eligible to the NRHP. If eligible historic resources would be affected by remedial action, a data recovery plan would be developed and implemented in consultation with the BLM, BIA, Arapahoe and Shoshone Indians, and SHPO as appropriate.

Archaeological resources

No known archaeological resources would be affected by remedial action at the Riverton tailings site and borrow site 2. An archaeologist would be present at these sites during subsurface excavations because some archaeological sites have been found in the area at depths of up to 4 feet beneath the surface (Reher et al., 1986). If archaeological sites eligible to the NRHP are found during remedial action, a data collection program would be developed and implemented in consultation with the BIA, Arapahoe and Shoshone Indians, and the SHPO as appropriate.

The borrow activities at borrow site 10 would be performed to avoid the four large lithic scatters identified at the site. If the scatters could not be avoided, a data collection program would be developed and implemented in consultation with the BLM and SHPO.

The Dry Cheyenne alternate disposal site and the Little Wind and Boulder Flats borrow sites have not been surveyed for cultural resources. Prior to surface disturbance at any of these sites, a Class III cultural resource survey of the site would be conducted to determine the presence of archaeological resources eligible to the NRHP. If eligible archaeological resources would be affected by remedial action, a data collection program would be developed and implemented in consultation with the BLM, BIA, Arapahoe and Shoshone Indians, and SHPO as appropriate.

Ethnographic resources

Additional data will be collected for the Arapahoe Indian historic site identified in the ethnographic survey to determine its importance to the Arapahoe Indians. If the site is important and would be affected by remedial action, the BIA and Arapahoe Indians would be consulted to determine proper mitigation measures.

The Boulder Flats borrow site is within the Wind River Indian Reservation but was not included in the ethnographic survey. Prior to surface disturbance at this borrow site, the Arapahoe and Shoshone Indians would be consulted to determine the need for an ethnographic survey of the site. If a survey were necessary and important ethnographic resources were identified, the Arapahoe and Shoshone Indians would be consulted to determine proper mitigative measures for resources that would be affected by remedial action.

4.10 POPULATION AND EMPLOYMENT

The following section summarizes the impacts of the remedial action alternatives on the Riverton area's population and work force. More detailed information is provided in Section E.2.1 of Appendix E, Socioeconomics.

Relocation to Gas Hills

Relocation to Gas Hills would involve an overall average work force of 70 workers over a 31-month period. The 12-month period when activities would be at their highest levels would involve 93 workers, including workers involved in the vicinity properties cleanup. It is expected that all but 10 of these workers would be hired from within Fremont County. Five of these in-migrants would bring their families with them, and total in-migration related to direct employment is estimated at 19 individuals.

Using an indirect employment multiplier of 1.8 (0.8 new indirect jobs created for each direct job), the 93 direct remedial action jobs would create an additional 74 indirect jobs. This multiplier is based on a study of the Fremont County economy by the Denver Research Institute, as cited in the Final Environmental Statement on the Gas Hills Uranium Project (NRC, 1980b). Because of the relatively short duration of the indirect employment and because there is substantial local unemployment (10.8 percent in 1983), it is assumed that the indirect jobs would be taken by local residents.

Over the 12-month peak period of relocation to Gas Hills, there would be a population increase of up to 19 persons and up to 167 new jobs created. This would represent a minor increase in the 1983 county population of over 41,000 and an increase in county employment of 1.2 percent over 1982 levels.

No action

The no action alternative would not involve any remedial action and, therefore, would have no impacts on the size of the local population or the area's employment base.

Stabilization in place

Stabilization in place would involve an overall average work force of 68 workers over a 24-month period. The 18-month period when activities would be at their highest levels would involve 78 workers, including workers involved in the vicinity properties cleanup. It is expected that all but 12 of these workers would be hired from within Fremont County. Total in-migration related to direct employment is estimated at 23 individuals. Up to 62 indirect jobs could be created, and it is assumed that the indirect jobs would be taken by local residents.

Over the 18-month peak period of stabilization in place, there would be a population increase of up to 23 persons, and up to 140 new jobs would be created. This would represent a minor increase in the 1983 county population and an increase in county employment of 1.0 percent over 1982 levels.

Disposal at the Dry Cheyenne site

Tailings disposal at the Dry Cheyenne site would involve an overall average work force of 81 workers over a 30-month period. During the 19-month peak period, the average work force would include 101 workers, including the vicinity properties cleanup work force. It is estimated that 88 of these workers would be current Fremont County residents. In- migration related to direct project employment is estimated at 24 individuals. Up to 81 indirect jobs could be created, and it is assumed that the indirect jobs would be taken by local residents.

The Dry Cheyenne alternative would result in a population increase of up to 24 persons and could create up to 182 new jobs for a 19-month period. This would represent a minor increase in the 1983 county population and a 1.4-percent increase in county employment over 1982 levels.

4.11 HOUSING, SOCIAL STRUCTURE, AND COMMUNITY SERVICES

The following section summarizes the impacts of the remedial action alternatives on housing, social structures, and community services in the Riverton area. Section E.2.2 of Appendix E, Socioeconomics, provides more detailed information.

Relocation to Gas Hills would involve hiring up to 10 workers from outside Fremont County during the peak period of remedial action. Stabilization in place would involve hiring 12 in-migrant workers, and the Dry Cheyenne alternative would bring 13 workers into the area. Given a 1980 housing stock in Riverton of 3,653 units plus an additional 500 moteltype rooms, negligible impacts would be expected on the local housing situation. As the no action alternative would not involve any in- migration of workers, there would be no impact on the local housing situation.

Because of the low levels of population in-migration (19 to 24 depending on the alternative), none of the action alternatives would have an appreciable effect on the local social structure. The no action alternative would involve no in-migration and would have no impact on the local social structure.

The in-migrant population would be expected to include four or five school-age children depending on the action alternative. Given a total enrollment in Riverton area public schools of over 3,300, no impacts would be expected from an additional four to five pupils.

In-migrant population water consumption would be expected to be 1,900, 2,300, or 2,400 gallons per day (using a 100-gallonds per day per-capita consumption factor), depending on the alternative. Direct remedial action uses (mostly nonpotable water for compaction, dust control, and the like) would range from 5,580,000 gallons for relocation to Gas Hills to 35,471,000 gallons for disposal at the Dry Cheyenne site. Adequate sources of water are available to provide the required quantities without impacting local water supplies.

The in-migrant, sewage generation would range from 1,900 gallons per day (gpd) to 2,400 gpd for the action alternatives, using a per-capita sewage generation factor of 100 gpd. The Riverton sewage system currently operates at 50 to 60 percent of its 5 million gpd capacity and can easily accommodate the small in-migrant sewage generation.

Because of the low levels of population increase associated with any action alternative, no adverse impacts would be expected on local public safety, health care, or recreational facilities. The no action alternative would not involve any in-migration and therefore, would have no impacts on local community services.

4.12 ECONOMIC STRUCTURE

This section summarizes the impacts of the remedial action alternatives on the local Fremont County economy. More detailed information is provided in Section E.2.3 of Appendix E, Socioeconomics.

Implementation of any of the action alternatives (including remedial action at the vicinity properties) would impact the local economy through wages and salaries paid to remedial action employees; through local spending for remedial action equipment and materials; and through indirect expenditures as remedial action dollars spent locally are respent locally on other goods and services. There also would be sales tax revenues that would accrue to state and local governments.

The total direct input to the local economy from relocation to Gas Hills is estimated at $17,346,000. This total includes $2,767,000 in local wages and salaries, and $14,579,000 in local expenditures for equipment and materials (e.g., gravel). This estimate is based on the assumption that all materials and 33 percent of the equipment would be obtained in Fremont County and 67 percent of the equipment would be obtained elsewhere in Wyoming. Using an indirect spending multiplier of 1.2238 for local expenditures (i.e., every dollar spent locally generates an additional $0.2238 in indirect spending) (WDEPAD, 1979), an additional $3,882,000 in local expenditures would be generated. The total local economic impact of disposal at the Gas Hills site would be up to $21,228,000.

There would be no local expenditures for the no action alternative. Consequently, there would be no local economic impact.

The total direct input to the local economy from stabilization in place is estimated at $8,878,000. This total includes $2,658,000 in local wages and salaries and $6,220,000 in local expenditures for equipment and materials. An additional $1,987,000 in local indirect expenditures would be generated. The total local economic impact of stabilization in place would be up to $10,865,000.

The total local economic impact for disposal at the Dry Cheyenne site would be up to $19,822,000. This total includes $4,455,000 for local wages and salaries, $11,742,000 for local equipment and materials expenditures, and $3,625,000 in local indirect expenditures.

4.13 TRANSPORTATION NETWORKS

Traffic impacts were assessed by estimating the peak remedial action traffic for each action alternative and comparing those estimates with the existing traffic volumes and capacities for the highway segments to be affected (Section 3.12). The estimated traffic impacts are conservative because remedial action traffic would be distributed over local highways rather than occurring entirely on any single highway. Traffic impacts would be short-term (i.e., for the duration of the remedial action); no long-term impacts would occur. All remedial action traffic would occur during normal weekday working hours. For any action alternative, there would be a substantial increase in traffic on Goes In Lodge Road in the vicinity of the Riverton tailings site; however, no quantitative assessment is possible because there are no traffic data for this road. The no action alternative would not involve any remedial action so there would be no traffic impacts.

Relocation to Gas Hills

Relocation to Gas Hills would primarily affect segments of Wyoming State Highways 789, 135, and 136 between the existing tailings site, the

Little Wind borrow site, and Gas Hills 45 to 60 road miles to the east. Incremental remedial action traffic would stem from worker commuting, site preparation, the haulage of the tailings and contaminated materials to the disposal site, the haulage of borrow materials from the Little Wind borrow site, and from miscellaneous trips.

Maximum traffic impacts would occur during months 20 through 31 of the 31-month schedule for relocation to Gas Hills. During these months, in addition to worker commuting, relocation of the tailings and contaminated materials to Gas Hills and the transportation of borrow materials from the Little Wind borrow site would be occurring simultaneously. Estimated traffic volumes would be 326 trips per day for tailings relocation (including return trips to the tailings site), 218 trips per day for the transportation of borrow materials, 36 trips per day for cleanup activities at the vicinity properties, 170 trips per day for worker commuting (85 workers times two trips per day, assuming one occupant per vehicle), and 200 trips per day for miscellaneous purposes.

If all of these trips were to occur on Wyoming State Highway 789, the total increase in traffic flows on this roadway would be 950 trips per day which would represent an increase of 21 percent over 1985 volumes. This same incremental volume (950 trips per day) on Wyoming State Highway 135 and 136 would represent 183- and 352-percent increases over the 1985 volumes on these lightly travelled roadways, respectively. In terms of peak hourly traffic flows, remedial action activities would add a maximum of 120 vehicles per hour on any roadway. Even if all remedial action traffic were added to each of these roadways, existing peak hourly traffic flows on both Wyoming State Highways 789, 135, and 136 are such that more than acceptable levels of service would still exist.

Stabilization in place

Stabilization in place would primarily affect segments of Wyoming State Highways 789 and 135 between the existing tailings site and borrow site 10. Incremental remedial action traffic would stem from worker commuting, site preparation, the haulage of borrow materials from borrow site 10, and from miscellaneous trips.

Maximum traffic impacts would occur during months 17 through 20 of the 24-month schedule for stabilization in place. During these months, in addition to worker commuting, the transportation of borrow materials from borrow site 10 would be ongoing. Estimated traffic volumes would include:

- o 216 trips per day for the transportation of borrow materials.
- o 36 trips per day for cleanup activities at the vicinity properties.
- o 144 trips per day for worker commuting (72 workers times two trips per day, assuming one occupant per vehicle).
- o 200 trips per day for miscellaneous purposes.

If all of these trips were to occur on Wyoming State Highway 789, the total increase in traffic flows on this roadway would be 596 trips per day which would represent an increase of 13 percent over 1985 volumes. This same incremental volume (596 trips per day) on Wyoming State Highway 135 would represent a 115-percent increase over the 1985 volumes on this lightly travelled roadway. In terms of peak hourly traffic flows, project activities would add a maximum of 75 vehicles per hour on any roadway. Even if all remedial action traffic were added to each of these roadways, existing peak hourly traffic flows on both Wyoming State Highways 789 and 135 are such that more than acceptable levels of service would still exist.

Disposal at the Dry Cheyenne site

Disposal at the Dry Cheyenne site would primarily affect short segments of Wyoming State Highways 789 and 135 and a segment of Wyoming State Highway 136 between Riverton and the alternate disposal site to the east.

Peak vehicular traffic impacts would occur between months 9 and 27, when tailings relocation and the transportation of clean fill (site restoration) and rock (erosion protection) would all be ongoing. During this period, remedial action traffic volumes would include:

- o 316 trips per day for tailings relocation, including return trips to the tailings site with clean fill for site restoration.
- o 36 trips per day for cleanup activities at the vicinity properties.
- o 24 trips per day for transportation of rock for erosion protection.
- o 186 trips per day for worker commuting (93 workers times two trips per day, assuming one occupant per vehicle).
- o 200 trips per day for miscellaneous purposes.

If the above maximum of 762 trips per day were to occur on Wyoming State Highway 789, it would represent an increase of 17 percent over 1985 volumes. The same incremental flow on Wyoming State Highways 135 and 136 would represent increases of 147 and 282 percent over 1985 volumes on these lightly travelled roadways, respectively. Peak hourly remedial action traffic would not be expected to exceed 95 vehicles per hour. Given existing peak hourly traffic flows on these roadways, more than acceptable levels of service would still exist on the three roadways even if all remedial action traffic were added to each roadway.

4.14 ENERGY AND WATER CONSUMPTION

All of the remedial action alternatives except no action would require the expenditure of energy to operate construction equipment and for on-site operations. In addition, water would be needed for personal consumption by the remedial action workers, compaction of the tailings and radon barrier, washdown of the haul trucks, and dust control. Table 4.7 lists the fuel, electricity, and water requirements for the action alternatives. The energy requirements for the relocation alternatives are much higher than for stabilization in place primarily due to transportation of the tailings and contaminated materials. The water requirement for the

Table 4.7 Summary of fuel, electricity, and water consumptions, Riverton remedial action alternatives

Alternative	Fuel (gallons)	Electricity (kilowatt-hours)	Water[a] (gallons)
Relocation to Gas Hills	2,082,000	415,000	5,580,000
Stabilization in place	1,160,000	293,000	22,221,000
Disposal at Dry Cheyenne site	1,697,000	621,000	35,471,000

[a]Excludes water consumed by in-migrant workers and their families (1,900 gallons per day for a 12-month peak period during relocation to Gas Hills; 2,300 gallons per day for an 18-month peak period during stabilization in place; and 2,400 gallons per day for a 19-month peak period during disposal at Dry Cheyenne).

Gas Hills alternative is the lowest because water consumption at Gas Hills is not considered. Section A.5 of Appendix A, Conceptual Designs, provides greater details on energy and water consumption; in-migrant water consumption is addressed in Section 4.11.

Fuel for construction equipment would be purchased from a local commercial source and would probably be stored in tanks at the site involved. No impacts on local fuel sources would be expected. At the Riverton tailings site, electricity would probably be supplied by the same local utility that services the active sulfuric acid plant at the site. This would not be expected to affect the availability of electricity at the site or in the Riverton area. Electricity at the Dry Cheyenne site would be supplied by diesel-powered generators at the site.

Potable water would be required for personal consumption by the remedial action workers (i.e., drinking water, showers, and laundry), and nonpotable water would be required for the construction activities (e.g., compaction and dust control). The water would be obtained in accordance with the applicable laws and regulations (Appendix G, Permits, Licenses, and Approvals). The city of Riverton water distribution system (Section E.1.5 of Appendix E, Socioeconomics) has adequate capacity to provide the amount of potable water required for any of the remedial action alternatives. Nonpotable water for the construction activities would probably be obtained from the Wind or Little Wind Rivers, and this should not affect the availability of water for other local uses. The maximum amount of nonpotable water required, 35,400,000 gallons or 109 acre-feet for the Dry Cheyenne alternative (Section A.5 of Appendix A, Conceptual Designs), represents less than 1 percent of the average annual discharge of the Wind River (approximately 673,000 acre-feet) or the Little Wind River (approximately 738,000 acre-feet) (Section C.1.1 of Appendix C, Water). Use of the well at the Riverton tailings site to provide water for remedial action could cause a small, short-term lowering of the local water level in the confined aquifer. For disposal at the Dry Cheyenne site, potable and nonpotable water would be trucked from sources in the Riverton area to the Dry Cheyenne site unless adequate water sources could be found closer to the disposal site.

4.15 ACCIDENTS NOT INVOLVING RADIATION

All of the remedial action alternatives except no action would involve the extensive use of heavy construction equipment (e.g., bulldozers, scrapers, and front-end loaders) and many heavy truck trips as tailings, contaminated materials, and clean borrow materials were transported between the final tailings disposal and borrow sites. Remedial action workers would also be commuting between their homes and the work sites. Because a high proportion of the remedial action work force is expected to be available locally, an average one-way commuting distance of 15 miles was assumed for remedial action workers for the Gas Hills and Dry Cheyenne relocation alternatives, with an average one-way commuting distance of 10 miles for stabilization in place.

The construction equipment used and transportation activities associated with each action alternative pose the risk of accidents and resulting injuries and fatalities. Based on nationwide data, the operation of all types of equipment (e.g., tractors, forklifts, cranes, bulldozers, and trucks) would result in approximately 0.15 non-fatal accidents leading to the loss of work time per man-year (DOT, 1977).

The following 1982 motor vehicle (including both trucks and automobiles) accident rate data for Fremont County are based on data obtained from personnel of the Wyoming Highway Department (Steen, 1984) and from a report on traffic accidents in Wyoming published by the Wyoming Highway Department (WHD, 1982). Fatal accidents in Fremont County occurred at the rate of one fatal accident for each 23,180,000 miles travelled (15 fatal accidents in an estimated 347,700,000 vehicle-miles travelled); injury accidents occurred at the rate of one for each 1,163,000 vehicle-miles travelled (299 injury accidents in 347,700,000 vehicle-miles travelled). Based on a 1982 report (Rao et al., 1982), nationwide truck travel in both urban and rural areas resulted in one fatality per 20,833,000 miles travelled and 0.82 injuries per 1 million miles travelled (equivalent to one injury per 1,270,000 miles travelled). The analyses presented below express expected transportation fatalities and injuries in terms of both of the above accident rate factors.

Non-radiological accident impacts associated with the action alternatives (Table 4.8) are estimated below based on the vehicle-miles travelled and man-years of labor associated with each alternative. It should be noted that the equipment use accident data include truck use and thus appear to be partly redundant with the purely transportation accident data.

Relocation to Gas Hills

Relocation to Gas Hills would have the most off-site vehicular travel among the action alternatives because the tailings and contaminated materials would be transported 45 to 60 road miles. As shown in Table 4.8,

Table 4.8 Non-radiological accident impacts

Remedial action alternative	Total off-site vehicle-miles travelled[a]	Total man-years of labor[a]	Traffic accident fatalities	Traffic accident injuries[b]	Equipment use accident injuries[b]	Total fatalities	Total injuries
Relocation to Gas Hills	10,809,000	187	0.47-0.52	8.51-9.29	28.1	0.47-0.52	36.6-37.4
Stabilization in place	1,965,000	143	0.08-0.09	1.55-1.69	21.5	0.08-0.09	23.1-23.2
Disposal at Dry Cheyenne site	3,565,000	209	0.15-0.17	2.81-3.07	31.4	0.15-0.17	34.2-34.5

[a]Includes 6 man-years of labor for vicinity properties cleanup activities (Section A.6 of Appendix A, Conceptual Designs).

[b]Injury accidents are defined as those leading to loss of work time.

10,809,000 total vehicle-miles would be involved, including the vicinity properties cleanup. Based on historical Fremont County accident rate data, 0.47 fatal accidents and 9.29 injury accidents would occur. Based on the nationwide, truck-only accident rate (which is similar to the Fremont County combined truck and automobile accident rate), 0.52 fatal accidents and 8.51 injury accidents would occur.

Relocation to Gas Hills would involve an estimated 187 man-years of labor including the vicinity properties cleanup. Assuming an equipment use accident factor of 0.15 injury accidents per man-year of labor, 28.1 injury accidents leading to loss of work time would be expected. The stabilization in place alternative would be expected to produce a total of 0.47 to 0.52 fatalities and 36.6 to 37.4 injuries.

No action

The no action alternative would not involve any remedial action and, therefore, would have no impacts in terms of construction or transportation accidents.

Stabilization in place

Stabilization in place would have the least off-site vehicular travel among the action alternatives because there would be no off-site transportation of the tailings and contaminated materials. As shown in Table 4.8, 1,965,000 total vehicle-miles would be involved, including the vicinity properties cleanup. Based on local accident rate data, 0.08 fatal accidents and 1.69 injury accidents would occur. Based on the nationwide, truck only accident rate, 0.09 fatal accidents and 1.55 injury accidents would occur. Stabilization in place would involve an estimated 143 man-years of labor (including the vicinity properties cleanup), and 21.5 injury accidents leading to loss of work time would be expected. The stabilization in place alternative would be expected to produce a total of 0.08 to 0.09 fatalities and 23.1 to 23.2 injuries.

Disposal at the Dry Cheyenne site

Disposal at the Dry Cheyenne site would involve a total of 3,565,000 vehicle-miles travelled. Fatal accidents would be expected to range from 0.15 (local data) to 0.17 (nationwide, truck only data); accident injuries would be expected to range from 2.81 (nationwide, truck only data) to 3.07 (local data). The 209 man-years of labor associated with disposal at Dry Cheyenne (including vicinity properties cleanup) would produce an estimated 31.4 equipment-use accidents. Thus, the Dry Cheyenne alternative would result in 0.15 to 0.17 fatalities and 34.2 to 34.5 injuries.

4.16 MITIGATIVE MEASURES

As stated in previous sections, Gas Hills is an area that contains several active (Title II) uranium mill tailings sites, and the specific active site for disposal of the inactive (Title I) Riverton tailings and contaminated materials would be selected by the Federal procurement process. Remedial action at the selected active site would be consistent with the EPA standards for active sites (40 CFR Part 192, Subparts D and E) and would be performed in accordance with a remedial action plan prepared by the owner and operator of the selected active site and to be approved by the NRC. The conceptual design for relocation to Gas Hills considers only remedial action at the Riverton tailings site and transportation of the tailings and contaminated materials to Gas Hills. Remedial action at the selected active tailings site may include mitigative measures that are not discussed in this document.

As stated in Section 2.3, the conceptual design for the Dry Cheyenne alternative is based on existing, published data. If this alternative were selected, additional site-specific data would be obtained before the final engineering design is made. This could necessitate the incorporation of mitigative measures that are not discussed in this document.

4.16.1 Mitigative measures during remedial action

The following mitigative measures were incorporated into the design and approach for each of the remedial action alternatives in order to reduce the environmental impacts:

- Excavation of the tailings, contaminated materials, and borrow materials at the Riverton site and borrow site 2 in the presence of an archaeologist to identify subsurface archaeological sites.
- Application of water and chemical dust suppressants to dirt and gravelled haul roads to inhibit dust emissions.
- Covering of haulage trucks to prevent the dispersion of tailings during relocation.
- Immediate cleanup of any off-site spills of contaminated materials in compliance with applicable regulations.
- Selection of borrow sites which are as close to the disposal sites as possible to reduce costs and eliminate the impacts of long haulage distances.
- Reclamation, including grading, topsoiling, and revegetating of borrow sites as required.
- Cleanup of any equipment used for remedial action before release to prevent the spread of contaminated materials.
- Use of local labor whenever possible to reduce the sociological impacts to the local communities and to provide economic benefits.
- Conducting operations only during normal daytime working hours to minimize noise disturbance to local residents.
- Maintaining close communications with the local population through an established public information task force.

The following mitigative measures were incorporated into the individual alternatives:

Relocation to Gas Hills

- o Location of the Little Wind borrow site to avoid any riparian habitats and maintenance of a 300-foot (minimum) buffer zone between the borrow site and the Little Wind River to protect wetlands, riparian habitats, and the river.
- o Backfilling, recontouring, and revegetating (as necessary) the areas disturbed at the Riverton tailings site by the removal of the tailings and contaminated materials.
- o Release of the Riverton tailings site after remedial action for use consistent with existing land use controls.

Stabilization in place alternative

- o Stockpiling of the surface soils encountered at the borrow sites for future reclamation of the sites.
- o Location of borrow site 10 to avoid disturbance of the nearby natural gas pipeline and the earthen dams northeast and southeast of the borrow site.
- o Backfilling, recontouring, and revegetating (as necessary) the areas disturbed during the cleanup and consolidation of the tailings and contaminated materials.

Dry Cheyenne alternative

- o Backfilling, recontouring, and revegetating (as necessary) the areas disturbed at the Riverton tailings site by the removal of the tailings and contaminated materials.
- o Backfilling, grading, and revegetating areas disturbed at the Dry Cheyenne disposal site for the construction staging area and the surface materials stockpile.
- o Release of the Riverton tailings site after remedial action for use consistent with existing land use controls.

4.16.2 Worker protection during remedial action

Training sessions applicable to the radiation hazards present at the site would be conducted for all employees prior to and during the remedial action. These sessions would include discussions of the industrial and radiological safety procedures, emergency procedures, and the effects of prenatal radiation exposure. Records would be maintained to document successful completion of the training by employees.

Controlled areas would be designated and conspicuously marked. Access to these areas would be restricted, and all personnel and equipment would be monitored for contamination. Access control records would be maintained. Those records would include a log of personnel and equipment entering and leaving the controlled areas and a log of dosimeters issued.

Protective clothing would be distributed to employees at the access control points when conditions warrant. Change and cleanup facilities would be provided.

Thermoluminescent dosimeters (TLDs) or film badges would be supplied to employees working in controlled areas for 40 hours in any 3 consecutive months. Dosimeters would be changed quarterly or more frequently if necessary. Urinalysis would be used to monitor employees internal exposures where potential ingestion of radioactive materials is indicated by air sampling data. Additional dosimetry might be required if positive results were noted. A system of employee exposure records would be maintained to document individual radiation exposures and the results of personnel dosimetry and bioassays.

Air particulate samples would be collected in work areas and at site boundaries. Samples would be analyzed for gross alpha levels and would be stored for later isotopic analyses, if necessary. Additional samples would be collected in work areas with limited ventilation and analyzed for radon daughter concentrations.

A respiratory protection program, with procedures for training employees and checking for the adequate fit of respirators, would be developed. Respirators would be used in work areas where the average mass dust loading is expected to reach 5 milligrams per cubic meter. Industrial hazards (e.g., noise levels) would be controlled in accordance with Occupational Safety and Health Administration (OSHA) regulations (e.g., the issuance of hearing protection).

Additional details regarding worker protection are available in the UMTRA Project Health and Safety Plan (DOE, 1983) and the remedial action plan (DOE, 1987).

4.16.3 Surveillance and maintenance

Title I of the UMTRCA defines the authorities and roles of the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission ("Commission") and the intent of licensing regarding inactive tailings sites in the various states. In part, Section 104(f)(2) of the UMTRCA reads:

> "...upon completion of the remedial action program...(the site) shall be maintained pursuant to a license issued by the Commission in such manner as will protect the public health, safety, and the environment. The Commission may, pursuant to such license or rule or order, require...monitoring, maintenance, and emergency measures necessary to protect public health and safety and other actions as the Commission deems necessary to comply with the standards (EPA) of Section 275...".

Title II of the UMTRCA authorized the NRC or agreement state to regulate active uranium mill tailings sites for operation and made the owners and operators of active sites responsible for remedial actions at the sites. Following remedial actions at the active sites, the sites will be under the direct control of the Federal Government, and the Federal agency having custody of the sites will monitor and maintain the sites as required by the NRC.

For the inactive and active uranium mill tailings sites, the NRC will issue licenses for the long-term surveillance and maintenance (including monitoring) of the disposal sites after the remedial actions are complete. These licenses may require the DOE or other Federal agency having custody of the sites to perform such surveillance, maintenance, and contingency measures as necessary to ensure that the sites continue to function as designed.

The surveillance and maintenance program for Gas Hills will be defined by the NRC; therefore, this program is not described in this document. For stabilization in place or disposal at the Dry Cheyenne site, the DOE would conduct the monitoring and maintenance of the disposal site pursuant to the requirements of the NRC's license until termination of the cleanup authority under the UMTRCA (i.e., 1993). At that time, the DOE or another agency to be designated by the President would maintain the site as required by the NRC. A detailed custodial surveillance and maintenance program would be defined jointly by the DOE and the NRC during the NRC license application and approval process. This program may include any or all of the following activities.

Site inspections

Site inspections would constitute a visual and definitive verification that the disposal site continues to function as designed and would assure continued compliance with the design standards. The DOE or another agency designated by the President would be responsible for the site inspections.

The site inspections would consist of two phases: Phase I, a systematic walk-over, is designed to qualitatively evaluate the condition of the disposal site; Phase II would consist of investigations to quantitatively assess changes in the disposal site that could lead to failure of the functional design in the absence of custodial maintenance. The Phase I inspections would be conducted on a specific schedule, such as annually, by a team of qualified professionals. The inspection team would review as-built drawings, engineering details, aerial photographs, and supporting documentation. A site walk-over would then be performed to evaluate any changes at the site with regard to factors such as erosion, flood effects, slope/cover system stability, settlement, displacement, plant or animal intrusion, and access control.

Based upon the evaluation and recommendations of the inspection team, Phase II studies might be conducted to quantitatively determine the magnitude and rate of effect of changes in the above factors. From these studies, the need for a corrective action (i.e., custodial maintenance) would be ascertained.

Aerial photography

Aerial photography might be used to supplement site inspections. The objectives might be to identify changes in site conditions (e.g., patterns of developing erosion that could affect the functional design), provide visual documentation of year-to-year variations in site conditions, and to identify activities (e.g., road conditions and storm drainage construction) adjacent to the site that might affect its function.

Aerial photography might be conducted on the same schedule as the site inspections. Photographs would be taken at both low (i.e., high resolution) and higher (i.e., for adjacent activities) altitudes and at oblique and vertical angles. The types of film, ground control, camera specifications, amount of aerial overlap, interpretative keys, and other requirements would be established prior to completion of remedial action.

Ground-water monitoring

Certain existing wells would be preserved during construction for use as monitoring wells after completion of the remedial action. In addition to these wells, a series of both shallow and deep wells might be installed for the purpose of monitoring ground-water quality. The locations for these wells would be selected in order to monitor the performance of the disposal site. Details of the ground-water monitoring would be developed during the NRC licensing process.

Reporting

Summary surveillance and monitoring reports that evaluate the results of these activities and recommend needed custodial maintenance (i.e., corrective actions) and future surveillance and monitoring would be prepared. Reports and supporting documentation would be placed on file with the DOE, NRC, State of Wyoming, and Fremont County.

Custodial maintenance

The need for custodial maintenance (i.e., corrective action) could only be determined by the site inspections and monitoring and by the NRC's and DOE's evaluation of the reports of these activities. However, it is anticipated that custodial maintenance would consist primarily of the following:

- o Limited earth/rock replacement because of unanticipated erosion, human or animal intrusion, or cover system disturbance. These activities are expected to be required infrequently.
- o Control of deep-rooted plants by infrequent application of herbicides or physical removal as required.

- Mechanical repairs to the security fence, gates, locks, and warning signs when necessary.

Contingency plans

In case of severe natural events (e.g., extreme rainfall or seismic events) or unusual human intrusion, procedures would be developed to initiate inspection and to institute custodial maintenance of the disposal site.

REFERENCES FOR SECTION 4.0

Anderson, Arthur, 1985a. Personal communication with Arthur Anderson, U.S. Fish and Wildlife Service, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated February 6, 1985.

Anderson, Arthur, 1985b. Personal communication with Arthur Anderson, U.S. Fish and Wildlife Service, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 4, 1985.

Anderson, Arthur, 1984. Personal communication with Arthur Anderson, U.S. Fish and Wildlife Service, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated August 27, 1984.

Askew, D. Lynn, 1987. Personal communication with D. Lynn Askew, Wyoming Department of Environmental Quality, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 14, 1987.

BLM (Bureau of Land Management), 1984. "Determination and Evaluation of Need for Consultation," File No. 6840, Lander Resource Area, Lander, Wyoming, June 31, 1984.

DOE (U.S. Department of Energy), 1985. Programmatic Environmental Report for Remedial Actions at UMTRA Project Vicinity Properties, UMTRA-DOE/AL-150327.0000, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1987. Remedial Action Plan and Site Design for Stabilization of the Inactive Uranium Mill Tailings Site at Riverton, Wyoming, UMTRA-DOE/AL-050507.0000, being prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1984. Final Environmental Impact Statement, Remedial Actions at the Former Vitro Chemical Company Site, South Salt Lake, Salt Lake County, Utah, DOE/EIS-0099-F, Washington, D.C.

DOE (U.S. Department of Energy), 1983. UMTRA Project Health and Safety Plan, UMTRA-DOE/AL-6, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOT (U.S. Department of Transportation), 1977. Tenth Annual Report, Fiscal Year 1976, Washington, D.C.

EPA (U.S. Environmental Protection Agency), 1983. Final Environmental Impact Statement for Standards for the Control of Byproduct Materials from Uranium Ore Processing (40 CFR 192), EPA 520/1-83-008-1 and 2, Washington, D.C.

EPA (U.S. Environmental Protection Agency), 1979. Compilation of Air Pollutant Emission Factors, AP-42, Supplements 1-13, Washington, D.C.

EPA (U.S. Environmental Protection Agency), 1974. Information on Levels of Environmental Noise Requirements to Protect the Public Health and Welfare with an Adequate Margin of Safety, EPA-550/9-74-004, Washington, D.C.

FBD (Ford, Bacon & Davis, Inc.), 1983. "Environmental Assessment of Remedial Actions on the Uranium Mill Tailings at the Riverton Site, Fremont County, Wyoming," unpublisned preliminary draft prepared by FBD, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Garcia, Pete, 1987. Personal communication with Pete Garcia, U.S. Nuclear Regulatory Commission, Uranium Recovery Field Office, Denver, Colorado, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 18, 1987.

Gooley, Edward, 1985. Personal communication with Edward Gooley, U.S. Army Corps of Engineers, Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 1, 1985.

Harms, Dale, 1984. Personal communication with Dale Harms, U.S. Fish and Wildlife Service, Helena, Montana, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated July 17, 1984.

Kessler et al. (F. M., Kessler, P. D. Schomar, P. C. Snanaud, and E. Rosendahl), 1978. Construction Site Noise Control Cost-Benefit Estimation Technical Background, Technical Report N-37, U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, Champaign, Illinois.

Lane, John, 1985. Personal communication with John Lane, Wyoming Highway Department, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated February 1, 1985.

Metzner, K., 1984. Personal communication with K. Metzner, City of Grand Junction, Colorado, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 3, 1984.

Miller, Ralph, 1984. Personal communication with Ralph Miller, Department of the Army, Omaha District Corps of Engineers, Omaha, Nebraska, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated July 10, 1984.

NAS (National Academy of Sciences), 1980. BEIR-III Report, The Effects on Population of Exposure to Low Levels of Ionizing Radiation, Advisory Committee on Biological Effects of Ionizing Radiation, National Research Council, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission), 1981a. MILDOS, A Computer Program for Calculating Environmental Radiation Doses from Uranium Recovery Operations, NUREG/CR-2011, PNL-3767, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission), 1981b. Data Base for Radioactive Waste Management Impacts Analyses Methodology Report, NUREG/CR-1759, Volume 3, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission), 1980a. Final Generic Environmental Impact Statement on Uranium Milling, NUREG-0706, Office of Nuclear Material Safety and Safeguards, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission), 1980b. Final Environmental Statement Related to the Operation of Gas Hills Uranium Project, Docket No. 40-299, Union Carbide Corporation, NUREG-0702, Washington, D.C.

Oakleaf, Robert, 1985. Personal communication with Robert Oakleaf, Wyoming Game and Fish Department, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 4, 1985.

Oakleaf, Robert, 1984. Personal communication with Robert Oakleaf, Wyoming Game and Fish Department, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated August 7, 1984.

Peel, Robert C., 1984. Memorandum from Robert C. Peel to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico; Subject: Field Inspection of Riverton site, Alternate Disposal Site and Borrow Sites (Nos. 2 and 10), dated September 11, 1984.

Pettingill, Harry, 1987. Personal communication with Harry Pettingill, U.S. Nuclear Regulatory Commission, Uranium Recovery Field Office, Denver, Colorado, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 30, 1987.

Rao et al. (R. K. Rao, E. L. Wilmot, and R. E. Luna) 1982. Non-Radiological Impacts of Transporting Radioactive Materials, SAND 81-1703, prepared by Sandia National Laboratories for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Reher et al. (C. Reher, T. Fisher, and D. Whiting), 1986. "Cultural Resource Survey in the Central Wind River Basin: The Riverton Uranium Tailings Project Survey," draft report prepared by Reher et al., Laramie, Wyoming, for the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico.

SHB (Sergent, Hauskins & Beckwith), 1985. "Geomorphic Evaluation, Riverton Uranium Mill Tailings Site, Uranium Mill Tailings Remedial Action Project," unpublished report prepared by SHB, Albuquerque, New Mexico, for the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico.

Steen, Gary, 1984. Personal communication with Gary Steen, Wyoming Highway Department, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 30, 1984.

Street, Phillip E., 1987. Personal communication with Phillip E. Street, U.S. Fish and Wildlife Service, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 20, 1987.

Taylor, Carol, 1985. Personal communication with Carol Taylor, U.S. Fish and Wildlife Service, Helena, Montana, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 4, 1985.

WDEPAD (Wyoming Department of Economic Planning and Development), 1979. Perspectives on the Economic Viability of Carbon, Fremont, Goshen and Sheridan Counties, Cheyenne, Wyoming.

WDEQ (Wyoming Department of Environmental Quality), 1985. Ambient Air Monitoring Data for 1984, Cheyenne, Wyoming.

WDEQ (Wyoming Department of Environmental Quality), 1984. Wyoming Air Quality Standards and Regulations, Cheyenne, Wyoming.

WDEQ (Wyoming Department of Environmental Quality), 1979. Memorandum from Charles A. Collins, Air Quality Supervisor, Air Quality Division; Subject: Fugitive Dust Emission Factors; January 24, 1979.

WGFD (Wyoming Game and Fish Department), 1983. "Riverton Valley Project, Level III Terrestrial Wildlife Impact Report," Pinedale, Wyoming.

WHD (Wyoming Highway Department), 1982. State of Wyoming Comprehensive Report on Traffic Accidents, Cheyenne, Wyoming.

Weber, Ed, 1987. Personal communication with Ed Weber, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 15, 1987.

Welch, Jack, 1984. Personal communication with Jack Welch, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated June 1, 1984.

Womack, Edward, 1984. Personal communication with Edward Womack, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated June 1, 1984.

GLOSSARY

absorbed dose, radiological	Radiation energy absorbed per unit mass, usually given in units of rads.
aggradation	Filling and raising the level of the bed of a stream or river by deposition of sediment.
alluvium	Sediment deposited by a flowing river.
alpha particle	A positively charged particle emitted from certain radionuclides. It is composed of two protons and two neutrons, and is identical to the helium nucleus.
anabranching	The division of a river by islands with widths greater than three times the water width at average discharge. The degree of anabranching is the percentage of reach length that is occupied by large bars or islands.
anisotropy	A variation in the general water flow direction within an aquifer. Water in an anisotropic aquifer may not flow parallel to the hydraulic gradient.
anomaly	A departure from the usual.
aquifer	A subsurface formation containing sufficiently saturated permeable material to yield usable quantities of water.
atom	A unit of matter; the smallest unit of an element consisting of a dense, central, positively charged nucleus surrounded by a system of electrons, equal in number to the number of nuclear protons and characteristically remaining undivided in chemical reactions except for a limited removal, transfer, or exchange of certain electrons.
avulsion	A rapid shift in a river or stream channel.
A-weighted scale	Sound pressure level scale which most closely matches the response of the human ear. This scale is most commonly used to measure environmental noise and is often supplemented by the time and duration of the noise to determine the total quantity of sound affecting people.
background radiation	Radiation arising from radioactive material other than that under consideration. Background radiation due to cosmic rays and natural radioactivity is always present, and there is always background radiation due to the presence of radioactive substances in building material, and the like.
beta particle	Charged particle emitted from the nucleus of an atom during radioactive decay, with mass and charge equal to those of an electron.
bioassay	A method for quantitatively determining the concentration of radionuclides in a body by measuring the quantities of those radionuclides that are eliminated from the body, usually in the urine or the feces.

Class I to III archaeological surveys	Relates to an archaeological investigation of probable occurrence of cultural resources within a given locale. A Class I survey is a literature search for predetermined archaeological features of historic significance; a Class II survey is a combination of a literature review and a partial but cursory excavation of an area to determine the presence of cultural resources; a Class III survey is an in-depth inspection of an area to determine the presence of archaeological materials where the likelihood of their occurrence is high, based on the history of the area.
colluvium	Weathered geologic material transported by gravity.
confined aquifer	An aquifer bounded above and below by relatively impermeable rock layers.
confining layer	A stratum immediately above or below an aquifer with a hydraulic conductivity less than that of the aquifer.
cross-bedded	Inclined at right angles to the current direction.
Curie (Ci)	The unit of radioactivity of any nuclide, defined as precisely equal to 3.7×10^{10} disintegrations per second.
daughter product(s)	A nuclide resulting from radioactive disintegration of a radionuclide, formed either directly or as a result of successive transformations in a radioactive series; it may be either radioactive or stable.
decay, radioactive	Disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particles, photons, or both.
decontamination	The reduction of radioactive contamination from an area to a predetermined level set by a standards-setting body such as the EPA, by removing the contaminated material.
differential settlement	The relative movement of two parts of a structure.
disintegrations per minute or second	The number of radioactive decay events occurring per minute or second.
disposal	The planned, safe, and permanent placement of radioactive waste.
dose	A general term denoting the quantity of radiation or energy absorbed, usually by a person; for special purposes, it must be qualified; if unqualified, it refers to absorbed dose.
dose, absorbed	The amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material at the point of interest; given in units of rads.
dose commitment	The cumulative dose equivalent that results and will result from exposure to radioactive materials over a discrete time period; given in units of rems.

dose equivalent	The quantity that expresses all kinds of radiation on a common scale for calculating the effective absorbed dose; defined as the product of the absorbed dose in rads and modifying factors, especially the qualifying factor; given in terms of rems. Often abbreviated "dose."
eolian	Deposited after transport by wind.
endemic	Belonging to or native to a locality or region.
erg	A unit of work or energy.
exposure	The presence of gamma radiation that may deposit energy in an individual; given in units of roentgens.
external dose	The absorbed dose that is due to a radioactive source external to the individual as opposed to radiation emitted by inhaled or ingested sources.
floodplain	Lowland or relatively flat areas that are subject to flooding. A 100-year floodplain has a 1 percent or greater probability of flooding in any given year.
fluvial	Of or pertaining to rivers; produced by river action.
flux, radon	The emission or emanation of radon gas from the earth or other material, usually measured in units of picoCuries per square meter per second.
frost heave	The lifting of a surface by the internal action of frost within the soil structure.
gamma	A high energy and deep penetrating form of radiation.
gamma dose	Radiation dose caused by gamma radiation.
gamma logging (or logs)	A technique for determining gamma radiation levels at various depths in a borehole.
gamma ray	High energy electromagnetic radiation emitted from some radioactive radionuclides. The energy levels are specified for different radionuclides.
gamma spectral analysis (gamma spectroscopy)	An analytical technique for identifying radionuclides based on their different gamma energy levels.
geomorphic	Of or like the earth, its shape, or surface configuration; geomorphology is the geological study of the configuration and evolution of land forms.
ground water	Water below the land surface, generally in a zone of saturation.
half-life	The time required for 50 percent of the quantity of a radionuclide to decay into its daughters.

health effect	Adverse physiological response to radiation exposure. In this report, one excess health effect is defined as one cancer death from exposure to radioactivity which is in addition to the normal occurrence of fatal cancer.
hydraulic conductivity	Ratio of flow velocity to driving force (for viscous flow under saturated conditions of a specified liquid in a porous medium).
hydraulic gradient	Pressure gradient; rate of change of pressure head per unit of distance of flow at a given point.
imbricated	Overlapped by stream flow (a "shingled" effect).
inert gas	One of the chemically unreactive gases: helium, neon, argon, krypton, xenon, and radon.
in-situ	In the natural or original position.
internal dose	The absorbed dose or dose commitment resulting from inhaled or ingested radioactivity.
isotopes	Nuclides having the same number of protons in their nuclei, but differing in the number of neutrons; the chemical properties of isotopes of a particular element are almost identical.
leachate	A solution obtained by leaching, as in the downward percolation of water through soil or solid waste containing soluble substances.
lek	A mating and display area for various upland game birds, including the sage grouse.
licensing	In this report, the process by which the NRC will, after the remedial actions are completed, approve the final disposition and controls over a disposal site. It will include a finding that the site does not and will not constitute a danger to the public health and safety.
liquefaction	A condition where a soil undergoes continued deformation at a constant low residual stress or with low residual resistance, due to the buildup and maintenance of high pore water pressures in excess of the effective confining pressure.
lithic (scatter)	Pertaining to stone.
loam	Soil material that contains 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand.
maintenance, custodial (passive)	The repair of fencing, the repair or replacement of monitoring equipment, revegetation, minor additions to soil cover, and general disposal site upkeep such as mowing grass.

man-rem — Unit of population exposure obtained by summing individual dose-equivalent values for all people in the population. Thus, the number of man-rems attributed to 1 person exposed to 100 rems is equal to that attributed to 100 people each exposed to 1 rem.

mass wasting — The slow downslope movement of rock debris (due to gravity).

meander — One of a series of somewhat regular and looplike bends in the course of a stream.

meander scar — Crescentic cuts in the upland bordering a stream.

micro — A prefix meaning one millionth (x 1/1,000,000 or 10^{-6}).

milli — A prefix meaning one thousandth (x 1/1000 or 10^{-3}).

mitigative measure measure — A measure implemented to reduce the adverse environmental impacts of remedial action (e.g., the application of water and chemical dust suppressants to dirt and gravelled haul roads to inhibit dust emissions.)

Modified Mercalli scale — A standard scale for the evaluation of the local intensity of earthquakes based on observed phenomena such as the resulting level of damage. Not to be confused with magnitude, such as measured by the Richter scale, which is a measure of the comparative strength of earthquakes at their sources.

monitor — To observe and make measurements to provide data for evaluating the performance and characteristics of the disposal site.

National Register of Historic Places — Established by the Historic Preservation Act of 1966. The Register is a listing of archaeological, historical, and architectural sites nominated for their local, state, or national significance by state and Federal agencies and approved by the Register staff.

native ground water — Naturally occurring ground water which has not had its chemical character altered as a result of human activities.

nuclide — A general term applicable to all atomic forms of the elements; nuclides comprise all the isotopic forms of all the elements. Nuclides are distinguished by their atomic number, atomic mass, and energy state.

orogeny — The process of mountain building, especially by folding and faulting of the earth's crust.

paleo-channel — Old or ancient channel.

passive institutional controls — Those controls which preclude human contact with the waste or require a continuing social order. Examples include Federal ownership of a disposal site, monuments on the site, records with agencies, and physical barriers (e.g., riprap covers, vegetation, waste burial).

perched ground water	Ground water separated from an underlying body of ground water by unsaturated rock.
percolate	To pass (a liquid) through a porous substance.
permeability	The ease with which liquids or gases penetrate or pass through a layer of soil. Technically, it is the volume of fluid that will flow through a unit area under a unit hydraulic gradient, measured in centimeters per second or equivalent units.
permissible dose	That dose of ionizing radiation that is considered acceptable by standards-setting bodies such as the EPA.
person-rem	Same as man-rem.
pico	A prefix meaning one trillionth (1 x 1/1,000,000,000,000 or 10^{-12}).
picoCurie	A unit of radioactivity defined as 0.037 disintegrations per second.
piezometric surface	The potentiometric surface of an aquifer. This represents the pressure exerted on a confined aquifer, or the water table in an unconfined aquifer.
primary succession type	A plant that colonizes an area not previously covered by vegetation.
proton	An electrically positive elementary particle found in the nucleus of an atom. Also, the nucleus of a hydrogen atom.
rad	A unit of measure for the absorbed dose of radiation. It is equivalent to 100 ergs per gram of material.
radioactive decay chain	A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nuclide results.
radioactivity (radioactive decay)	The property of some nuclides of spontaneously emitting particles or gamma radiation or of spontaneous fission.
radioisotope	A radioactive isotope of an element with which it shares almost identical chemical properties.
radionuclide	A radioactive nuclide.
radium-226 (Ra-226)	A radioactive daughter product of uranium-238. Radium is present in all uranium-bearing ores; it has a half-life of 1620 years.
radon-222 (Ra-222)	The gaseous radioactive daughter product of radium-226; it has a half-life of 3.8 days.

radon daughter product	One of several short-lived radioactive daughter products of radon-222. All are solids.
range type	A distinctive kind of rangeland that has a certain potential for producing rangeland plants. Each type has its own combination of environmental conditions and characteristic plant communities.
recharge	Resupply, replenish.
rem	A unit of dose equivalent equal to the absorbed dose in rads times quality factor times any other necessary modifying factor. It represents the quantity of radiation that is equivalent in biological damage to 1 rad of x-rays.
Richter scale	A logarithmic scale ranging from 1 to 10, used to express the magnitude or total energy of an earthquake.
riparian	Of, on, or pertaining to the bank of a natural course of water.
riprap	Rock used for the protection of bluffs or structures exposed to erosional forces from direct surface runoff or adjacent flooding.
roentgen	A unit of measure of ionizing radiation in air; 1 roentgen in air is approximately equal to 1 rad and 1 rem in tissue.
scat	The feces or fecal droppings of wildlife.
soil infiltration rate	The rate at which water enters the soil surface and moves vertically downward.
soil percolation rate	The rate at which water moves through soil in all directions.
solifluction	The process of slow flowage from higher to lower ground of soils saturated with water.
stabilization	The reduction of radioactive contamination in an area to a predetermined level by encapsulating or covering the contaminated material.
surveillance	The observation of the disposal site for purposes of visual detection of need for custodial care, evidence of intrusion, and compliance with other license and regulatory requirements.
tailings, uranium mill	The wastes remaining after most of the uranium has been extracted from uranium ore.
thalweg	The line joining the deepest points of a stream channel.
thorium-230 (Th-230)	A radioactive-daughter product of uranium-238; it has a half-life of 80,000 years and is the parent of radium-226.

transmissivity, hydraulic	A measure of the ability of an aquifer to transmit water equal to the product of the permeability and the thickness of the aquifer, expressed in gallons per day per foot of drawdown.
UMTRA Project	Uranium Mill Tailings Remedial Action Project of the U.S. Department of Energy.
unconfined aquifer	An aquifer without an upper confining layer. Also known as phreatic or water-table aquifers.
uranium-238 (U-238)	A naturally-occurring radioisotope with a half-life of 4.5 billion years; it is the parent of uranium-234, thorium-230, radium-226, radon-222, and others.
vicinity property	A property in the vicinity of a designated UMTRA Project tailings site that is determined by the DOE, in consultation with the NRC, to be contaminated with residual radioactive material derived from that site, and which is determined by the DOE to require remedial action.
water table	The surface of a body of unconfined ground water at which pressure is equal to that of the atmosphere.
working level (WL)	A measure of radon daughter product concentrations. Technically, it is any combination of short-lived radon decay products in 1 liter of air that will result in the ultimate emission of alpha particles with a total energy of 130,000 million electron volts.
working-level month (WLM)	The exposure resulting from inhalation of air with a month (WLM) concentration of 1 WL for 170 working hours. Continuous exposure of a member of the general public to 1 WL for one year results in approximately 53 WLM.
xeric	Extremely dry.

ABBREVIATIONS AND ACRONYMS

ac	Acre; a unit of area = 43,560 square feet
AEC	U.S. Atomic Energy Commission
ANL	Argonne National Laboratory, Argonne, Illinois
atm	Atmosphere; a unit of pressure = 30 inches of mercury
BEIR	Advisory Committee on the Biological Effects of Ionizing Radiation of the National Academy of Sciences (also their report)
BFEC	Bendix Field Engineering Corporation, Grand Junction, Colorado
BIA	Bureau of Indian Affairs, U.S. Department of the Interior
BLM	Bureau of Land Management, U.S. Department of the Interior
BRH	Bureau of Radiological Health, U.S. Department of Health, Education, and Welfare
°C	Degrees Centigrade or Celsius
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
cfs	Cubic feet per second
cfs/ft	Cubic feet per second per foot
Ci	Curie; a unit of radioactivity = 3.7×10^{10} disintegrations per second
cm	Centimeters; a unit of length = 0.394 inch
CO	Carbon monoxide
CSU	Colorado State University, Fort Collins, Colorado
cy	Cubic yards; a unit of volume = 27 cubic feet
D	Diameter; for example, D_{50} denotes the diameter of 50 percent of an amount of rock by weight
dBA	Decibels on the A-weighted sound measurement scale; a logarithmically based unit of sound intensity weighted to account for human auditory responses
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation

EA	Environmental assessment
e.g.	For example
EGR	External gamma radiation
EIS	Environmental impact statement
EPA	U.S. Environmental Protection Agency
et al.	And others
et seq.	And the following
°F	Degrees Fahrenheit
FBD	Ford, Bacon & Davis Inc., Salt Lake City, Utah (1983 and thereafter)
FBDU	Ford, Bacon & Davis Utah Inc., Salt Lake City, Utah (prior to 1983)
FONSI	Finding of No Significant Impact
fps	feet per second
FR	Federal Register
ft^2	Square feet; a unit of area = 144 square inches
ft	Foot; a unit of length = 12 inches
FWS	U.S. Fish and Wildlife Service, U.S. Department of the Interior
g	Grams; a unit of weight = 0.035 ounce
g	Gravity; a force expressed as acceleration equal to 32 feet per second per second
GECR	Geochemistry and Environmental Chemistry Research, Inc., Rapid City, South Dakota
gpd	Gallons per day
gpm	Gallons per minute
HC	Hydrocarbon
HGCC	Hydrogeochemical Characterization Committee, Colorado State University, Fort Collins, Colorado
hr	Hour; a unit of time = 60 minutes
ICRP	International Commission on Radiological Protection
i.e.	That is (to say)

ISCST	Industrial Source Complex Dispersion Model; an air quality computer code
kw	Kilowatt
kwh	Kilowatt hours
l	Liter; a unit of volume = 1.057 quarts
LBL	Lawrence Berkeley Laboratory, University of California, Berkeley, California
L_{dn}	Day-night sound level, measured in decibels
L_{eq}	Equivalent sound level, measured in decibels
m	Meter; a unit of length = 3.28 feet; also milli, a prefix meaning one-thousandth (10^{-3})
m^2	Square meter; a unit of area = 10.76 square feet
MCE	Maximum Credible Earthquake
mg	Milligram; a thousandth of a gram
mg/l	Milligrams per liter
mg/m^3	Milligrams per cubic meter
$microg/m^3$	Micrograms per cubic meter
microR/hr	Microroentgens per hour
Mound	Monsanto Research Corporation - Mound, Miamisburg, Ohio
mR/hr	Milliroentgens per hour
MSRD	Mountain States Research and Development, Tucson, Arizona
MWR	Mountain West Research, Inc., Billings, Montana
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NEPA	National Environmental Policy Act of 1969 (PL91-190)
NOAA	National Oceanic and Atmospheric Administration, U.S. Department of Commerce
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NRC	U.S. Nuclear Regulatory Commission

NRHP	National Register of Historic Places
O_3	Ozone
ORNL	Oak Ridge National Laboratory, Oak Ridge, Tennessee
OSHA	Occupational Safety and Health Administration, U.S. Department of Labor
p	Pico, a prefix meaning one trillionth (10^{-12})
Pb-210	Lead-210
pCi/g	PicoCuries per gram
pCi/l	PicoCuries per liter
pCi/m^2s	PicoCuries per square meter per second
PHS	Public Health Service, U.S. Department of Health and Human Services
PL	Public Law
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
Po-210	Polonium-210
ppm	Parts per million
R	Roentgen; a unit of gamma radiation = 1 rem
RAECOM	Radon Attenuation Effectiveness and Cover Optimization with Moisture Effects; a radon attenuation computer code
RAP	Remedial action plan
Ra-226	Radium-226
RDC	Radon-daughter concentration
Rn-222	Radon-222
SCS	Soil Conservation Service, U.S. Department of Agriculture
sec	Second; a unit of time
SHB	Sergent, Hauskins & Beckwith, Phoenix, Arizona
SHPO	State Historic Preservation Officer
SNL	Sandia National Laboratories, Albuquerque, New Mexico
SO_2	Sulfur dioxide

SO_x	Sulfur oxides
Tn-230	Thorium-230
TLD	Tnermoluminescent dosimeter
TSP	Total suspended particulates
UMTRA Project	Uranium Mill Tailings Remedial Action Project
UMTRCA	Uranium Mill Tailings Radiation Control Act of 1978 (PL95-604)
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USBR	Bureau of Reclamation, U.S. Department of the Interior
USGS	U.S. Geological Survey, U.S. Department of the Interior
WDAFC	Wyoming Department of Administration and Fiscal Control, State of Wyoming
WDEPAD	Wyoming Department of Economic Planning and Development, State of Wyoming
WDEQ	Wyoming Department of Environmental Quality, State of Wyoming
WDRT	Wyoming Department of Revenue and Taxation, State of Wyoming
WESC	Wyoming Employment Security Commission, State of Wyoming
WGFD	Wyoming Game and Fish Department, State of Wyoming
WHD	Wyoming Highway Department, State of Wyoming
WL	Working level (a measure of radon-daugnter-product concentration)
WLM	Working-level month (exposure to 1 WL for 170 hours)
yr	Year(s)

AGENCIES, ORGANIZATIONS, AND PERSONS CONSULTED

Agency/Organization	Person	Subject
Arix Engineers Riverton, Wyoming	Harry LaBonde	Flood studies
Bureau of Indian Affairs, Billings Area Office Billings, Montana	Jim Charles Richard Whitesell	Cultural resources
Bureau of Indian Affairs, Wind River Agency Fort Washakie, Wyoming	Richard Harbour Art Hallet Ray Nation Bob Robertson	Biology, cultural resources, geology, highway statistics, land use
Bureau of Land Management, Lander Resource Area Lander, Wyoming	Roger Birk Fred Georgeson Jack Kelly Ray Packer Craig Sorenson Ed Weber Jack Welch Edward Womack	Biology, cultural resources, geology, land use, scenic resources, water
City of Riverton Riverton, Wyoming	Richard Cisar Bernard Scott	Socioeconomics, water
Department of the Army, Corps of Engineers Albuquerque, New Mexico	Don Soards	Water
Department of the Army, Corps of Engineers Riverton, Wyoming	Edward Gooley	Floodplains, wetlands
Department of the Army, Omaha District Corps of Engineers Omaha, Nebraska	Ralph Miller Michael Gilbert	Floodplains, wetlands
Environmental Protection Agency, Environmental Services Division Denver, Colorado	Irwin Dickstein Tom Entzminger Marshall Payne James Zieche	Water quality
Fremont County Assessor's Office Lander, Wyoming		Socioeconomics
Fremont County Clerk's Office Lander, Wyoming		Socioeconomics
Fremont County Planner's Office Lander, Wyoming	Ron Martin Ray Price	Socioeconomics, land use

AGENCIES, ORGANIZATIONS, AND PERSONS CONSULTED (Continued)

Agency/Organization	Person	Subject
Fremont County Treasurer's Office Lander, Wyoming		Socioeconomics
Soil Conservation Service Lander, Wyoming	Jack Iiams	Flood studies, meteorology, soils
St. Stephen's Mission Riverton, Wyoming	Kathryn Brown Don Johnson	Historic resources, population statistics
St. Stephen's Mission School Riverton, Wyoming	Jim Doyle	Population statistics
U.S. Bureau of Reclamation Billings, Montana	Howard Gunnarson Jim Horn	Water
U.S. Bureau of Reclamation Denver, Colorado	Lou Schreiner	Water
U. S. Bureau of Reclamation Riverton, Wyoming	Richard Brohl	Flood studies and meteorology
U.S. Fish and Wildlife Service Cheyenne, Wyoming	Arthur Anderson	Threatened and endangered species, wetlands
U. S. Fish and Wildlife Service Lander, Wyoming	Dick Baldes	Biology
U. S. Fish and Wildlife Service Helena, Montana	Wayne Brewster	Threatened and endangered species, wetlands
U.S. Geological Survey Water Resources Division Cheyenne, Wyoming	Stan Druse	Water
Western Nuclear, Inc. Riverton, Wyoming	W. L. McFarland	Acid plant operations
Wind River Housing Authority Fort Washakie, Wyoming	Lucille McAdams	Housing statistics
Wyoming Department of Administration and Fiscal Control Cheyenne, Wyoming		Socioeconomics

AGENCIES, ORGANIZATIONS, AND PERSONS CONSULTED (Concluded)

Agency/Organization	Person	Subject
Wyoming Department of Economic Planning and Development Cheyenne, Wyoming	Anne McGowan	Socioeconomics
Wyoming Department of Environmental Quality, Air Quality Division Cheyenne, Wyoming	Bernard Daily	Air quality, meteorology
Wyoming Department of Environmental Quality, Water Quality Division Cheyenne, Wyoming	Jeff Hermanski	Water quality
Wyoming Department of Revenue and Taxation Cheyenne, Wyoming		Socioeconomics
Wyoming Game and Fish Department Cheyenne, Wyoming	Walt Gasson	Biology
Wyoming Game and Fish Department Lander, Wyoming	Forrest Hammond Marvin Hockley Robert Oakleaf Tom Ryder	Biology
Wyoming Highway Department Cheyenne, Wyoming	Ron Skidmore Garry Steen Eric Taylor John Lane	Highway statistics
Wyoming Recreation Commission Cheyenne, Wyoming	Sheila Bricher-Wade	Historical resources
Wyoming State Engineer's Office Cheyenne, Wyoming	Mike Penz	Water
Wyoming Water Development Commission Cheyenne, Wyoming	John Wade	Water
Wyoming Water Research Center Laramie, Wyoming	Walt Eifert	Water

LIST OF PREPARERS

Person	Organization	Responsibility
Arrie Bachrach	Jacobs	Socioeconomics/Land Use
Kenneth Baker	Jacobs-Weston	Manager, Radiological Services
Denise Bierley	Jacobs-Weston	Scenic and Cultural Resources/ Permits
Theresa Bond	Jacobs-Weston	Graphics
Michael Bone	Jacobs-Weston	Engineering/Surface Water
James Brinkman	Jacobs-Weston	Ground Water
Steve Byers	Jacobs	Weather/Air Quality/Noise
Jack Caldwell	Jacobs-Weston	Manager, Engineering Services
Susan Colarullo	Sergent, Hauskins and Beckwith	Ground Water
Steven Cox	Jacobs-Weston	Graphics
Paul Darr	Sergent, Hauskins and Beckwith	Ground Water/Geology
Victoria Dery	Jacobs-Weston	Engineering
Bill Deutsch	Jacobs-Weston	Acting Manager, Hydrological Services
Tom Farmer	Sergent, Hauskins and Beckwith	Ground Water
Laura Gaetjens	Jacobs-Weston	Graphics
Steven Green	Jacobs-Weston	Radiation
Keith Hinds	Jacobs-Weston	Public Concerns
Jack Hoopes	Jacobs-Weston	Geology/Soils/Public Concerns
Mark Jackson	Jacobs-Weston	Vicinity Properties
Dale Jones	Jacobs-Weston	NEPA Management
Jim Kapuranis	Jacobs-Weston	Engineering
Berg Keshian	Jacobs-Weston	Acting Manager, Engineering Services

LIST OF PREPARERS (Continued)

Person	Organization	Responsibility
David Lechel	Jacobs-Weston	Manager, Environmental Services
Lily Mace	Jacobs-Weston	Word Processing
Gary Meunier	Jacobs	Weather/Air Quality/Noise
Carol Meyer	Jacobs-Weston	Technical Editor
Mark Miller	Jacobs-Weston	Manager, Radiological Services
David Morycz	Jacobs	Weather/Air Quality/Noise
Eloise Mulford	Jacobs-Weston	Biology
Marc Nelson	Jacobs-Weston	NEPA Management
Laura Parrott	Jacobs-Weston	Word Processing/Editing
Robert Peel	Jacobs-Weston	Cultural Resources/Permits/ Site Manager
Kelly Peil	Jacobs-Weston	Site Manager
Reta Petersen	Jacobs-Weston	Editing
Mark Pingle	Jacobs	Land Use/Socioeconomics/ Transportation
Raoul Portillo	Jacobs-Weston	Surface Water
Pam Preisen	Jacobs-Weston	Word Processing/Editing
Ron Rager	Sergent, Hauskins and Beckwith	Engineering Geomorphology
C.H. Persson-Reeves	Jacobs-Weston	Geology/Soils
Kim Ries	Jacobs-Weston	Ground Water
Larry Rogers	Jacobs-Weston	Biology
Josie Sanchez	Jacobs-Weston	Word Processing
Shirley Santistevan	Jacobs-Weston	Word Processing
Robert Schoenfelder	Jacobs-Weston	Radiation
Elizabeth Wagner	Jacobs-Weston	Graphics

LIST OF PREPARERS (Concluded)

Person	Organization	Responsibility
Michael Silva	Jacobs-Weston	Engineering
Gail Sutton	Jacobs-Weston	Assistant Technical Editor
John Thackston	Jacobs-Weston	Manager, Hydrological Services
Duane Truitt	Jacobs-Weston	Engineering
Phillip Zelle	Jacobs-Weston	Radiation

DOE/EA-0254

ENVIRONMENTAL ASSESSMENT OF REMEDIAL ACTION AT THE RIVERTON URANIUM MILL TAILINGS SITE RIVERTON, WYOMING

APPENDICES

JUNE, 1987

U.S. Department of Energy
UMTRA Project Office
Albuquerque, New Mexico

TABLE OF CONTENTS

APPENDIX A

CONCEPTUAL DESIGNS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

A.1 INTRODUCTION

A.1.1 PURPOSE

This appendix provides the information needed to understand the conceptual designs for the remedial action alternatives addressed in this environmental assessment. This appendix is intended to provide sufficient details for the reader to evaluate the feasibility and assess the impacts of each remedial action alternative; however, this appendix is not intended to provide the detailed engineering necessary to implement the alternatives.

The conceptual design for the proposed action (relocation to Gas Hills) is based on data and calculations applicable to the stabilization in place alternative (e.g., the total volume of tailings and contaminated materials), and the details of these data and calculations are available in the remedial action plan (RAP) (DOE, 1987). The proposed action consists of relocating the tailings and contaminated materials from the inactive (Title I) Riverton tailings site to an active (Title II) uranium mill tailings site. The tailings and contaminated materials would be stabilized at the active site in accordance with a remedial action plan prepared by the owner and operator of the site and to be approved by the U.S. Nuclear Regulatory Commission (NRC); therefore, the engineering details for stabilization at the active site (e.g., design features for control of radon emanation and erosion protection) are not considered in this conceptual design.

The conceptual design for the stabilization in place alternative is based on field studies, laboratory testing, and various modeling techniques. For disposal at the Dry Cheyenne site, the conceptual design is based on existing, published data and assumptions for various factors (e.g., soil type and availability) that are based on the data and calculations applicable to the stabilization in place alternative.

A.1.2 DESIGN OBJECTIVES

Title I of the Uranium Mill Tailings Radiation Control Act (UMTRCA), Public Law 95-604, authorized the U.S. Department of Energy (DOE) to perform remedial action at the inactive Riverton tailings site (as well as at many other inactive sites) to reduce the potential public health impacts from the residual radioactivity remaining in the tailings. Title II of the UMTRCA authorized the NRC or agreement state to regulate the operation and eventual reclamation of active uranium mill tailings sites. The purpose of all remedial actions under Titles I and II of the UMTRCA is to stabilize and control the uranium mill tailings (residual radioactive wastes) and other contaminated materials in a manner that complies with the U.S. Environmental Protection Agency (EPA) standards, Title 40, Code of Federal Regulations, Part 192, Subparts A through E (40 CFR Part 192, Subparts A through E). Consistent with this purpose and the EPA standards applicable to the clean-up of open lands and habitable buildings, the following major design objectives were established for the proposed action:

- Reduce contaminant levels (radium-226) in areas released for unrestricted use to levels consistent with the EPA standards.

- o Reduce radiation levels in habitable buildings (including vicinity properties) to levels consistent with the EPA standards.

- o Protect against releases of contaminants from the Riverton site during construction.

- o Minimize areas disturbed at the Riverton site during construction, and minimize human exposure to contaminated materials.

- o Ensure, to the extent practicable, that existing or anticipated beneficial uses of ground and surface waters at the Riverton tailings site are not adversely affected.

The major design objectives for the other remedial action alternatives (stabilization in place and disposal at the Dry Cheyenne site) are identical to the objectives established for the proposed action and also include the following objectives for the disposal site:

- o Reduce the average radon flux from the disposal site to levels consistent with the EPA standards.

- o Design controls to be effective for up to 1,000 years to the extent reasonably achievable, and, in any case, for at least 200 years.

- o Minimize the land area to be occupied by the stabilized tailings.

- o Prevent inadvertent human intrusion into the stabilized tailings.

- o Minimize plant root penetration and animal burrowing into the stabilized tailings.

A.1.3 Borrow sites

The proposed action, relocation to Gas Hills, would require earthen borrow materials for restoration of the areas disturbed at the Riverton tailings site during remedial action. The Little Wind borrow site (Table A.1.1 and Figure A.1.1) was chosen as the source of these borrow

Table A.1.1 Borrow sites for the remedial action alternatives

Remedial action alternative	Borrow sites: Earth	Borrow sites: Gravel and rock
Relocation to Gas Hills	Little Wind borrow site	None
Stabilization in place	Borrow site 10	Boulder Flats borrow site
Disposal at Dry Cheyenne site	Dry Cheyenne disposal site	Borrow site 2

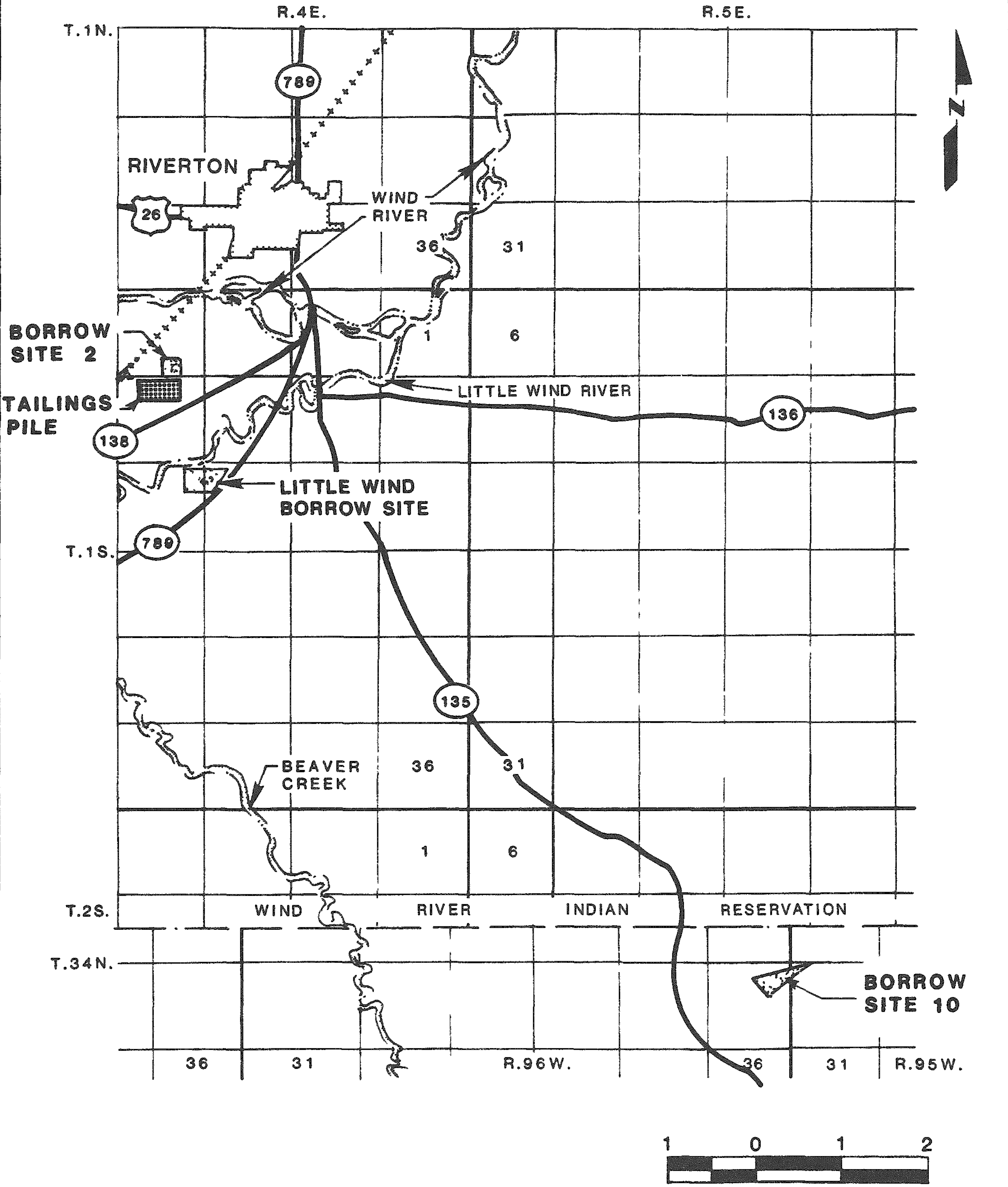


FIGURE A.1.1
LOCATIONS OF LITTLE WIND BORROW SITE AND BORROW SITES 2 AND 10

materials. This borrow site is within the Wind River Indian Reservation, but both the surface and minerals of the site are privately owned. Gravel for the access roads at the Riverton site would be purchased from a commercial source.

The stabilization in place and Dry Cheyenne disposal alternatives would require earthen and rock borrow materials for road construction, stabilization of the tailings and contaminated materials, and restoration of disturbed areas at the affected sites. For these alternatives, the earthen and rock materials used for stabilization of the tailings would be required to have specific engineering properties (e.g., rock size and durability for erosion protection). Initially, ten sites were identified as potential sources of borrow materials for remedial action at the Riverton site. Preliminary investigations eliminated three of these sites from further consideration because of unsuitable conditions such as insufficient quantities of materials and existing drainage patterns. Detailed studies and evaluations of the remaining seven sites resulted in the selection of borrow sites 2 and 10 as sources of borrow materials (Figure A.1.1).

Borrow site 2 was originally selected as the source of gravel and rock for both stabilization in place and disposal at the Dry Cheyenne site. This borrow site is within the designated tailings site, and the surface and minerals of the site are privately owned. Completion of the flood analysis for the tailings site revealed that stabilization in place would require large-diameter rocks to armor the stabilized tailings pile against erosion from flooding and river meander. The rock sizes required are not available from borrow site 2, and another investigation was conducted to identify sites as potential sources of the required rock sizes. Only one site could be identified nearby, and this site, the Boulder Flats borrow site (Table A.1.1 and Figure A.1.2), was chosen as the source of gravel and rock for stabilization in place. This site is within the Wind River Indian Reservation, but both the surface and minerals of the site are privately owned. Borrow site 2 (Table A.1.1) would be used as the source of gravel and rock for the Dry Cheyenne alternative.

Earthen borrow materials for stabilization in place would be obtained from borrow site 10 (Table A.1.1). This site is on Federal land administered by the BLM. Earthen borrow materials for the Dry Cheyenne alternative would be obtained from the partially below-grade excavation of the disposal site itself.

The borrow sites included in this EA were selected as the sources of the necessary borrow materials for impacts analyses purposes. The borrow sites to be used for the remedial action will be selected during the final design.

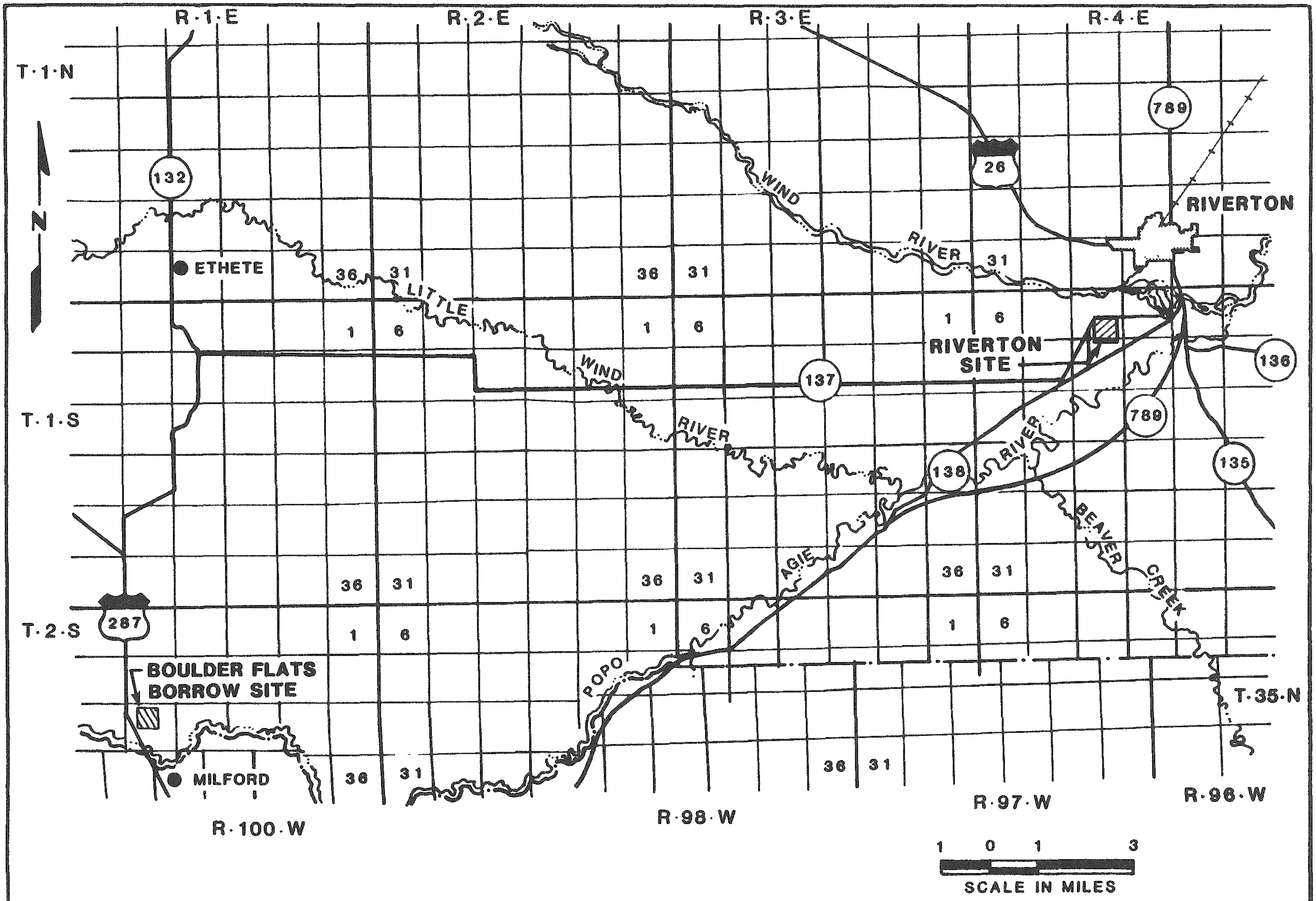


FIGURE A.1.2
LOCATION OF BOULDER FLATS BORROW SITE

A-5 - 6

A.2 PROPOSED ACTION - RELOCATION TO GAS HILLS

A.2.1 MAJOR CONSTRUCTION ACTIVITIES

The principal feature of the conceptual design is the relocation of the Riverton tailings and contaminated materials (Title I) to Gas Hills (Figure A.2.1). Gas Hills is an area 45 to 60 road miles east of the Riverton site that contains several active (Title II) uranium mill tailings sites. A specific Title II site within the Gas Hills would be selected by the Federal procurement process. The Riverton tailings and contaminated materials would be consolidated with the Title II tailings at the selected site and then stabilized in accordance with a remedial action plan to be approved for the active site by the NRC.

The areas disturbed at the Riverton tailings site during remedial action would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, revegetated as necessary, and released for use consistent with existing land use controls. The uncontaminated soil for backfilling of the disturbed areas would be excavated from the Little Wind borrow site 3 road miles south of the Riverton site (Figure A.1.1).

This design would require the following major construction activities at the Riverton tailings site:

<u>Site preparation</u>

- Grubbing and clearing (as necessary), erection of a temporary security fence, and construction of an off-site staging area and on-site access roads.
- Demolition of the mill building and wash house at the site.
- Construction of a waste-water retention pond according to applicable regulations (Appendix G, Permits, Licenses, and Approvals) to protect against the release of contaminants from the site during construction.
- Construction of drainage control measures according to applicable regulations (Appendix G, Permits, Licenses, and Approvals) to direct all generated waste-water and storm-water runoff to the retention pond during construction.
- Installation of measures to control erosion from all disturbed areas during remedial action.
- Decontamination of the scale and pump houses at the site.

<u>Tailings relocation</u>

- Consolidation of contaminated materials from the windblown areas and vicinity properties onto the tailings site.

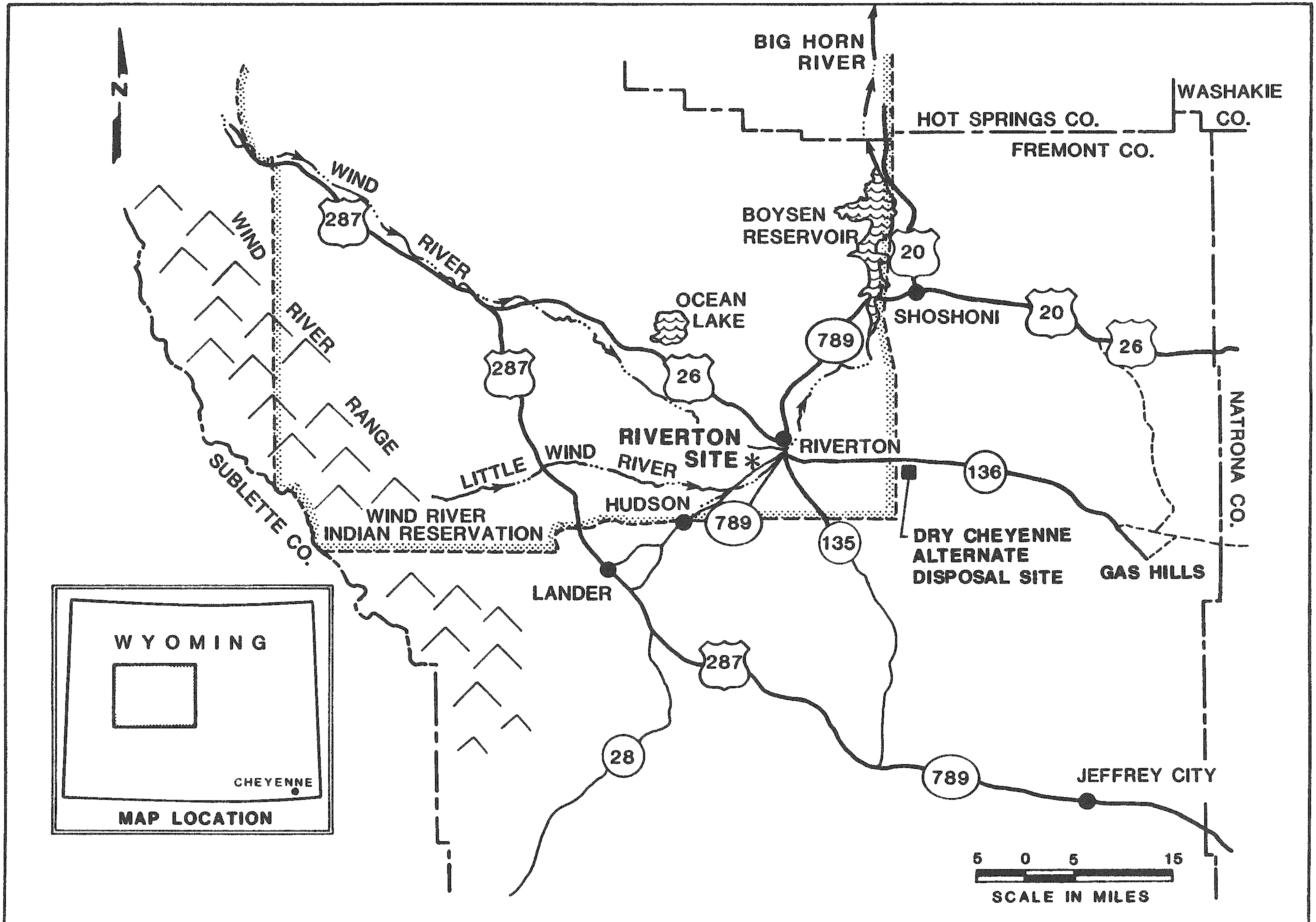


FIGURE A.2.1 RIVERTON SITE LOCATION

- Excavation of the tailings and contaminated materials from the tailings site and relocation of the materials (including demolition debris) by truck to Gas Hills.

Borrow materials

- Excavation of the earthen borrow materials required for site restoration from the Little Wind borrow site (Figure A.1.1).

Site restoration

- Backfilling, recontouring to promote surface drainage, and revegetation (as necessary) of all areas disturbed at the Riverton site during remedial action.

- Reclamation of the Little Wind borrow site according to applicable regulations (Appendix G, Permits, Licenses, and Approvals).

A.2.2 DESCRIPTION OF FINAL CONDITION

The Riverton tailings and contaminated materials would be relocated to Gas Hills to be stabilized at a selected active uranium mill tailings site. Stabilization of the tailings and contaminated materials at the selected site would be conducted in accordance with a remedial action plan prepared by the owner and operator of the active site and to be approved by the NRC. After decontamination of the Riverton tailings site, the disturbed areas at the site (153 acres) would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, and revegetated as necessary. The 173-acre Riverton site would then be released for use consistent with existing land use controls.

A.2.3 MAJOR ASSUMPTIONS

- The quantity of contaminated soils beneath the tailings is based on 70 acres contaminated to an average depth of 3 feet.

- Demolition debris would be relocated to Gas Hills with the tailings and contaminated materials.

- Uncontaminated soil would be obtained from the Little Wind borrow site 3 road miles south of the Riverton tailings site.

- All disturbed areas at the Riverton tailings site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, and revegetated as necessary.

- The Little Wind borrow site would be reclaimed according to the requirements of the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals).

A.2.4 RADON CONTROL AND LONG-TERM STABILITY

Control of radon emanation from the Riverton tailings site would be accomplished by relocating all of the tailings and contaminated materials to Gas Hills.

A.2.5 GROUND-WATER PROTECTION

The shallow ground water beneath and southeast of the Riverton tailings pile has been contaminated primarily by percolating leachate generated by the natural dewatering of the tailings during and immediately after the uranium milling. Lesser but continuing contamination is due to precipitation filtering through the tailings pile and possibly to the rising of the shallow ground water into the pile. Relocation of the tailings and contaminated materials to Gas Hills would remove the source of any future ground-water contamination at the Riverton site, and the natural flow and discharge of the shallow ground water into the Little Wind River would reduce the existing concentrations of the contaminants to background levels in approximately 45 years. At this time, aquifer restoration would not be a cost-effective means of controlling or cleaning up the ground-water contamination at the Riverton site (Section C.2.6 of Appendix C, Water).

When the EPA issues revisions to the water protection standards (40 CFR Part 192.20 (a)(2)-(3)) that were remanded by the U.S. Tenth Circuit Court of Appeals, the DOE will re-evaluate the ground-water issues at the Riverton site to assure that the revised standards are met. Performing remedial action to relocate the tailings prior to the EPA issuing new standards will not affect the measures that are ultimately required to meet the revised EPA water protection standards. The DOE has characterized the conditions at the Riverton site and does not anticipate that any substantial changes to the remedial action would be required.

A.2.6 CONSTRUCTION SEQUENCE

The following construction sequence is outlined as a possible means of accomplishing relocation to Gas Hills.

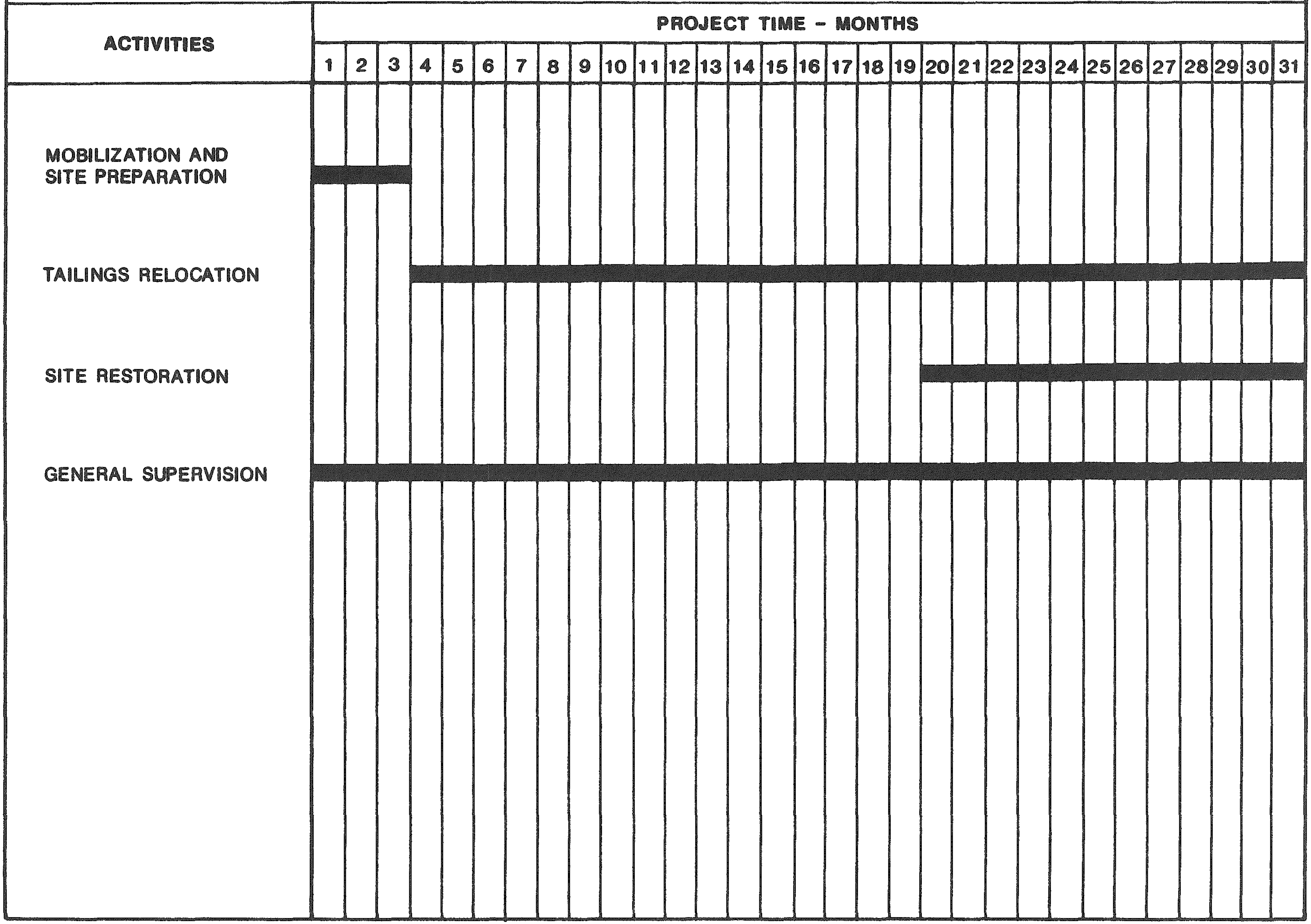
Initially, a site security system would be set up and coordinated with staging and vehicle decontamination areas. This would provide control of traffic entering and leaving the Riverton tailings site.

The next major item of site preparation would consist of construction of a waste-water retention pond. Materials excavated from the pond area would be stockpiled for later use as fill. Site preparation would also include construction of access roads at the Riverton tailings site and construction of drainage and erosion control measures at the Riverton site and the Little Wind borrow site. Concurrent with these initial activities, the building demolition and decontamination would be performed.

Next, the contaminated materials from the windblown areas and the vicinity properties would be consolidated at the Riverton tailings site. The tailings and contaminated materials would then be excavated from the Riverton site and relocated (with the demolition debris) by truck to Gas Hills. The final stages of remedial action would involve backfilling, recontouring, and revegetating (as necessary) the disturbed areas at the Riverton site and reclaiming the Little Wind borrow site.

Figure A.2.2 shows a construction schedule for relocation to Gas Hills.

FIGURE A.2.2 REMEDIAL ACTION SCHEDULE, RELOCATION TO GAS HILLS



A.3 STABILIZATION IN PLACE

A.3.1 MAJOR CONSTRUCTION ACTIVITIES

The principal feature of the conceptual design is the consolidation of all of the tailings and other contaminated materials onto the present location of the existing tailings pile as indicated in Figure A.3.1.

The tailings and contaminated materials would be covered with a layer of earthen materials to control radon emanation and inhibit water infiltration and plant root penetration. This earthen cover, herein referred to as a radon barrier, would consist of materials excavated from borrow site 10 that is 13 road miles southeast of the tailings site (Figure A.1.1). Generally, the major soil type available at this borrow site is a low plasticity, silty clay with occasional thin stringers of silty sand and sand.

The radon barrier would be covered with rock to protect against water and wind erosion and burrowing by animals. The rock for this erosion protection barrier would be excavated from the Boulder Flats borrow site 27 road miles southwest of the tailings site (Figure A.1.2). Gravel for haul road construction would also be obtained from this borrow site. The materials available at this borrow site are well-rounded cobbles of igneous origin.

This design would require the following major construction activities:

<u>Site preparation</u>

- o Grubbing and clearing (as necessary), erection of a temporary security fence, and construction of an on-site staging area and access roads.
- o Demolition of the mill building and wash house at the site.
- o Construction of a waste-water retention pond according to applicable regulations (Appendix G, Permits, Licenses, and Approvals) to protect against the release of contaminants from the site during construction.
- o Construction of drainage control measures according to applicable regulations (Appendix G, Permits, Licenses, and Approvals) to direct all generated waste-water and storm-water runoff to the retention pond during construction.
- o Installation of measures to control erosion from all disturbed areas during remedial action.
- o Decontamination of the scale and pump houses at the site.

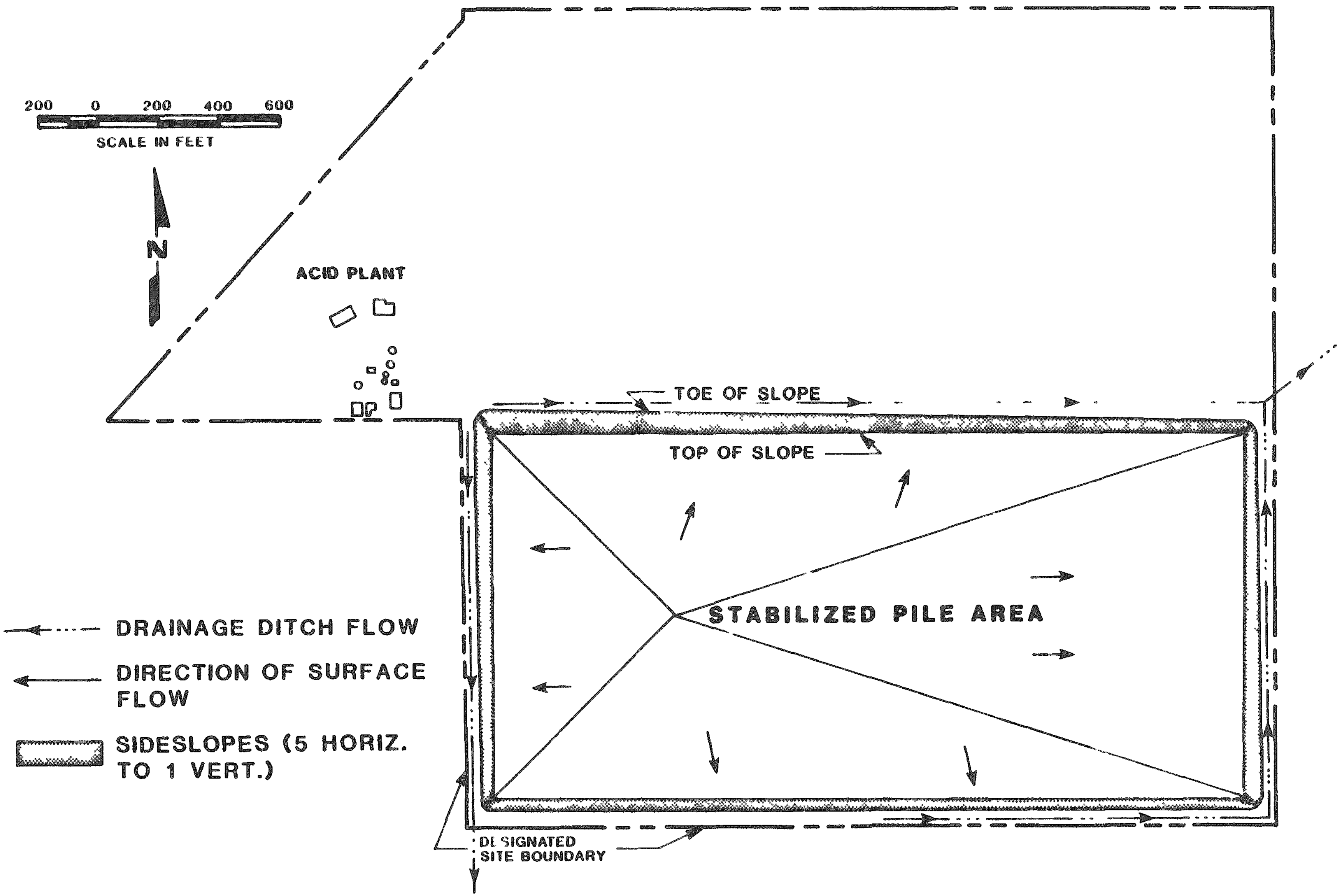


FIGURE A.3.1 FINAL CONDITION, RIVERTON SITE

Tailings relocation

- Consolidation of all contaminated materials from the windblown, mill, and ore storage areas, and from the vicinity properties, onto the existing tailings pile.

- Even distribution of the demolition debris within an area of the existing tailings pile.

Borrow materials

- Construction of 0.5 mile of gravelled haul road to the Boulder Flats borrow site and excavation and sorting of the gravel to be placed on the haul roads to borrow site 10 and the Boulder Flats borrow site.

- Construction of 1 mile of gravelled haul road to borrow site 10 and excavation of the borrow materials required for the radon barrier over the tailings pile and for site restoration.

- Excavation and sorting of the rock to be placed over the tailings pile from the Boulder Flats borrow site.

Radon barrier

- Placement of a 6-foot-thick, compacted, earthen cover over the tailings and contaminated materials to inhibit radon emanation, water infiltration, and plant root penetration.

Erosion protection barrier

- Placement of rock over the radon barrier (1 foot thick on the top and 2 feet thick on the sideslopes) to protect against erosion and penetration by burrowing animals.

- Placement of a tapered, 5-foot-thick, 32-foot-wide, riprap (rock) apron around the base of the stabilized tailings pile to protect against flooding and river meander.

Site restoration

- Construction of an unpaved access road on top of the riprap apron around the base of the stabilized tailings pile.

- Construction of a drainage ditch around the outside edge of the riprap apron.

- Backfilling, recontouring to promote surface drainage, and revegetation (as necessary) of all areas disturbed at the Riverton site during remedial action.

- Installation of a security fence with locked gates and warning signs around the stabilized tailings pile to discourage inadvertent human intrusion.

- Reclamation of borrow site 10 and the Boulder Flats borrow site according to applicable regulations (Appendix G, Permits, Licenses, and Approvals).

A.3.2 DESCRIPTION OF FINAL CONDITION

The stabilized tailings pile would be rectangular in shape, measuring approximately 2,500 feet long in the east-west direction and 1,200 feet wide in the north-south direction (Figure A.3.1). The final restricted area inside the security fence would encompass 80 acres. The consolidated contaminated materials would be covered with a 6-foot-thick, compacted, radon barrier. The stabilized pile would have maximum sideslopes of 20 percent (5 horizontal to 1 vertical) and a slightly convex top. The top and sides would be covered with 1-foot and 2-foot-thick layers of graded rock, respectively, for erosion protection. The final stabilized pile would be a maximum of approximately 27 feet above the surrounding terrain (Figure A.3.2).

The rock erosion protection barrier would tie into a tapered, 5-foot-thick, 32-foot-wide, riprap (rock) apron placed around the base of the tailings pile. An unpaved access road would be constructed around the base of the pile on top of the riprap apron, and a drainage ditch would be constructed around the outside edge of the riprap apron. The ditch would divert surface-water runoff around and away from the pile. A security fence with locked gates and warning signs would enclose the pile, road, and ditch.

The remaining disturbed areas at the Riverton site would be backfilled with uncontaminated soil from borrow site 10 to a level compatible with the surrounding terrain, recontoured to promote surface drainage, revegetated as necessary, and released for use consistent with existing land use controls.

A.3.3 MAJOR ASSUMPTIONS

- The quantity of contaminated soils beneath the tailings is based on 70 acres contaminated to an average depth of 3 feet.
- The pile would be constructed with 20 percent sideslopes (5 horizontal to 1 vertical) and 1 to 2 percent topslopes.
- Demolition debris would be evenly distributed within an area of the tailings pile that would be adequately covered with relocated tailings and contaminated materials during reshaping of the pile.
- All soils contaminated by windblown tailings would be spread evenly over the reshaped tailings pile.
- Radon barrier materials would be obtained from borrow site 10 that is 13 road miles southeast of the existing tailings site.
- All gravel and rock materials would be obtained from the Boulder Flats borrow site 27 road miles southwest of the tailings site.

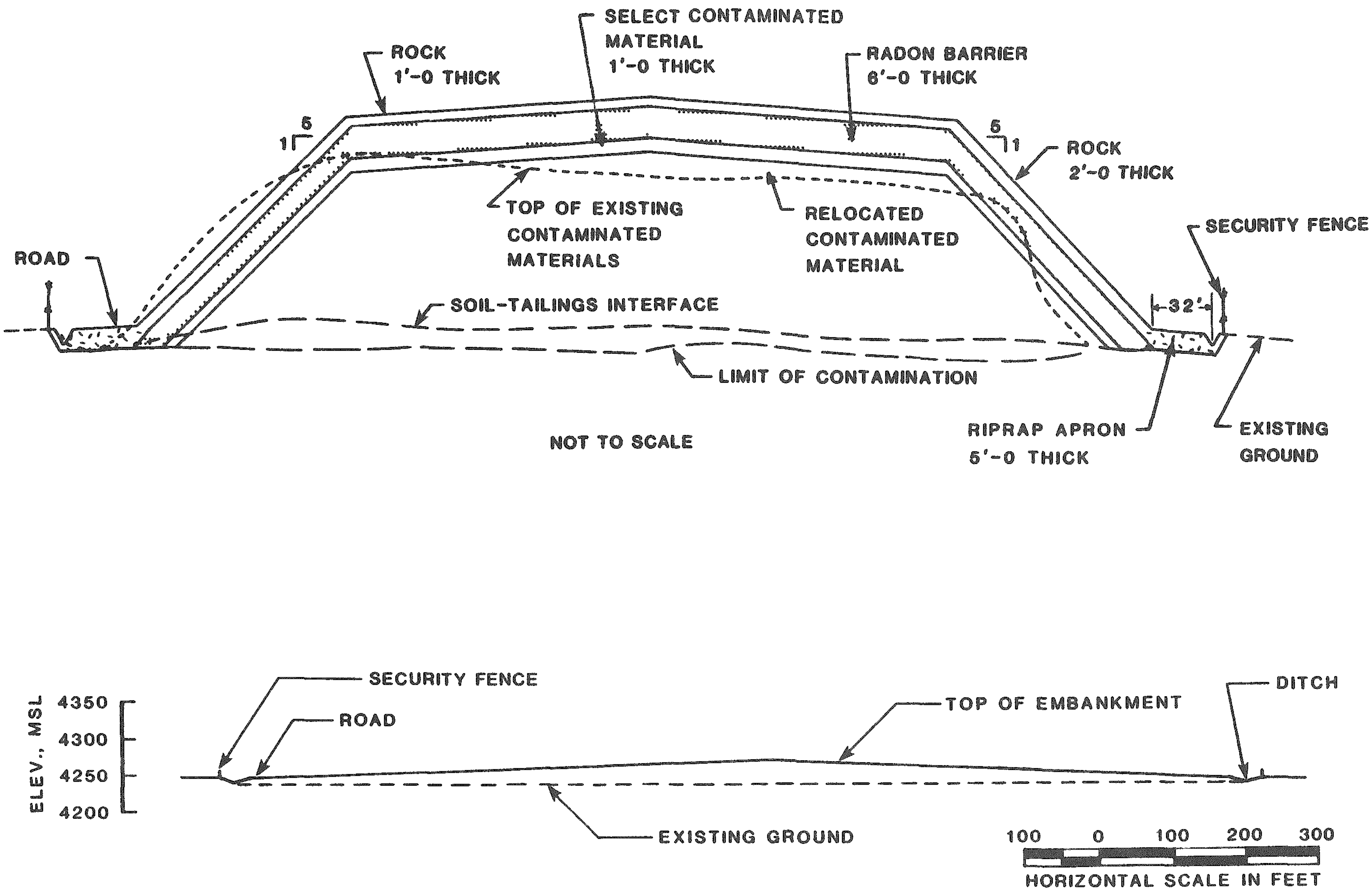


FIGURE A.3.2
STABILIZATION IN PLACE, TYPICAL CROSS-SECTION

- All disturbed areas outside the fenced disposal site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, and revegetated as necessary.

- Borrow site 10 and the Boulder Flats borrow site would be reclaimed according to the free use permit issued by the Bureau of Land Management (BLM) and the permit to mine issued by the State of Wyoming (Appendix G, Permits, Licenses, and Approvals).

A.3.4 RADON CONTROL

Control of radon emanation from the stabilized tailings pile would be accomplished through a combination of techniques including the following:

- Decontamination of a large portion of the present tailings site by excavating and placing contaminated materials on the existing tailings pile.

- Placing windblown soils and lesser contaminated soils over the reshaped tailings and contaminated materials.

- Placing a 6-foot-thick, compacted, radon barrier over the consolidated tailings and contaminated materials.

Data on the distribution of radium in the tailings and the properties of the borrow materials available at borrow site 10 have been used to estimate the radon barrier thickness. Using the concentration of radium in the tailings and the type and thickness of borrow materials, the computerized RAECOM model (NRC, 1984) was then used to estimate the post-remedial action radon flux of the stabilized tailings pile. This flux was estimated at 20 pCi/m^2s.

A.3.5 LONG-TERM STABILITY

The remedial action has been designed so the stabilized tailings pile would withstand the forces of nature for a long period of time (up to 1,000 years, to the extent reasonably achievable, or, in any case, for at least 200 years). Several conceivable forms of natural erosion have been investigated and are discussed below.

A.3.5.1 Water erosion

To reduce the potential for water erosion by surface runoff, several control features were incorporated into the design to reduce surface runoff velocities. The sideslopes of the stabilized tailings pile would be limited to 5 horizontal to 1 vertical (20 percent). The top of the pile would be gently crowned (1 to 2 percent) to promote drainage.

Severe rainfall events have the potential to develop rills and gullies on the steeper (20 percent) sideslopes of the stabilized tailings pile and erode some or all of the radon barrier in small, undefinable areas. One such potential rainfall event is the Probable Maximum Precipitation (PMP). The PMP is defined as the maximum precipitation that could occur from the most severe combination of meteorological conditions that are reasonably possible in a region. For the Riverton site, the PMP was calculated to be 8.3 inches of rain in 1 hour with a maximum intensity of 25 inches per hour for a 5-minute period. This PMP would generate sheet flow rates ranging from 0.4 to 1.2 cubic feet per second per foot of slope width (cfs/ft) on the pile.

To protect the tailings pile from the impact of an unlikely PMP, the pile would have a layer of rock as part of the cover system. The rock protection requirements to withstand sheet erosion on the pile top and sideslopes during a PMP event are shown in Table A.3.1.

Table A.3.1 *Sheet flow rock protection requirements*

Location	Rock size [a]	Rock thickness [a]	PMP design sheet flow rates
Top	$D_{50} \geq 1.5$ inches	$\geq 1.5 \times D_{100}$	0.4 cfs/ft
	$D_{100} \leq 3.0$ inches	12 inches minimum	
Sideslopes	$D_{50} \geq 6.0$ inches	$\geq 1.5 \times D_{100}$	1.2 cfs/ft
	$D_{100} \leq 12.0$ inches	18 inches plus 6-inch filter layer	

[a] D_{50} and D_{100} are the diameters of 50 and 100 percent of the rock by weight, respectively.

A.3.5.2 Wind erosion

High winds gusting to more than 75 miles per hour can occur during intense summer storms in the Riverton area (FBDU, 1981) and could damage the radon barrier of the stabilized tailings pile. The same rock layers used to protect against water erosion would protect against any hazards posed by wind erosion at the site.

A.3.5.3 Flood protection

The Riverton tailings site is on a low floodplain terrace in the Wind River valley 2.5 miles upstream of the confluence of the Wind and Little Wind Rivers (Figure A.3.3). The Wind River modern channel approaches to within 1 mile of the site on the north, and the present channel of the Little Wind River is 0.5 mile southeast of the site.

Because of the topography and the location of the tailings site with respect to the Wind and Little Wind Rivers, flooding presents a potential hazard to the long-term stability of the stabilized tailings pile. Flood flows surrounding the pile with high flow velocities could damage the compacted, earthen radon barrier; furthermore, flooding could cause rapid shifts of the river channels or localized scour that could undercut and erode the pile.

In order to design adequate protection against flooding for the stabilized tailings pile, a flood analysis of the tailings site area was performed using the HEC-1 (COE, 1981) and HEC-2 (COE, 1982) computer models. This analysis evaluated the Probable Maximum Flood (PMF) using the PMP for a severe summer storm as recommended by Hydrometeorological Report No. 55 (NOAA, 1984). Section C.1.2.1 of Appendix C, Water, contains a detailed discussion of this flood analysis.

The flood analysis resulted in calculations of the peak flood flow in each river, the corresponding flow in the other river, and the combined peak flows as shown in Table A.3.2. The analysis indicated that the worst flood flow situation would occur on the Wind River side of the stabilized tailings pile when the Wind River is at its peak flood flow of 403,000 cubic feet per second (cfs). At this peak, approximately 25 percent of the flood flow would be down the meander scar southwest of the pile resulting in inundation of the area shown in Figure A.3.4. The stabilized tailings pile would be an island with water depths less than 10 feet around the pile sides and flow velocities less than 15 feet per second (fps). To protect the stabilized tailings pile from these maximum flood conditions, a design flow with a water depth of 10 feet and a flow velocity of 15 fps was chosen.

The rock protection requirements for the design flow are shown in Table A.3.3. A tapered, riprap apron 5 feet thick and 32 feet wide with 15- to 18-inch mean diameter rocks would be placed around the base of the stabilized tailings pile to satisfy these requirements. This apron would also protect the stabilized pile against rapid shifts of the river channels and localized scour.

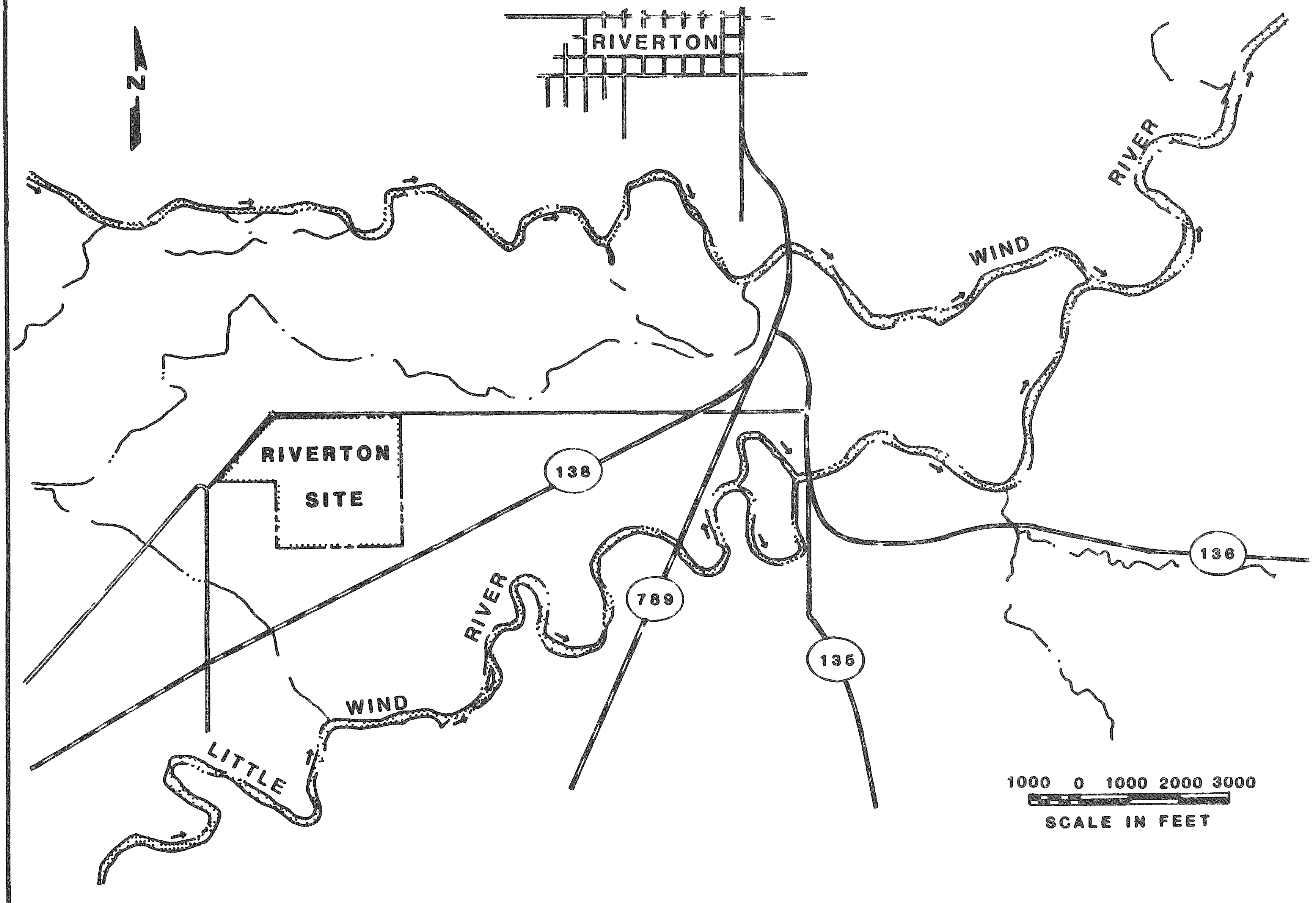


FIGURE A.3.3
WIND AND LITTLE WIND RIVERS, RIVERTON TAILINGS SITE

Table A.3.2 Peak river flood flows, Wind and Little Wind Rivers

	Flows in cubic feet per second		
	Wind River	Little Wind River	Maximum combined flow
Peak	403,000	557,000	---
Corresponding flow in Little Wind River	214,000	---	481,000
Corresponding flow in Wind River	---	123,000	239,000
Combined peak	617,000	680,000	720,000

Table A.3.3 Flooding rock protection requirements

Rock size[a]	Rock thickness[a]	Design flow
$D_{50} \geq 15.0$ inches	$\geq 1.5 \times D_{100}$	10 feet deep
$D_{50} \leq 18.0$ inches	5 feet minimum	15 feet per second

[a] D_{50} and D_{100} are the diameters of 50 and 100 percent of the rock by weight, respectively.

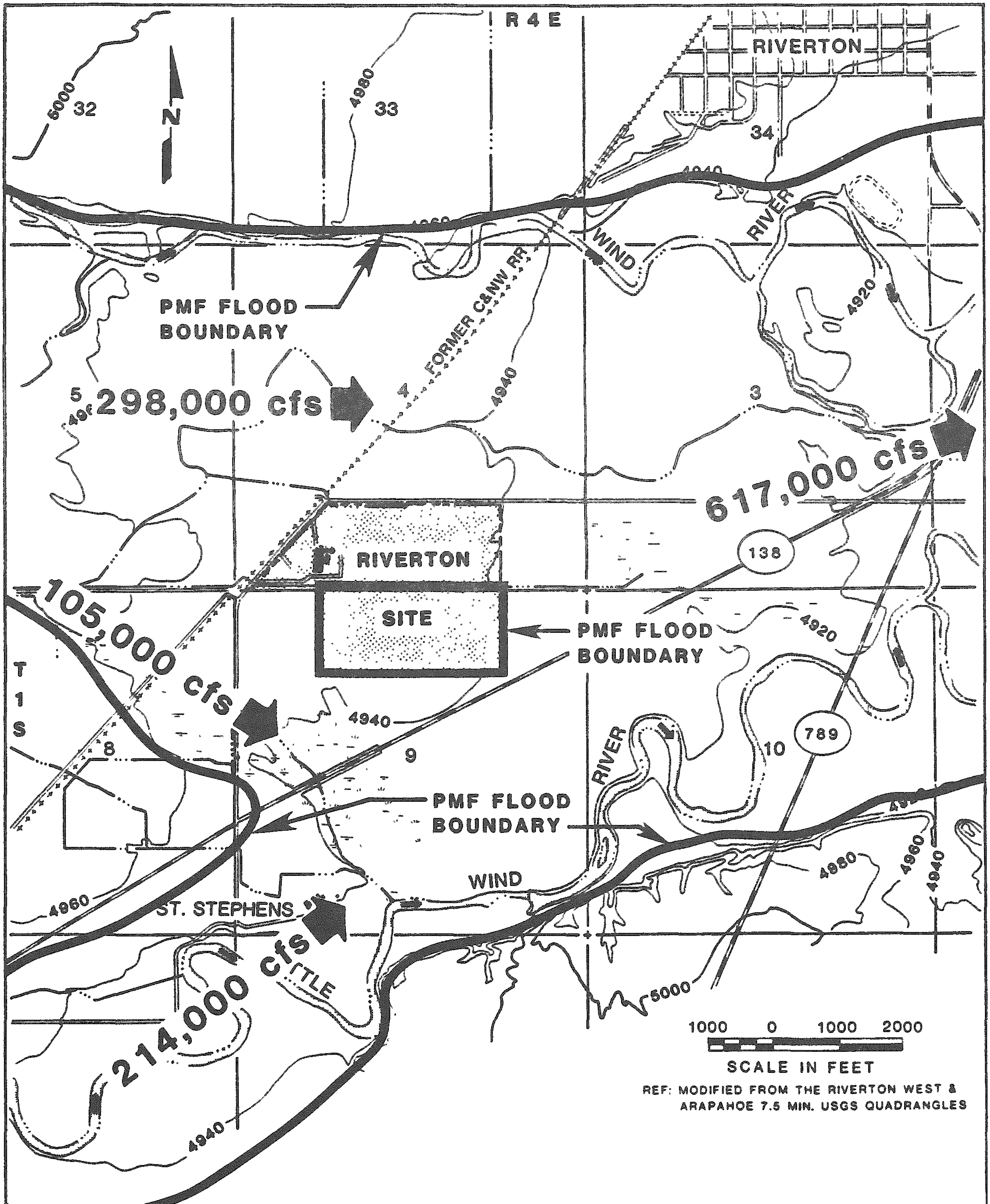


FIGURE A.3.4
PMF FLOW DISTRIBUTION FOR RIVERTON SITE AREA

A.3.5.4 Geomorphology (river meander)

A geomorphic evaluation of the tailings site area (SHB, 1985) was performed to assess the possibility that the channels of the Wind and Little Wind Rivers could move toward the site. Geologic evidence indicates that the Wind River could migrate laterally across its floodplain within a 2,000-year period. The extent of possible channel migration is unpredictable; however, the rate of migration could exceed 0.5 mile per 1,000 years. The present Wind River channel is 1 mile north of the site. It also appears that aggradation (channel filling) or large-scale flooding could result in avulsion, or rapid channel shift, of the Wind River across the floodplain. The effect of Boysen Reservoir (20 miles northeast of Riverton) on the long-term behavior of the Wind River near the tailings site is difficult to predict. The accumulation of sediment in the reservoir could result in a raising of the base level of the river and consequent channel aggradation. The Little Wind River is more stable and more deeply incised, and the potential for its migration toward the site is much less.

The stabilized tailings pile would be surrounded with a riprap apron to protect the pile against erosion that could result from a PMF. This riprap apron would also protect the pile against erosion that could result from river meander or sudden shifts in the channels of the Wind and Little Wind Rivers.

A.3.5.5 Slope stability and seismic risk

Slope failure due to slope instability under static and seismic loading is another phenomena that could affect the integrity of the stabilized tailings pile. With the dense foundation soils beneath the tailings pile and the use of relatively flat (5 horizontal to 1 vertical) sideslopes, it is anticipated that the stabilized tailings pile would be stable under all loading conditions (MSRD, 1982).

Several standard methods of stability analysis were performed for each loading condition to estimate factors of safety against slope failure. In particular, the seismic loading conditions were evaluated by applying the horizontal ground acceleration resulting from a Maximum Credible Earthquake (MCE). The evaluation estimated an MCE of magnitude 6.8 (Richter scale) which would generate an on-site peak horizontal ground acceleration of 0.13 gravity (SHB, 1983). Gravity (g) is a force expressed as acceleration equal to 32 feet per second per second.

The principal seismic hazard to the stabilized tailings pile is the potential for slope failure due to seismically induced liquefaction of the tailings or underlying soils. The coarse-grained alluvium underlying the Riverton tailings site should not be susceptible to seismically induced liquefaction, and zones of saturated slime tailings that might be susceptible to liquefaction under horizontal ground accelerations of 0.10 to 0.15 g are not present in the Riverton tailings pile (SHB, 1983).

The factors of safety against slope failure under both static and seismic loading for the designed slopes exceed the generally accepted limits of 1.5 and 1.0, respectively (COE, 1970).

A.3.5.6 Differential settlement

Differential settlement of the stabilized tailings pile has the potential hazard of cracking the radon barrier due to horizontal strains and thus could affect the integrity of the pile. Differential settlement could also increase the potential for gullying action due to concentrations of surface runoff.

Due to the difficulty in controlling differential settlement of the reshaped tailings pile, settlement monitoring devices would be installed to measure the total settlement of the tailings and underlying soils caused by reshaping of the tailings. Upon the completion of a majority of all of the settlement, the earthen radon barrier would be placed over the tailings pile, and the settlement would be monitored again. Final grading and compaction of the radon barrier would be performed only after sufficient settlement had occurred to prevent cracking of the radon barrier and concentrating surface runoff flows.

A.3.5.7 Frost heave and solifluction

Frost heave and solifluction are processes which pose a hazard to the long-term performance of any structure constructed to isolate the tailings at the site. Climatic conditions at the site favor the occurrence of these processes during the winter.

Frost heave and associated frost creep or frost sloughing are processes which probably would occur under the climatic conditions at the tailings site. The latter two occur in fine-grained sediments on slopes (Lindell and Lobacz, 1980) and can be mitigated by using an aggregate (rock) cover.

Frost heave is the expansion toward the surface from the freeze-thaw cycle and generally has the largest movement from the winter-summer cycle of freeze-thaw. The process requires that adequate soil moisture be present to form ice lenses in fine-grained soil. The remedial action design includes the use of sufficiently impermeable earthen materials to restrict ice lens formation and sufficiently porous aggregate to restrict water buildup over the radon barrier to mitigate this problem.

Solifluction is the action of slow flowage in saturated soils in periglacial regions (Ritter, 1978). Only the surface layer is affected, and very low slopes can flow if saturated. The remedial action design includes the use of a permeable aggregate (rock) in the upper portion of the cover system which would remove the saturation prerequisite for this process, and the hazard would be mitigated.

A.3.6 GROUND-WATER PROTECTION

Two ground-water systems have been identified in the vicinity of the tailings site. An unconfined aquifer exists in the shallow, alluvial deposits and the hydrologically-connected, upper sandstone of the Wind River Formation. A confined aquifer exists in the deeper sandstone strata of the Wind River Formation. Presently, the unconfined aquifer is not used downgradient of the tailings site. Some shallow wells upgradient of the site and beyond the Little Wind River are used for stock watering, and the Little Wind River is used for irrigation. The confined aquifer is heavily used for the city of Riverton's municipal water supply and for other industrial and private supplies.

The shallow, unconfined ground water beneath and southeast of the tailings pile has been contaminated primarily by percolating leachate generated by the natural dewatering of the tailings during and immediately after the uranium milling. Lesser but continuing contamination is due to precipitation filtering through the tailings pile and possibly to the rising of the shallow ground water into the pile. The natural flow of the ground water toward the Little Wind River would eventually dissipate the contamination.

For the protection of ground water, the goal of the stabilization in place remedial action alternative is to ensure, to the extent practicable, that existing or anticipated beneficial uses of ground water and interconnected surface water are not adversely affected. This goal was assessed in terms of:

- o Existing and predicted contamination of aquifers and usable surface waters.
- o Background water quality.
- o Pertinent EPA and State of Wyoming water-quality standards.
- o Known health effects or other known adverse effects associated with the existing and predicted ground-water contamination.
- o The availability of alternate water supplies.
- o Costs of ground-water protection or restoration measures.

For stabilization in place, the design features considered for ground-water protection included:

- o Sloping the top and sides of the stabilized tailings pile to promote the drainage of precipitation off of the pile.

- Placing a low permeability cover over the tailings pile to inhibit the filtration of precipitation through the pile.

- Placing a low permeability liner under the tailings pile to inhibit the migration of contaminants from the pile into the shallow ground water.

- Placing an underground bentonite slurry wall around the base of the tailings pile to minimize the migration of contaminants from the pile into the shallow ground water.

- Restoration of the shallow ground water.

Evaluations of these features (Section C.2.6 of Appendix C, Water) revealed that, at this time, a liner, a slurry wall, and restoration of the shallow ground water are not feasible or cost-effective means of controlling or cleaning up the ground-water contamination. Sloping the top and sides of the tailings pile and placing a low permeability cover over the tailings have been included in the remedial action design.

After remedial action, there would be a substantial decrease in the contamination of the unconfined aquifer. Sloping of the top and sides of the stabilized tailings pile would promote the drainage of precipitation off of the pile, and the compacted radon barrier over the pile would inhibit the infiltration of precipitation through the pile. These measures would minimize the leaching of contaminants into the underlying unconfined aquifer. With the substantial decrease in the generation and migration of contamination from the tailings pile, the natural movement and discharge of the unconfined ground water into the Little Wind River would eventually reduce the existing concentrations of the contaminants to background levels. It is estimated that this natural reduction in the contamination of the unconfined aquifer would take 65 years. Although there is a potential for downward migration of the contamination in the unconfined aquifer to the confined aquifer, this migration would be slowed by the various low-permeability strata (shale, siltstone, and claystone) of the Wind River Formation. It is estimated that downward migration of the contamination to the deeper, usable units of the confined aquifer would take 1,700 years.

When the EPA issues revisions to the water protection standards (40 CFR Part 192.20 (a)(2)-(3)) that were remanded by the U.S. Tenth Circuit Court of Appeals, the DOE will re-evaluate the ground-water issues at the Riverton site to assure that the revised standards are met. Performing remedial action to stabilize the tailings prior to the EPA issuing new standards will not affect the measures that are ultimately required to meet the revised EPA water protection standards. The DOE has characterized the conditions at the Riverton site and does not anticipate that any substantial changes to the remedial action would be required if the stabilization in place alternative were selected.

A.3.7 CONSTRUCTION SEQUENCE

The following construction sequence is outlined as a possible means of accomplishing stabilization in place.

Initially, a site security system would be set up and coordinated with staging and vehicle decontamination areas. This would provide control of traffic entering and leaving the Riverton tailings site.

The next major item of site preparation would consist of construction of a waste-water retention pond. Materials excavated from the pond area would be stockpiled for later use as fill. Site preparation would also include construction of 1.5 miles of gravelled haul roads to borrow site 10 and the Boulder Flats borrow site and construction of drainage and erosion control measures at the tailings site, borrow site 10, and the Boulder Flats borrow site.

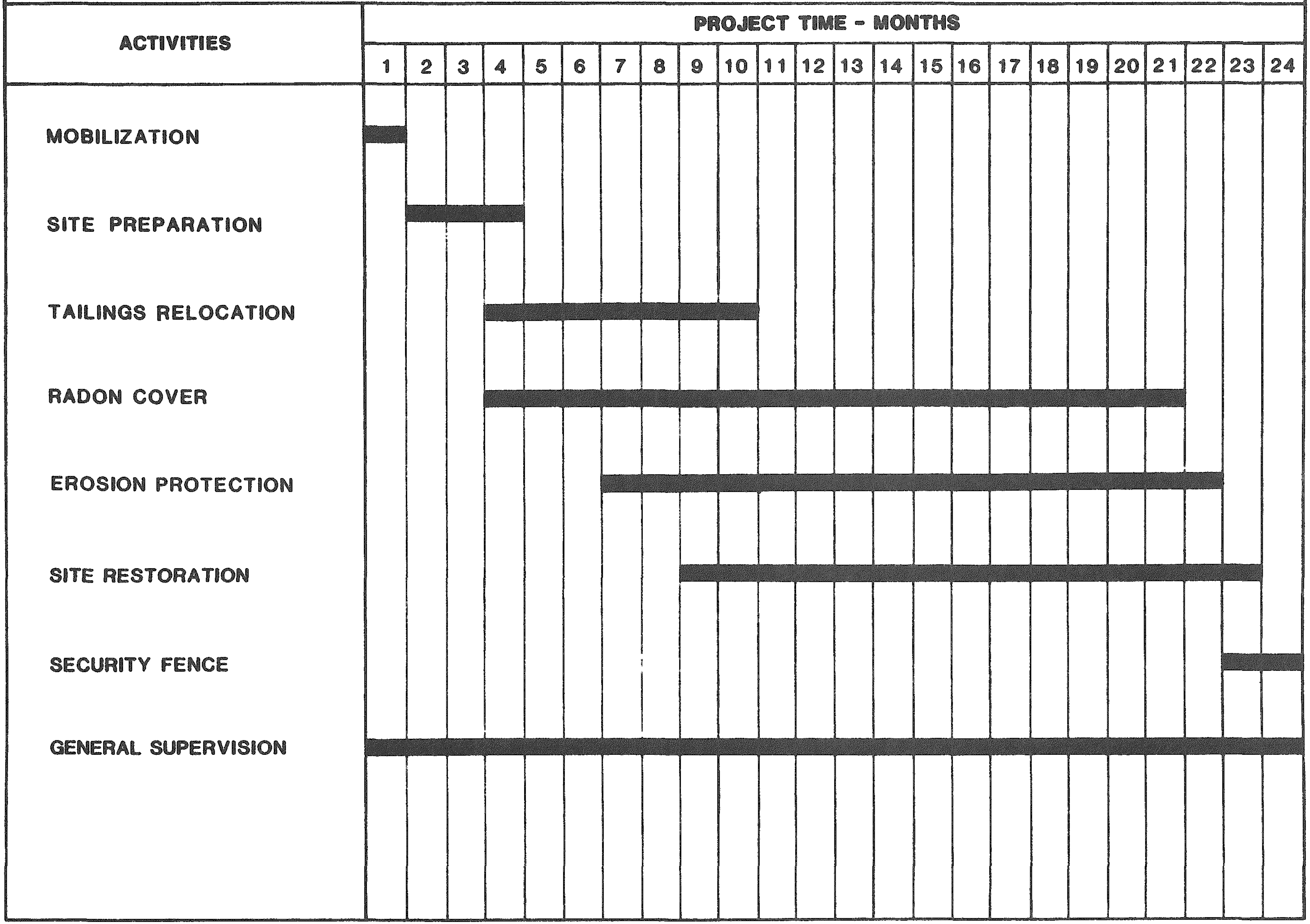
Concurrent with these initial activities, the building demolition and decontamination would also be performed. However, the movement of debris from demolition would not begin until a sufficient area had been prepared within the existing tailings pile to allow final placement.

Next, the existing tailings pile would be partially excavated to reshape its configuration. As this work was being performed in stages, windblown contaminants would be relocated and placed in an even layer over the existing tailings.

The radon barrier construction would be conducted in stages beginning when all the contaminated materials were in place on the tailings pile. The earthen borrow materials would be obtained from borrow site 10 southeast of the tailings site and placed and compacted in lifts to the design thickness of 6 feet. The final stages of remedial action would involve placement of the erosion protection barrier over the radon barrier; construction of the riprap apron around the base of the stabilized tailings pile; construction of an access road, drainage ditch, and security fence around the stabilized tailings pile; overall site drainage grading; backfilling, recontouring, and revegetating (as necessary) the disturbed areas at the Riverton site; and reclaiming borrow site 10 and the Boulder Flats borrow site.

Figure A.3.5 shows a construction schedule for stabilization in place.

FIGURE A.3.5 REMEDIAL ACTION SCHEDULE, STABILIZATION IN PLACE



A.4 DISPOSAL AT THE DRY CHEYENNE SITE

A.4.1 MAJOR CONSTRUCTION ACTIVITIES

This remedial action alternative would involve moving all of the tailings and contaminated materials and consolidating them into a partially below-grade, gently contoured pile at the Dry Cheyenne site (Figure A.2.1). The surface materials removed from the below-grade disposal area would be stockpiled and used later for the radon barrier and uncontaminated soil at the Riverton tailings site. The surface materials at the Dry Cheyenne site are assumed to have the same characteristics as borrow materials from borrow site 10 proposed for stabilization in place (Section A.1.3).

The contaminated materials would be covered with a radon barrier to control radon emanation and inhibit water infiltration and plant root penetration. The radon barrier would be covered with rock to counter the erosional effects of water and wind. All gravel and rock materials would be obtained and processed from borrow site 2 at the existing tailings site (Figure A.1.1). This design would require the following major construction activities:

At the Riverton tailings site:

<u>Site preparation</u>

- o Grubbing and clearing (as necessary), erection of a temporary security fence, and construction of an on-site staging area and access roads.
- o Demolition of the mill building and wash house at the site.
- o Construction of a waste-water retention pond according to applicable regulations (Appendix G, Permits, Licenses, and Approvals) to protect against the release of contaminants from the site during construction.
- o Construction of drainage control measures according to applicable regulations (Appendix G, Permits, Licenses, and Approvals) to direct all generated waste-water and storm-water runoff to the retention pond during construction.
- o Installation of measures to control erosion from all disturbed areas during remedial action.
- o Decontamination of the scale and pump houses at the site.

<u>Borrow materials</u>

- o Excavation and sorting of the gravel to be placed on the haul road to the Dry Cheyenne site from borrow site 2.
- o Excavation and sorting of the rock to be placed over the tailings and contaminated materials from borrow site 2.

Tailings relocation

- Consolidation of contaminated materials from the windblown areas and vicinity properties onto the existing tailings site.
- Excavation of all tailings and contaminated materials from the tailings site, and relocation of all of the materials (including demolition debris) by truck to the Dry Cheyenne site.

Site restoration

- Backfilling, recontouring to promote surface drainage, and revegetation (as necessary) of all areas disturbed at the site during remedial action.
- Reclamation of borrow site 2 according to applicable regulations (Appendix G, Permits, Licenses, and Approvals).

At the Dry Cheyenne alternate disposal site:

Site preparation

- Construction of a 2-mile gravelled haul road from State Highway 136 to the disposal site.
- Grubbing and clearing (as necessary), erection of a temporary security fence, and construction of staging and stockpile areas.
- Construction of a waste-water retention pond according to applicable regulations (Appendix G, Permits, Licenses, and Approvals) to protect against the release of contaminants from the site during construction.
- Construction of drainage control measures according to applicable regulations (Appendix G, Permits, Licenses, and Approvals) to direct all generated waste-water and storm-water runoff to the retention pond during construction.
- Installation of measures to control erosion from all disturbed areas during remedial action.

Tailings relocation

- Excavation of the partially below-grade disposal area with stockpiling of the excavated surface materials.
- Placement of the tailings and contaminated materials into the disposal area to form a partially below-grade, gently contoured pile.
- Even distribution of the demolition debris within the tailings and contaminated materials.

Radon barrier

- Placement of a 6-foot-thick, compacted, earthen cover over the tailings and contaminated materials to inhibit radon emanation, water infiltration, and plant root penetration.

Erosion protection barrier

- Placement of rock over the radon barrier (1 foot thick on the top and 2 feet thick on the sideslopes) to protect against erosion and penetration by burrowing animals.

Site restoration

- Construction of an unpaved access road around the toe of the stabilized tailings pile and a drainage ditch around three sides of the pile.
- Installation of a security fence with locked gates and warning signs around the stabilized tailings pile to discourage inadvertent human intrusion.
- Reclamation of all areas disturbed at the site during remedial action according to applicable regulations (Appendix G, Permits, Licenses, and Approvals).

A.4.2 DESCRIPTION OF FINAL CONDITION

The stabilized tailings pile would cover 40 acres of the disposal site (Figure A.4.1), and the final restricted area would cover 47 acres.

The below-grade excavation of the disposal area would extend to an average depth of 16 feet. The tailings and contaminated materials would be covered with a 6-foot-thick, compacted, radon barrier obtained from the stockpiled surface materials excavated from the disposal area. The stabilized tailings pile would have maximum sideslopes of 20 percent and a slightly convex top. The top and sides would be covered with 1-foot and 2-foot-thick layers of graded rock, respectively, for erosion protection. The final stabilized pile would be a maximum of 30 to 35 feet above the surrounding terrain (Figure A.4.2).

The rock erosion protection barrier would tie into an unpaved access road which would loop the toe of the stabilized tailings pile. A security fence with locked gates and warning signs would enclose the pile and roadway. A drainage ditch adjacent to the roadway on three sides of the pile would provide drainage and divert surface runoff around and away from the pile.

After completion of the stabilized tailings pile at the disposal site and decontamination of the Riverton tailings site, the disturbed areas at each site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote

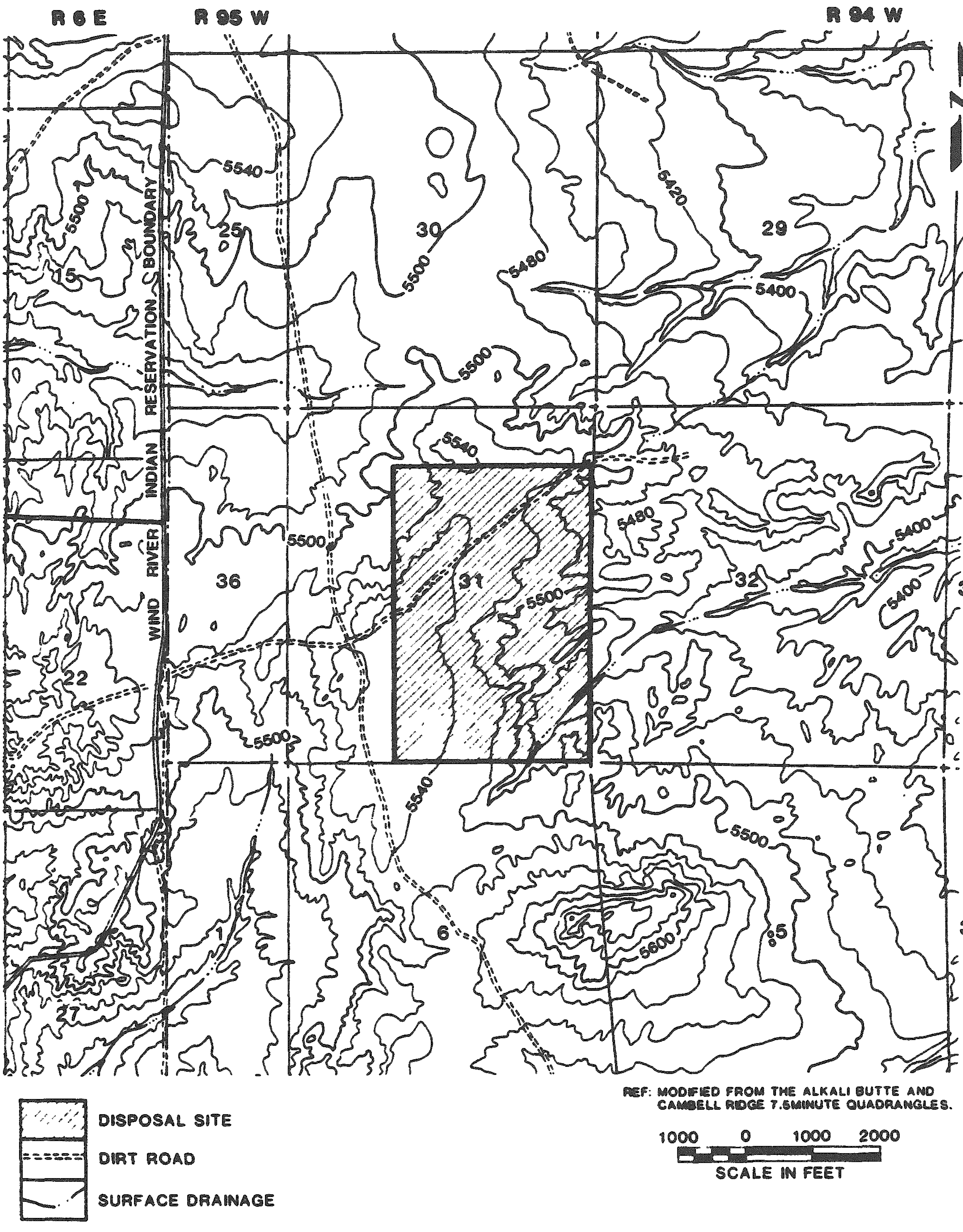


FIGURE A.4.1 DRY CHEYENNE ALTERNATE DISPOSAL SITE

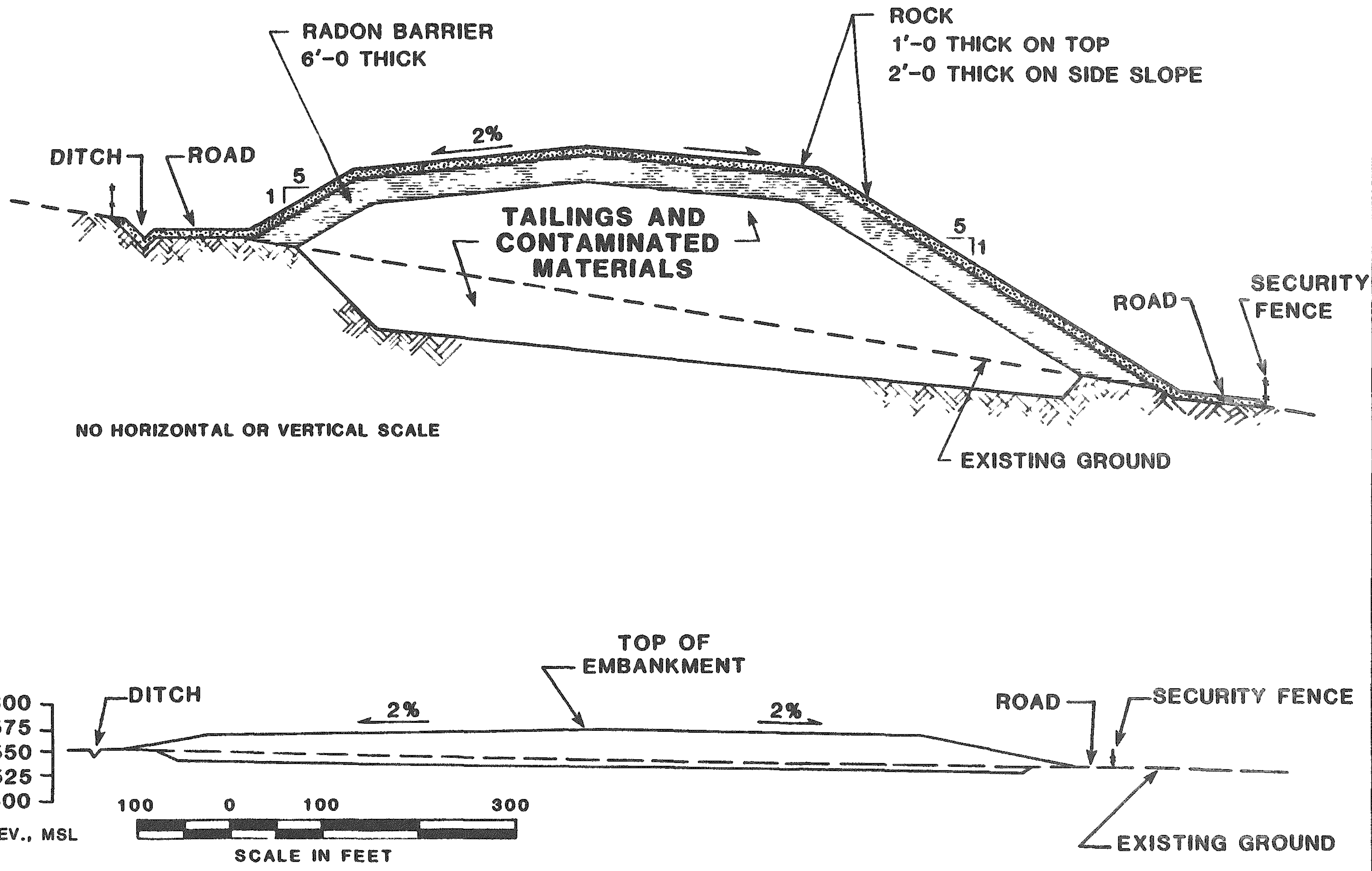


FIGURE A.4.2
DRY CHEYENNE DISPOSAL SITE, TYPICAL CROSS-SECTION

surface drainage, and revegetated as necessary or reclaimed according to applicable regulations (Appendix G, Permits, Licenses, and Approvals).

A.4.3 MAJOR ASSUMPTIONS

- o Partially below-grade disposal would be possible to an average depth of 16 feet below the existing grade at the alternate disposal site.
- o Surface materials excavated from the disposal area would be suitable for use as radon barrier materials and would have the same characteristics as analyzed borrow materials from the borrow site proposed for stabilization in place (borrow site 10).
- o The quantity of contaminated soils beneath the tailings is based on 70 acres contaminated to an average depth of 3 feet.
- o No ground water is assumed to exist in the surface soils at the Dry Cheyenne alternate disposal site.
- o The disposal area would be excavated to the extent necessary to obtain all radon barrier and site restoration materials.
- o All gravel and rock materials would be obtained from borrow site 2 within the existing tailings site.
- o All disturbed areas at the Riverton tailings site would be backfilled with uncontaminated soil to a level compatible with the surrounding terrain, recontoured to promote surface drainage, and revegetated as necessary.
- o All disturbed areas outside the fenced disposal site (except the haul road to the disposal site) would be reclaimed according to applicable regulations (Appendix G, Permits, Licenses, and Approvals).

A.4.4 RADON CONTROL

Control of radon emanation from the existing tailings site would be accomplished by relocation of the tailings and contaminated materials to the alternate disposal site. Control of radon emanation from the stabilized tailings at the disposal site would be accomplished through a combination of techniques including the following:

- o Placing the tailings and contaminated materials in a partially below-grade disposal area.
- o Placing a 6-foot thick, compacted, radon barrier over the consolidated tailings and contaminated materials.

Data on the distribution of radium in the tailings and the properties of the borrow materials available at borrow site 10 have been used to develop the estimate of radon barrier thickness.

A.4.5 LONG-TERM STABILITY

The remedial action for the stabilization in place alternative (Section A.3) has been designed to withstand the forces of nature for a long period of time (up to 1,000 years). The conditions for remedial action at the Dry Cheyenne alternate disposal site would be similar to those for stabilization in place except for the potential hazards from flooding and river meander. Therefore, the erosion protection requirements are assumed to be the same except for the protection required for flooding and river meander.

The Dry Cheyenne relocation alternative would incorporate the same measures to assure long-term stability against water and wind erosion, slope failure and seismic risk, differential settlement, and frost heave and solifluction as discussed for stabilization in place (Section A.3.5).

No flood flows are expected to impact the alternate disposal site because of its distance from and elevation above the closest stream channel. Therefore, flood protection and river meander are not stability considerations for this remedial action alternative.

A.4.6 GROUND-WATER PROTECTION

The top and sides of the stabilized tailings pile would be sloped to promote the drainage of precipitation off of the pile, and the compacted, earthen radon barrier over the pile would inhibit the infiltration of precipitation through the pile. These measures would minimize the leaching of contaminants into the underlying strata. Since it is assumed that no shallow ground water exists at the Dry Cheyenne alternate disposal site, no additional ground-water protection measures are considered necessary for this remedial action alternative. On-site data would be obtained to verify the absence of shallow ground water if this alternative were to be selected.

Relocation of the tailings and contaminated materials to the Dry Cheyenne site would remove the source of any future ground-water contamination at the Riverton tailings site, and the natural flow and discharge of the shallow ground water into the Little Wind River would reduce the existing concentrations of contaminants to background levels in approximately 45 years. At this time, aquifer restoration would not be a cost effective means of controlling or cleaning up the ground-water contamination at the Riverton site (Section C.2.6 of Appendix C, Water).

When the EPA issues revisions to the water protection standards (40 CFR Part 192.20 (a)(2)-(3)) that were remanded by the U.S. Tenth Circuit Court of Appeals, the DOE will re-evaluate the ground-water issues at the Riverton site to assure that the revised standards are met. Performing remedial action to stabilize the tailings prior to the EPA issuing new standards will not affect the measures that are ultimately required to meet the revised EPA water protection standards. The DOE has characterized the conditions at the Riverton site and does not anticipate that any substantial changes to the remedial action would be required if this alternative were selected.

A.4.7 CONSTRUCTION SEQUENCE

This remedial action alternative would involve similar activities at the Riverton tailings site and the Dry Cheyenne alternate disposal site. The following construction sequence is outlined as a possible means of accomplishing the remedial action.

Initially, 2 miles of gravelled haul road would be constructed from Highway 136 to the alternate disposal site. A site security system would then be established at each site and coordinated with staging and vehicle decontamination areas. This would provide control of traffic entering and leaving each site and prevent unauthorized traffic from entering either site. The next major item of site preparation would consist of constructing waste-water retention ponds at each site. Materials excavated from each pond would be stockpiled for later use as fill. Site preparation would also include construction of drainage and erosion control measures.

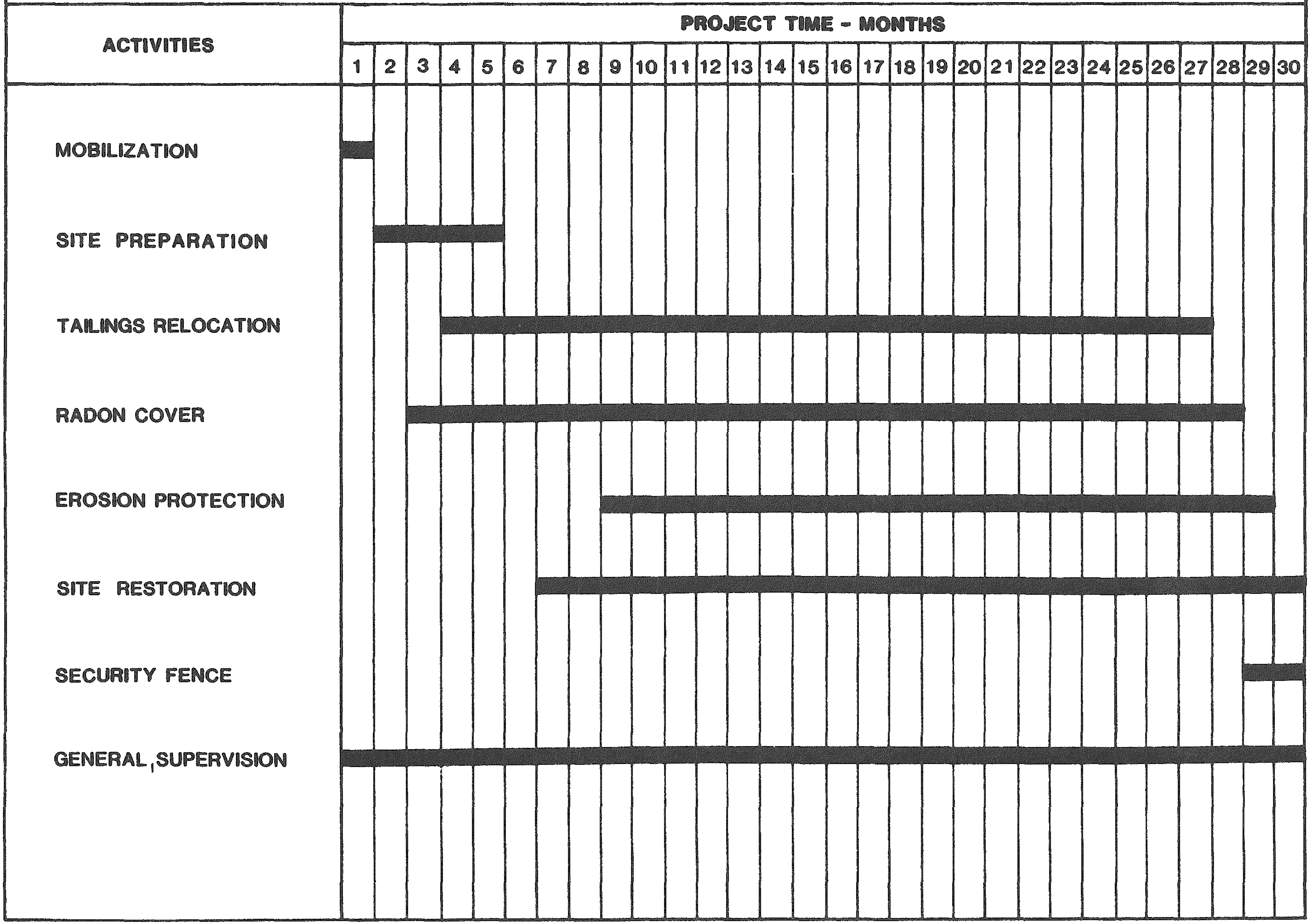
Once the initial site preparation at the Dry Cheyenne site was completed, preparation of the disposal area would begin. This would involve the excavation and stockpiling of surface materials to allow for partially below-grade disposal of the tailings. Concurrently, the building demolition and decontamination at the Riverton site would be performed. Contaminated materials would be excavated from the windblown areas and consolidated with the existing tailings pile. However, the final movement of tailings and demolition debris would not begin until the haul road to the disposal site was completed and a sufficient area had been opened and prepared at the disposal site.

Radon barrier materials obtained from the surface materials excavated from the disposal area would be added to the relocated pile after the tailings and contaminated materials were in place. The final stages of remedial action would involve placement of the erosion protection barrier over the radon barrier; the construction of an access road, drainage ditch, and security fence around the stabilized tailings pile; re-establishing overall site drainage; and reclamation of disturbed areas at the alternate disposal site.

The disturbed areas at the Riverton tailings site would be backfilled, recontoured, and revegetated (as necessary). The fill would be obtained from the surface materials excavated and stockpiled at the Dry Cheyenne alternate disposal site. Borrow site 2 would be reclaimed.

Figure A.4.3 shows the schedule for the Dry Cheyenne alternative.

FIGURE A.4.3 REMEDIAL ACTION SCHEDULE, DISPOSAL AT DRY CHEYENNE SITE



A.5 CONSTRUCTION ESTIMATES

Estimates of equipment and personnel requirements; fuel, electricity, and water consumptions; major earthwork volumes; and construction costs for each remedial action alternative are summarized in Tables A.5.1 through A.5.11.

Table A.5.1 Equipment use, relocation to Gas Hills[a]

Type of equipment	Pieces of equipment per month of project time																															Total equipment-months per type of equipment
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Bulldozer-D8	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	5	5	5	5	5	5	5	5	5	5	5	5	114
Front-end loader	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	5	5	5	5	5	5	5	5	5	5	5	5	108
10cy[b] truck with 8cy pup	0	0	0	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	48	48	48	48	48	48	48	48	48	48	48	48	1,232
Grader	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	3	17
Compacter	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Water truck	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	31
Crane	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Seeder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3
Total pieces of equipment per month of project time	8	5	5	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	59	60	60	60	60	60	60	60	60	60	61	64	1,510[c]

[a]Does not include the equipment used for remedial action at the selected active tailings site at Gas Hills.
[b]Cubic yard.
[c]Average = 1,510 total equipment-months/31 months = 49 pieces of equipment per month.

Table A.5.2 Personnel requirements, relocation to Gas Hills[a]

Type of personnel	Number of personnel per month of project time																															Total man-months per type of personnel
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Truck drivers	3	1	1	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	49	49	49	49	49	49	49	49	49	49	49	51	1,267
Equipment operators	5	4	4	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	11	11	11	11	11	11	11	11	11	11	12	13	244
Operator supervisors	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	105
Laborers	13	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	15	15	15	15	15	15	15	15	15	15	15	20	398
General supervision and field services	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	155
Total man-months per month of project time	29	17	17	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	84	84	84	84	84	84	84	84	84	84	85	93	2,169

[a]Does not include the personnel required for remedial action at the selected active tailings site at Gas Hills; personnel requirements based on one 8-hour shift per day, 5 days per week; peak employment = 93; average employment = 2,169 total man-months/31 months = 70.

Table A.5.3 Equipment use, stabilization in place

Type of equipment	Pieces of equipment per month of project time																								Total equipment-months per type of equipment
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Bulldozer-D8	0	5	5	7	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	2	1	0	91
Front-end loader	0	1	1	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	2	1	0	72
10cy[a] truck with 8cy pup	0	5	5	27	27	27	38	38	44	44	44	44	44	44	44	44	44	44	44	44	38	12	0	0	745
Grader	0	1	2	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	3	2	1	0	49
Scraper	0	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	18
Compactor	0	1	1	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	28
Water truck	0	1	1	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	28
Backhoe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	6
Crane	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Hydromulcher	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	3
Total pieces of equipment per month of project time	0	17	18	47	42	42	54	54	61	56	56	56	56	56	56	56	58	58	58	58	55	23	6	0	1,043[b]

[a]Cubic yard.
[b]Average = 1,043 total equipment-months/24 months = 43 pieces of equipment per month.

Table A.5.4 Personnel requirements, stabilization in place[a]

Type of personnel	Number of personnel per month of project time																								Total man-months per type of personnel
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Truck drivers	0	5	5	27	27	27	38	38	44	44	44	44	44	44	44	44	44	44	44	44	38	12	0	0	745
Equipment operators	0	12	13	20	15	15	16	16	17	12	12	12	12	12	12	12	14	14	14	14	17	11	6	0	298
Operator supervisors	0	2	2	5	4	4	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6	2	1	0	108
Laborers	0	2	2	3	3	3	3	3	3	2	2	2	2	2	2	2	3	3	3	3	3	2	1	0	54
General supervision and field services	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	432
Total man-months per month of project time	18	39	40	73	67	67	80	80	88	82	82	82	82	82	82	82	85	85	85	85	82	45	26	18	1,637

[a]Personnel requirements based on one 8-hour shift per day, 5 days per week.
Peak employment = 88.
Average employment = 1,637 total man-months/24 months = 68.

Table A.5.5 Equipment use, disposal at Dry Cheyenne site

Type of equipment	Pieces of equipment per month of project time																														Total equipment-months per type of equipment
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Bulldozer-D8	0	6	6	8	8	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	2	1	1	142
Front-end loader	0	1	1	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	2	2	0	124
10cy[a] truck with 8cy pup	0	8	8	41	41	38	38	38	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	3	3	0	997
Grader	0	1	1	2	2	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	1	0	96
Scraper	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	0	52
Compactor	0	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	0	49
Water truck	0	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	0	49
Crane	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Hydromulcher	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	5
Total pieces of equipment per month of project time	0	19	21	60	60	55	58	58	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	62	62	62	14	9	2	1,518[b]

[a]Cubic yard.
[b]Average = 1,518 total equipment-months/30 months = 51 pieces of equipment per month.

Table A.5.6 Personnel requirements, disposal at Dry Cheyenne site[a]

Type of personnel	Number of personnel per month of project time																														Total man-months per type of of personnel
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Truck drivers	0	8	8	41	41	38	38	38	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	3	3	0	997
Equipment operators	0	11	13	19	19	17	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	21	21	21	11	6	2	521
Operator supervisors	0	2	3	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	2	1	1	172
Laborers	0	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	1	81
General supervision and field services	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	660
Total man-months per month of project time	22	45	48	91	91	86	89	89	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	94	94	94	40	34	26	2,431

[a]Personnel requirements based on one 8-hour shift per day, 5 days per week.
Peak employment = 94.
Average employment = 2,431 total man-months/30 months = 81.

Table A.5.7 Fuel consumption, Riverton remedial action alternatives

	Fuel consumption (gallons)		
Type of equipment	Relocation to Gas Hills	Stabilization in place	Disposal at Dry Cheyenne site
D8 dozer	211,000	132,000	206,000
Front-end loader	200,000	85,000	147,000
10cy[a] truck with 8cy pup	1,630,000	788,000	1,053,000
Grader	15,000	40,000	76,000
Scraper	NA[b]	31,000	89,000
Compactor	7,000	52,000	91,000
Water truck	16,000	15,000	26,000
Backhoe	NA[b]	11,000	NA[b]
Crane	1,000	4,000	6,000
Hydromulcher or seeder	2,000	2,000	3,000
Totals	2,082,000	1,160,000	1,697,000

[a]Cubic yard.
[b]Not applicable.

Table A.5.8 Electricity consumption, Riverton remedial action alternatives

Facility	Electricity consumption (kilowatt-hours)		
	Relocation to Gas Hills	Stabilization in place	Disposal at Dry Cheyenne site
Field office(s)	91,000	36,000	90,000
Change-shower trailer(s)	208,000	162,000	410,000
Laundry	104,000	81,000	103,000
Dewatering	12,000	14,000	18,000
Totals	415,000	293,000	621,000

Table A.5.9 Water consumption, Riverton remedial action alternatives

Water use	Water consumption (gallons)		
	Relocation to Gas Hills	Stabilization in place	Disposal at Dry Cheyenne site
Compaction			
o Site preparation	230,000	340,000	890,000
o Tailings relocation	NA[a]	2,500,000	15,000,000
o Radon cover	NA[a]	15,400,000	9,000,000
o Erosion protection	NA[a]	1,750,000	1,000,000
o Restoration	NA[a]	1,385,000	5,210,000
Compaction Totals	230,000	21,375,000	31,100,000
Laundry and showers	740,000	41,000	71,000
Decontamination	3,180,000	110,000	2,500,000
Dust control	1,430,000	695,000	1,800,000
Totals	5,580,000	22,221,000	35,471,000

[a]Not applicable.

Table A.5.10 Summary of major earthwork volumes, Riverton remedial action alternatives

Activity	Estimated in-place volume (cubic yards)		
	Relocation to Gas Hills	Stabilization in place	Disposal at Dry Cheyenne site
Site preparation			
o New haul road			
1. Base course	NA[a]	12,000	36,000
2. Gravel	NA[a]	6,000	16,000
o Strip and stockpile topsoil at borrow site	NA[a]	40,000	NA[a]
Tailings relocation			
o Excavate, haul, spread, and compact	1,500,000	250,000	1,500,000
Radon barrier			
o Excavate and stockpile for site restoration	NA[a]	NA[a]	430,000
o Excavate, haul, spread, and compact	NA[a]	670,000	390,000
Erosion protection	NA[a]	175,000	99,000
Site restoration			
o Backfill excavations	430,000	113,000	430,000
o Replace stripped topsoil	NA[a]	40,000	NA[a]

[a]Not applicable.

Table A.5.11 Summary of construction costs, Riverton remedial action alternatives[a]

Activity	Costs (1987 dollars)		
	Relocation to Gas Hills	Stabilization in place	Disposal at Dry Cheyenne site
Site preparation	1,767,000	844,000	1,506,000
Tailings relocation	17,390,000	269,000	10,536,000
Radon barrier	NA[b]	4,861,000	2,171,000
Erosion protection	NA[b]	2,722,000	1,408,000
Decontamination	96,000	43,000	246,000
Site restoration	1,906,000	1,001,000	3,156,000
Fencing	2,000	134,000	99,000
Subtotals	21,161,000	9,874,000	19,122,000
Construction contingency[c]	1,058,000	1,481,000	2,868,000
Vicinity properties	1,484,000	1,484,000	1,484,000
Totals	23,703,000	12,839,000	23,474,000

[a]These cost estimates do not include the costs of:

- o Property acquisition.
- o Engineering design.
- o Construction management (including field supervision).
- o Overall project management.
- o Long-term surveillance and maintenance.

The costs of these items would differ between the remedial action alternatives depending on the type and ownership of the property, the type and amount of engineering design required, and the duration of the remedial action.

[b]Not applicable.

[c]The construction contingencies are 5 percent of the subtotal for relocation to Gas Hills and 15 percent of the subtotals for stabilization in place and disposal at the Dry Cneyenne site.

A.6 VICINITY PROPERTIES

Vicinity properties are properties outside the designated Uranium Mill Tailings Remedial Action (UMTRA) Project site boundary that may have been contaminated by tailings dispersed by water or wind erosion or by removal by man before the potential hazard of the tailings was known. Properties that are identified as vicinity properties are typically located by aerial radiological surveys or street-by-street, mobile, gamma-ray scanning. The EPA standards are used to determine which properties are eligible for remedial action.

A street-by-street, mobile gamma-ray scan of the Riverton area was performed in 1971 and identified 87 radiation anomalies. On-site surveys found evidence of the presence of tailings at 14 of these locations. In September, 1980, an aerial radiological survey identified several locations, in addition to the tailings pile, exhibiting above-background gamma radiation levels. Another mobile gamma-ray scan in June, 1982, resulted in the identification of 50 vicinity properties that required detailed on-site surveys. On-site surveys were conducted, and the results were compared with the EPA standards. Twenty-five of the vicinity properties were determined to be eligible for remedial action.

The 25 vicinity properties in the Riverton area include single-family residences, commercial structures, a vacant lot, and a motel. Detailed on-site surveys of all of the properties have been conducted by Oak Ridge National Laboratory. The results of these surveys will be used to determine if the properties warrant remedial action under the UMTRCA of 1978, Public Law 95-604. The 25 vicinity properties eligible for remedial action were used in the calculation of the environmental impacts discussed in this document. The impacts of remedial action at the vicinity properties were previously assessed in a programmatic environmental report (DOE, 1985).

All of the remedial action alternatives except no action include remedial action at the vicinity properties. The major construction activities associated with remedial action at the vicinity properties include:

- o Excavation of the contaminated materials (usually 200 cubic yards or less per property) with front-end loaders and hand-held shovels.
- o Relocation of the contaminated materials using 10-cubic yard capacity trucks to the Riverton tailings site for temporary storage.
- o Restoration of the vicinity properties (i.e., backfilling, recontouring, and revegetating disturbed areas) as needed.
- o Final stabilization of the contaminated materials with the tailings.

The following engineering estimates were used to assess the impacts of each remedial action alternative (except no action) addressed in this document:

o Number of properties.	25
o Average distance from Riverton tailings site (miles).	4
o Estimated average volume (maximum) of contaminated materials per property (cubic yards).	200

o Average number of truck trips to remove contaminated materials and return uncontaminated fill to each property.	20
o Duration of project (construction seasons).	2
o Total man-years of labor.	6.2
o Engineering and management costs (1987 dollars).	602,000
o Remedial action costs (1987 dollars).	1,484,000
o Total costs (1987 dollars).	2,086,000

REFERENCES FOR APPENDIX A

COE (U.S. Army Corps of Engineers), 1982. HEC-2 Water Surface Profiles, User's Manual, Computer Program 723-X6-L202A, Water Resources Support Center, Hydrology Engineering Center, Davis, California.

COE (U.S. Army Corps of Engineers), 1981. HEC-1 Flood Hydrograph Package, User's Manual, Computer Program 723-X6-L2010, Water Resources Support Center, Hydrology Engineering Center, Davis, California.

COE (U.S. Army Corps of Engineers), 1970. Engineering and Design Stability of Earth and Rock-Fill Dams, Manual No. 1110-2-1902, Department of the Army, Office of the Chief of Engineers, Washington, D.C.

DOE (U.S. Department of Energy), 1987. Remedial Action and Site Design Plan for Stabilization of the Inactive Uranium Mill Tailings Site at Riverton, Wyoming, UMTRA-DOE/AL-05007.0000, being prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1985. Programmatic Environmental Report for Remedial Actions at UMTRA Project Vicinity Properties, UMTRA-DOE/AL-150327.0000, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

FBDU (Ford, Bacon & Davis Utah Inc.), 1981. Engineering Assessment of Inactive Uranium Mill Tailings, Riverton Site, Riverton, Wyoming, DOE/UMT106, prepared by FBDU, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Lindell, K. A., and E. F. Lobacz, 1980. Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost, Special Report 80-34, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

MSRD (Mountain States Research and Development), 1982. Economic Evaluation of Inactive Uranium Mill Tailings, Riverton, Site, Riverton, Wyoming, UMTRA-DOE/ALO-178, prepared by MSRD, Tucson, Arizona, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

NOAA (National Oceanic and Atmospheric Administration), 1984. Hydrometeorological Report No. 55, Probable Maximum Precipitation Estimates - United States Between the Continental Divide and the 103rd Meridian, Silver Springs, Maryland.

NRC (U.S. Nuclear Regulatory Commission), 1984. Radon Attenuation Handbook for Uranium Mill Tailings Cover Design, NUREG/CR-3533, Washington, D.C.

Ritter, D. F., 1978. Process Geomorphology, William C. Brown Publishers, Dubuque, Iowa.

SHB (Sergent, Hauskins & Beckwith), 1985. "Geomorphic Evaluation, Riverton Uranium Mill Tailings Site, Uranium Mill Tailings Remedial Action Project," unpublished report prepared by SHB, Albuquerque, New Mexico, for the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico.

SHB (Sergent, Hauskins & Beckwith), 1983. "Evaluation of Potential Earthquake Effects, Riverton Site, Fremont County, Wyoming, Uranium Mill Tailings Remedial Action Project," unpublished report prepared by SHB, Albuquerque, New Mexico, for the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico.

APPENDIX B

WEATHER AND AIR QUALITY

TABLE OF CONTENTS

LIST OF TABLES

B.1 INTRODUCTION

The following appendix provides detailed meteorological data and information on the air quality assessment techniques and assumptions. Specifically included are the methodologies used in the emissions calculations and computer modeling, a description of the computer model, and supporting technical information.

B.2 METEOROLOGICAL DATA

Meteorological data are presented in Tables B.2.1 and B.2.2. Table B.2.1 presents average daily, monthly, and annual temperature data and average monthly and annual precipitation data. Table B.2.2 presents annual average wind speeds and the frequency of occurrence for winds in each of the 16 compass directions.

Table B.2.1 Temperature and precipitation at Riverton, Wyoming[a]

	Temperature (°F)[b]			Precipitation (inches)		
Month	Average daily maximum	Average daily minimum	Average monthly	Average	Number of days that have 0.10 inch or more	Average snow and sleet
January	30.1	0.5	15.3	0.21	1	3.4
February	37.1	6.7	21.9	0.25	1	4.2
March	47.3	18.5	32.9	0.52	2	6.5
April	59.3	29.2	44.3	1.32	3	6.1
May	69.7	38.5	54.1	1.81	5	1.8
June	79.6	45.9	62.8	1.26	3	0.6
July	89.2	51.1	70.2	0.67	2	0.0
August	87.0	48.5	67.8	0.44	1	0.0
September	76.4	39.4	57.9	0.76	2	0.6
October	62.9	29.5	46.2	0.82	2	2.9
November	43.5	14.6	29.1	0.53	2	6.5
December	34.0	5.4	19.7	0.20	1	3.2
Year	59.7	27.3	43.5	8.79	25	35.8

[a]The elevation of Riverton, Wyoming, is 4,954 feet above mean sea level.
[b]Degrees Fahrenheit.

Ref. DOC, 1970.

Table B.2.2 Average annual wind speeds at Riverton, Wyoming

Direction	Frequency[a] (percent)	Average speed (miles per hour)
N	6.0	8.0
NNE	3.9	7.2
NE	4.8	6.5
ENE	3.4	6.1
E	5.6	5.9
ESE	1.3	5.7
SE	1.4	5.7
SSE	1.1	5.7
S	3.4	6.0
SSW	2.1	6.8
SW	3.3	6.7
WSW	6.4	6.8
W	10.1	7.4
WNW	5.8	7.9
NW	5.8	6.9
NNW	2.9	6.8
Calm	31.9	0.0
All directions	99.2	6.8

[a]The percentages do not total 100 percent due to rounding.

Ref. DOC, 1976.

B.3 EMISSIONS INVENTORY

The emissions inventory includes estimates of combustion emissions from the construction equipment and fugitive dust emissions from the various remedial action activities. For relocation to Gas Hills, the emissions inventory included only the combustion and fugitive dust emissions from the remedial action activities at the Riverton tailings site and Little Wind borrow site.

Combustion emissions (Tables B.3.1, B.3.2, and B.3.3) are based on the emissions factors presented in Table B.3.4 and the equipment fuel consumption rates presented in Tables B.3.1 through B.3.3. Fugitive dust emissions (Table B.3.5) are based on the emissions factors presented in Table B.3.6 and the quantities of materials moved and the equipment usage estimates as detailed in Section A.5 of Appendix A, Conceptual Designs. The estimates of fugitive dust emissions assume a 50-percent reduction in emissions due to the implementation of a dust control program at each of the sites and a 60-percent reduction in emissions due to the use of a chemical dust suppressant on gravelled haul roads (WDEQ, 1979). Fugitive dust emissions due to wind erosion of the areas disturbed by remedial action activities were not considered. Combustion emissions (Tables B.3.1 through B.3.2) have been estimated for the entire remedial action, while fugitive dust emissions have been calculated for each month of the remedial action alternatives (Table B.3.5). Federal and State of Wyoming ambient air quality standards are presented in Table B.3.7.

Table B.3.1 Construction equipment combustion emissions, relocation to Gas Hills

Equipment type	Fuel consumption (gallons)	Emissions (pounds)[a]				
		HC	NO_x	SO_x	CO	TSP
Bulldozer	10,672	4,361	94,803	6,573	13,884	3,118
Front-end loader	99,584	2,635	47,900	6,227	13,153	4,789
Motor grader	15,120	263	5,655	470	1,179	336
Compactor	6,864	167	3,350	213	783	166
Water truck	15,624	542	7,718	486	1,472	470
Crane	384	13	190	12	36	12
Seeder	2,016	70	996	63	190	60
Haulage truck[b]	NA[b]	88,784	405,241	54,501	556,437	25,492
Totals		96,835	565,853	68,545	587,134	34,443

[a]Based on the emissions factors presented in Table B.3.4 and the fuel consumption rates given in Section A.5 of Appendix A, Conceptual Designs.

[b]Based on the emissions factors presented in Table B.3.4 and 8,790,500 vehicle-miles traveled; NA indicates not applicable.

Table B.3.2 Construction equipment combustion emissions, stabilization in place

Equipment type	Fuel consumption (gallons)	Emissions (pounds)[a]				
		HC	NO_x	SO_x	CO	TSP
Bulldozer	132,132	2,735	59,459	4,123	8,707	1,956
Front-end loader	85,536	1,129	20,529	2,669	5,637	2,053
Motor grader	39,600	629	14,810	1,232	3,089	879
Scraper	30,888	1,303	12,942	964	3,036	843
Compactor	51,744	1,257	25,251	1,609	5,899	1,252
Water truck	14,784	513	7,303	460	1,393	445
Backhoe	10,560	139	2,534	329	696	253
Crane	4,356	151	2,152	135	410	131
Hydromulcher	1,584	55	782	49	149	48
Haulage truck[b]	NA[b]	12,884	58,805	7,909	80,745	3,699
Totals		20,795	204,567	19,479	109,761	11,559

[a]Based on the emissions factors presented in Table B.3.4 and the fuel consumption rates given in Section A.5 of Appendix A, Conceptual Designs.

[b]Based on the emissions factors presented in Table B.3.4 and 1,275,600 vehicle-miles traveled; NA indicates not applicable.

Table B.3.3 Construction equipment combustion emissions, disposal at Dry Cheyenne site

Equipment type	Fuel consumption (gallons)	Emissions (pounds)[a]				
		HC	NO_x	SO_x	CO	TSP
Bulldozer	206,184	4,268	92,783	6,433	13,588	3,052
Front-end loader	147,312	1,945	35,355	4,596	9,708	3,535
Motor grader	76,032	1,323	28,436	2,365	5,930	1,688
Scraper	89,232	3,766	37,388	2,784	8,772	2,436
Compactor	90,552	2,200	44,189	2,816	10,323	2,191
Water truck	25,872	898	12,781	805	2,437	779
Crane	5,808	202	2,869	181	547	175
Hydromulcher	2,640	92	1,304	82	249	79
Haulage truck[b]	NA[b]	35,552	162,272	21,824	222,816	10,208
Totals		50,246	417,377	41,886	274,370	24,143

[a]Based on the emissions factors presented in Table B.3.4 and the fuel consumption rates given in Section A.5 of Appendix A, Conceptual Designs.

[b]Based on the emissions factors presented in Table B.3.4 and 3,520,000 vehicle-miles traveled; NA indicates not applicable.

Table B.3.4 Construction equipment combustion emissions factors

Equipment type	Units	HC	NO_x	SO_x	CO	TSP
Bulldozer	Pounds/1000 gallons	20.7	450.0	31.2	65.9	14.8
Front-end loader	Pounds/1000 gallons	13.2	240.0	31.2	65.9	24.0
Motor grader	Pounds/1000 gallons	17.4	374.0	31.1	78.0	22.2
Scraper	Pounds/1000 gallons	42.2	419.0	31.2	98.3	27.3
Compactor	Pounds/1000 gallons	24.3	488.0	31.1	114.0	24.2
Water truck	Pounds/1000 gallons	34.7	494.0	31.1	94.2	30.1
Backhoe	Pounds/1000 gallons	13.2	240.0	31.2	65.9	24.0
Crane	Pounds/1000 gallons	34.7	494.0	31.1	94.2	30.1
Hydromulcher or seeder	Pounds/1000 gallons	34.7	494.0	31.1	94.2	30.1
Haulage truck	Pounds/1000 miles traveled	10.1	46.1	6.2	63.3	2.9

Ref. EPA, 1979.

Table B.3.5 Fugitive dust emissions as a function of time, Riverton remedial action alternatives[a]

Project month	Emissions (tons)		
	Relocation to Gas Hills	Stabilization in place	Disposal at Dry Cheyenne site
1	4.22	NA	NA
2	4.22	9.11	9.86
3	4.22	9.11	12.05
4	8.80	27.40	70.04
5	8.80	22.60	70.04
6	8.80	22.60	65.40
7	8.80	23.65	66.57
8	8.80	23.65	66.57
9	8.80	25.98	69.66
10	8.80	22.81	69.66
11	8.80	22.81	69.66
12	8.80	22.81	69.66
13	8.80	22.81	69.66
14	8.80	22.81	69.66
15	8.80	22.81	69.66
16	8.80	22.81	69.66
17	8.80	23.90	69.66
18	8.80	23.90	69.66
19	8.80	23.90	69.66
20	18.84	23.90	69.66
21	18.84	26.08	69.66
22	18.84	7.80	69.66
23	18.84	4.45	69.66
24	18.84	NA	69.66
25	18.84	NA	69.66
26	18.84	NA	69.66
27	18.84	NA	69.66
28	18.84	NA	9.55
29	18.84	NA	5.26
30	18.84	NA	1.11
31	18.84	NA	NA
Totals	379.54	457.70	1,699.99

[a]Based on the emissions factors presented in Table B.3.6 and the volumes of materials moved and equipment usage estimates as presented in Section A.5 of Appendix A, Conceptual Designs. Fugitive dust emissions assume a 50-percent reduction for equipment working on the sites due to a dust control (watering) program and a 60-percent reduction for vehicles traveling on gravelled haul roads due to the use of a chemical dust suppressant. NA indicates not applicable.

Table B.3.6 Fugitive dust emissions factors

Activity	Emissions factor	Reference
Overburden removal and haul road work: scrapers, graders, bulldozers	32 pounds/hour	WDEQ, 1979
Tailings removal: front-end loader	0.003 pound/ton removed	WDEQ, 1979
Haul road travel[a]	5.88 pounds/vehicle-mile traveled	EPA, 1979
Open-bed truck transport	0.0057 pound/vehicle-mile traveled	CDH, 1981
Backhoe	0.04 pound/cubic yard removed	WDEQ, 1979

[a]Based on the equation (EPA, 1979):

$$EF = (0.81)\,(s)\,\left(\frac{V}{30}\right)\,\left(\frac{365-W}{365}\right)\,\left({}^{N}/_{4}\right)\,(0.62)\,\frac{(100-C)}{100}$$

Where:

EF = emission factor.
s = silt content (15 percent).
V = vehicle speed (30 miles per hour).
W = number of days with precipitation of 0.01 inch or greater (80).
N = number of truck wheels (10).
C = percent reduction in emissions (60 percent).

Table B.3.7 Summary of Federal and State of Wyoming ambient air quality standards

Pollutant Averaging period	Federal primary standard[a,b]	Federal secondary standard[a,b]	State of Wyoming standard[a,c]
Ozone			
1-hour average	0.12 ppm (235 microg/m^3)	0.12 ppm (235 microg/m^3)	None
Carbon monoxide			
8-hour average	9 ppm (10,080 microg/m^3)	9 ppm (10,080 microg/m^3)	10 mg/m^3
1-hour average	35 ppm (40,000 microg/m^3)	35 ppm (40,000 microg/m^3)	40 mg/m^3
Nitrogen dioxide			
annual average	0.05 ppm (100 microg/m^3)	0.05 ppm (100 microg/m^3)	100 microg/m^3
Sulfur dioxide			
annual average	0.03 ppm (80 microg/m^3)	None	60 microg/m^3
24-hour average	0.14 ppm (365 microg/m^3)	None	260 microg/m^3
3-hour average	None	None	1,300 microg/m^3
Total suspended particulates (TSP)			
annual average	75.0 microg/m^3	60.0 microg/m^3	60.0 microg/m^3
24-hour average	260.0 microg/m^3	150.0 microg/m^3	150.0 microg/m^3
Lead			
quarterly (3-month average)	1.5 microg/m^3	None	None

[a]Parts per million - ppm; milligrams per cubic meter - mg/m^3; micrograms per cubic meter - microg/m^3.

[b]Ref. Title 40, Code of Federal Regulations, Part 50. Federal standards, other than those based on annual averages or annual geometric means, are not to be exceeded more than once per year. The Federal primary standard defines the level of air quality deemed necessary, with an adequate margin of safety, to protect the public health while the Federal secondary standard defines the level of air quality deemed necessary to protect the public welfare from any known or anticipated adverse effects of the pollutant.

[c]Ref. WDEQ, 1985. State of Wyoming standards are not to be equaled or exceeded.

B.4 COMPUTER MODEL DESCRIPTION AND METHODOLOGY

The maximum 24-hour increases in ambient particulates concentrations were estimated using the Industrial Source Complex Dispersion Model for short-term applications (ISCST) (Bowers et al., 1979). The ISCST was developed for the U.S. Environmental Protection Agency (EPA) and is recommended for use in the analysis of fugitive dust emissions. The ISCST allows examination of multiple-point, area and volume sources, multiple meteorological conditions, gravitational settling, and dry deposition.

Fugitive dust emissions calculated for the remedial action alternatives were apportioned among area and volume sources representing the dust producing activities expected during remedial action operations. Tailings excavation and relocation and cover placement operations which involve earthmoving activities within the designated disposal sites were defined as area sources. The effective height of the emitting area was assumed to be equivalent to the physical height of the tailings pile, storage pile, or other appropriate emissions source as suggested by the ISCST User's Guide. Dust emissions from truck transport traffic along the gravelled haul roads and paved highways were represented by a string of surface-based volume sources. The lateral and vertical dispersion parameters defining the initial volume from which emissions are dispersed were determined by following procedures suggested in the ISCST User's Guide (Bowers et al., 1979).

Receptors were placed downwind of each set of emissions sources along preselected, wind direction radials within areas where high ambient concentrations would be expected. All receptors were located outside the fenceline surrounding each activity area. Several receptors were placed along each radial at varying distances downwind to provide information on the behavior of particulates concentrations as a function of distance from the source.

Gravitational settling of particles within the plume and dry deposition of those particles on the ground surface are accomplished in the ISCST through the use of a tilted plume and a surface reflection coefficient. The mass fraction, gravitational settling velocity, and surface reflection coefficient are required for each particle size category into which the total emissions are subdivided. A site-specific particle size distribution for the tailings was unavailable. A size distribution derived from measurements made at surface mining operations throughout the Rocky Mountain region was substituted. Although dust emitted by mining operations would be expected to differ in terms of composition and chemical properties from dust emitted by the movement of uranium tailings, many of the excavation operations and types of equipment used are similar. Based on the size distribution derived for mining and excavation emissions and characteristic diameters assumed for each category, the settling velocity and surface reflection coefficient were determined for each category using techniques outlined in the ISCST User's Guide (Bowers et al., 1979). The particle size distribution and deposition parameters used in the analysis are presented in Table B.4.1.

Site-specific, hourly, sequential meteorological data were not available for use in the modeling analysis; therefore, a simplified, conservative approach was adopted. Light winds (2.5 meters per second) were assumed to blow persistently from a single direction under stable mixing conditions (Pasquill-Gifford Category E). This meteorological scenario produced maximum ground-level concen-

Table B.4.1 Particle size distribution and deposition parameters used in the air quality impacts analysis

Particle size class	Diameter range (microns)	Mass distribution (percent)	Characteristic diameter (microns)	Gravitational settling velocity[a] (meters per second)	Surface reflection coefficient
1	0-2.5	3	1.1	7.20×10^{-5}	1.00
2	2.5-5	4	3.3	6.48×10^{-4}	1.00
3	5-10	9	7.0	2.92×10^{-3}	0.90
4	10-15	5	12.0	8.57×10^{-3}	0.78
5	>15	79	25.0	3.72×10^{-2}	0.65

[a]Based on a particle density of 2 grams per cubic meter.

trations from near-surface emission sources. The persistence of these conditions was assumed not to exceed 6 hours during a single 24-hour period. This assumption is consistent with other screening models.

Emissions considered in the modeling runs were those occurring in the peak phase of activity. Invariably, activities in this peak phase included consolidation or relocation of the tailings. Also included, where appropriate, were emissions generated by travel on the paved roads and gravelled haul roads. For relocation to Gas Hills, maximum emissions would occur in months 20 through 31 when remedial action activities would include tailings excavation and relocation and site restoration at the Riverton site. In the case of stabilization in place, maximum emissions would occur in the ninth month when activities would include site preparation, consolidation of the tailings, placement of the radon barrier, and erosion protection measures. For disposal at the Dry Cheyenne site, maximum emissions would occur in the fourth month during site preparation, relocation of the tailings, and placement of the radon barrier. For modeling purposes, activities were assigned to several areas at each site. In the case of gravelled haul roads, emissions were distributed over the length of the roads. The specific inputs used in the model and the area over which emissions were distributed are presented in Table B.4.2.

Table B.4.2 ISCST model TSP emissions inputs, Riverton remedial action alternatives

Remedial action alternative	Location	Activity	Emissions rate[a] (grams per second)	Area of activity (square meters)
Relocation to Gas Hills	Riverton site	Tailings relocation Site restoration	4.21	62,500
	Little Wind borrow site	Excavation and loading	0.91	90,000
		Haul road	7.49[b]	NA[b]
Stabilization in place	Riverton site	Tailings consolidation Erosion protection Radon barrier Site restoration	5.38	250,000
	Borrow site 10	Excavation and loading	0.75	90,000
		Haul road	10.38[c]	NA[c]
Disposal at Dry Cheyenne site	Dry Cheyenne site	Site preparation Tailings relocation Radon barrier	4.71	187,500
		Haul road	36.20[d]	NA[d]
	Riverton site	Tailings relocation	3.45	62,500

[a]Based on 24 hours per day for modeling daily averages.

[b]Haul road emissions considered travel on 0.5 mile of gravelled road to the borrow site; NA indicates not applicable.

[c]Haul road emissions considered travel on 1 mile of gravelled road to the borrow site; NA indicates not applicable.

[d]Haul road emissions considered travel on 2 miles of gravelled road to the Dry Cheyenne site; NA indicates not applicable.

REFERENCES FOR APPENDIX B

Bowers et al. (J.F. Bowers, J.R. Bjorklund, and C.S. Cheney), 1979. Industrial Source Complex Dispersion Model (ISCST) User's Guide, Volumes I and II, Research Triangle Park, North Carolina.

CDH (Colorado Department of Health), 1981. Inter-office communication from Thomas Tistinic, Public Health Engineer, Air Pollution Control Division; Subject: Fugitive Dust Emissions; September 30, 1981.

DOC (U.S. Department of Commerce), 1976. Annual Wind Direction Versus Wind Speed Summary for Riverton, Wyoming, 1967-1971, prepared by the National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina, Job No. 14094.

DOC (U.S. Department of Commerce), 1970. Climatological Summary of Riverton, Wyoming, Climatography of the United States No. 20-48, Asheville, North Carolina.

EPA (U.S. Environmental Protection Agency), 1979. Compilation of Air Pollutant Emission Factors, AP-42, Supplements 1-13, Washington, D.C.

WDEQ (Wyoming Department of Environmental Quality), 1985. Ambient Air Monitoring Data for 1984, Cheyenne, Wyoming.

WDEQ (Wyoming Department of Environmental Quality), 1979. Memorandum from Charles A. Collins, Air Quality Supervisor, Air Quality Division; Subject: Fugitive Dust Emission Factors; January 24, 1979.

APPENDIX C

WATER

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

OIST OF FIGURES (Concluded)

LIST OF TABLES

LIST OF TABLES (Concluded)

C.1 SURFACE WATER

C.1.1 SURFACE-WATER FEATURES

C.1.1.1 Riverton tailings site

The Riverton tailings site is on a nearly level alluvial terrace that forms the drainage divide between the Wind River, 1 mile north of the site, and the Little Wind River, 0.5 mile southeast of the site (Figure C.1.1). The confluence of these two rivers is 2.5 miles east of the site. The minimum elevation of the tailings site is 4,940 feet above mean sea level.

A drainage ditch runs south along the eastern boundary of the tailings site to the northeast corner of the tailings pile and then turns east and flows into a marshy area east of the site (Figure C.1.2). Another drainage ditch runs through the field west of the tailings pile and into a marshy area south of the site. A system of irrigation canals in the northeast corner of the tailings site flows generally south to the northern edge of the tailings pile and then off the site to the south and east. A separate irrigation canal runs south along the eastern site boundary and then parallel to the drainage ditch flowing into the marshy area to the east.

The Wind River drainage basin above the confluence of the Wind and Little Wind Rivers consists of 4,300 square miles (Figure C.1.3) bordering the east slope of the Continental Divide in the west-central portion of Wyoming. The Wind River basin consists of 2,300 square miles while the Little Wind River basin contains 2,000 square miles. The Little Wind River drainage basin can be further divided into three tributary basins consisting of the Little Wind River, Popo Agie River, and Beaver Creek. The drainage areas for each specific drainage basin were calculated and are as follows:

Drainage basin	Drainage area (square miles)
Wind River	2,270
Little Wind River	740
Popo Agie River	810
Beaver Creek	450
Total	4,270

The Wind River basin above the confluence of the rivers is surrounded by a series of mountain ranges composed of faulted and folded Precambrian, Paleozoic, and Mesozoic rocks. These include the Wind River Range on the west, the Absaroka Range and Owl Creek Mountains on the north, and the Granite Mountains to the southeast. The

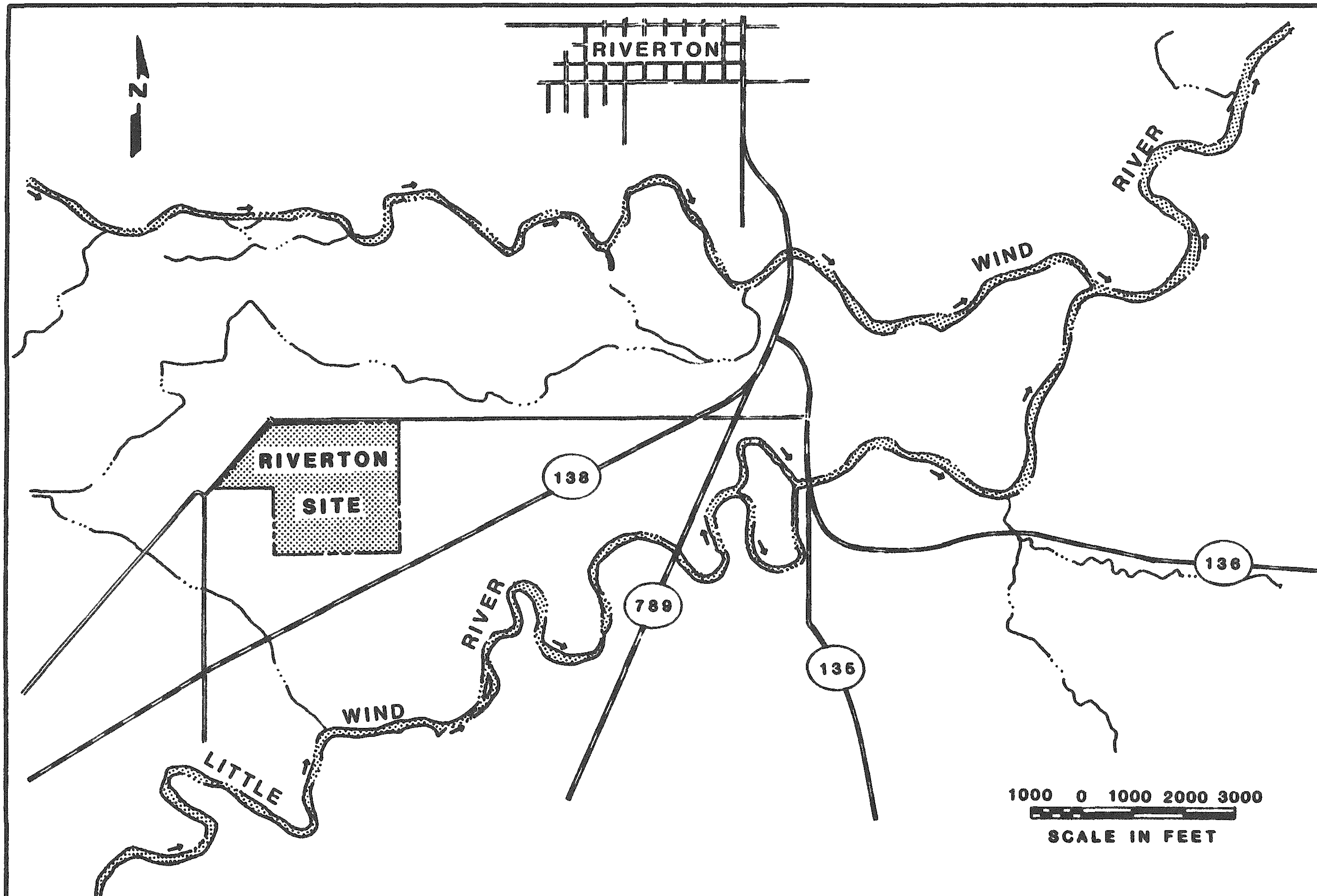


FIGURE C.1.1
RIVERTON TAILINGS SITE LOCATION

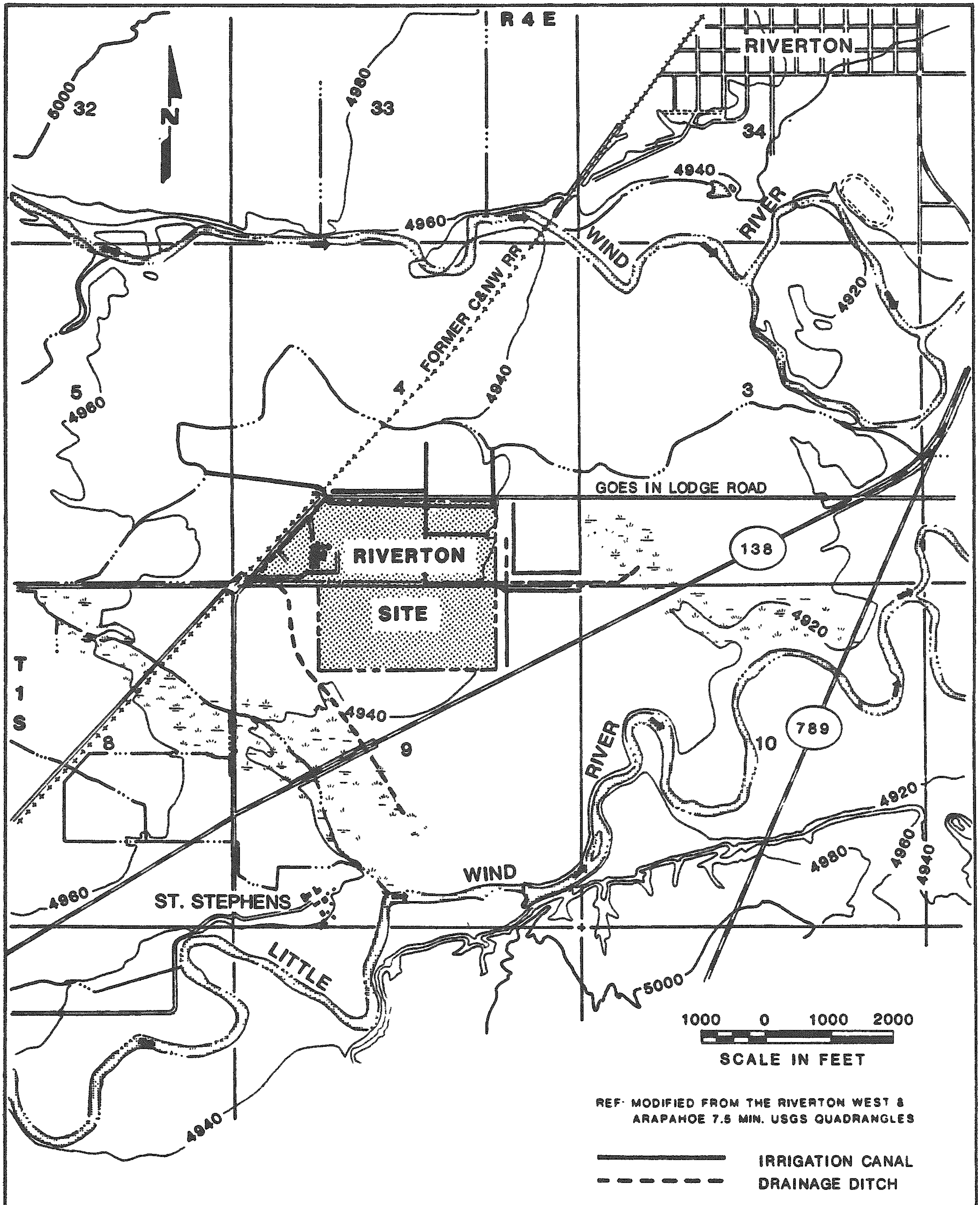


FIGURE C.1.2
EXISTING DRAINAGE CONDITIONS, RIVERTON SITE

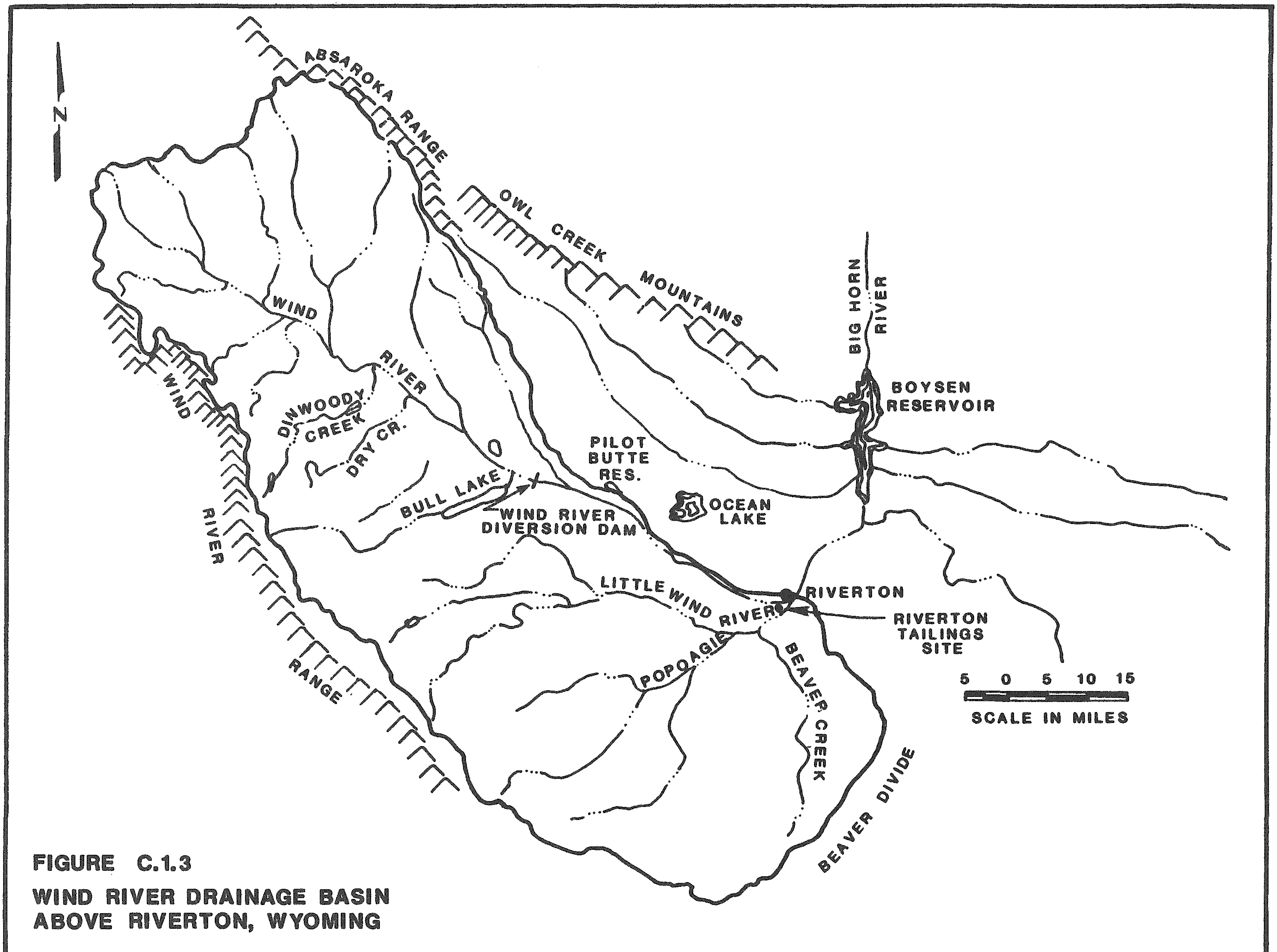


FIGURE C.1.3

WIND RIVER DRAINAGE BASIN ABOVE RIVERTON, WYOMING

Wind, Little Wind, and Popo Agie Rivers drain primarily the northeast slope of the Wind River Mountains while Beaver Creek drains the northwest side of the Granite Mountains from Beaver Divide. The area south of the Owl Creek Mountains and north of the Wind River between Riverton and the Wind River Diversion Dam drains east and enters the Wind River below the confluence of the rivers (DOI, 1981a).

Of the four watercourses, the Wind River has the longest travel distance. From its headwaters, the Wind River flows 77 miles to the Wind River Diversion Dam, the only structure on the upper Wind River. The river flows another 37 miles from the diversion dam to its confluence with the Little Wind River (DOI, 1981a).

The Wind River Mountains are rugged with steeply eroded slopes. The crest varies from about 9,000 feet near the head of the Wind River to 12,000 feet at the head of the Little Wind River and down to about 7,000 feet at the extreme southern tip of the watershed. The maximum elevation of 13,785 feet is on Gannet Peak. These mountains are of granite with some sandstones and limestones lying along their lower flanks. In the upper reaches, there are many small glacial lakes and a few glaciers which maintain summer stream flow. Irregular, small patches of conifers cover the slopes between 7,000 and 10,000 feet, and the remaining slopes are bare rock or covered with grass and brush (DOI, 1944).

The Wind River basin appears to have once been a large floodplain of the Wind River. A few gravel-capped terraces reveal the extent and height of the original deposition. Rough, sharp sandstone and shale breaks and gently sloping alluvial valleys mark the basin's topography. The slopes and bottomlands consist of poorly consolidated sandstone and shale of the Wind River Formation of Eocene Age. This formation consists of interbedded, lenticular, red, blue, and green shales; gray siltstone; and yellow to brown sandstones. This is the parent material of the soil mantle of the Wind River basin which is shallow and coarse textured on the higher slopes grading to fine textured soils of moderate depths near the bottom of swales (DOI, 1981a).

The U.S. Geological Survey (USGS) maintains gauging stations on both the Wind and Little Wind Rivers close to the Riverton site. The Wind River gauging station is 1.4 miles upstream from the confluence of the two rivers. Flow records are available for this station from 1913 to the present. A maximum flow of 13,300 cubic feet per second (cfs) was measured on June 15, 1935 (USGS, 1984a). Table C.1.1 contains the yearly mean and maximum discharges recorded at this station. Monthly average flows at the same station for a 34-year period are given in Table C.1.2.

The gauging station on the Little Wind River is 1.8 miles upstream from its confluence with the Wind River, and

Table C.1.1 Mean and maximum discharges for the Wind River at Riverton, Wyoming (Station No. 06228000)

Water year (Oct-Sept)	Mean discharge (cfs)[a]	Maximum discharge (cfs)[a]
1913	1,626	9,490
1914	1,315	7,900
1915	incomplete data for water year	
1916	1,339	7,120
1917	1,460	9,080
1918	no data for water year	
1919	611	2,220
1920	1,366	7,880
1921	1,343	11,200
1922	1,273	6,900
1923	1,423	8,350
1924	1,339	7,850
1925	1,377	7,360
1926	1,009	4,220
1927	1,496	9,400
1928	1,520	10,100
1929	incomplete data for water year	
1930	1,194	7,960
1931	911	6,270
1932	992	7,700
1933	944	8,990
1934	511	2,500
1935	944	11,400
1936	937	5,570
1937	863	5,550
1938	759	3,520
1939	607	3,310
1940	417	2,780
1941	779	4,680
1942	985	5,820
1943	1,282	6,220
1944	1,005	6,630
1945	917	5,340
1946	737	2,830
1947	1,262	8,250
1948	917	5,510
1949	775	4,160
1950	978	4,450
1951	1,243	6,950
1952	812	4,770
1953	529	6,570
1954	634	4,590
1955	316	1,930

Table C.1.1 Mean and maximum discharges for the Wind River at Riverton, Wyoming (Station No. 06228000) (Concluded)

Water year (Oct-Sept)	Mean discharge (cfs)[a]	Maximum discharge (cfs)[a]
1956	966	7,600
1957	1,080	8,770
1958	702	5,600
1959	466	3,580
1960	254	1,130
1961	402	3,430
1962	787	6,210
1963	741	7,050
1964	657	4,890
1965	1,056	7,010
1966	420	2,080
1967	1,061	9,090
1968	594	3,490
1969	582	3,280
1970	411	3,620
1971	1,117	8,990
1972	973	7,310
1973	561	4,390
1974	834	7,430
1975	754	6,960
1976	683	3,710
1977	250	1,110
1978	712	4,880
1979	461	3,870
1980	602	4,820
1981	377	6,650
1982	666	5,190
1983	929	6,340

[a]Cubic feet per second.

Ref. USGS, 1984a.

Table C.1.2 Monthly average flows, Wind River at Riverton, Wyoming (Station No. 06228000)

Month[a]	Average (cfs)[b]	Maximum (cfs)[b]	Minimum (cfs)[b]
October	651	1,020	334
November	475	670	330
December	380	490	285
January	360	423	294
February	365	441	287
March	325	428	224
April	370	691	152
May	970	2,916	170
June	2,364	4,800	703
July	1,283	2,690	410
August	364	947	132
September	338	710	150

[a]Water years 1950-1983.
[b]Cubic feet per second.

Ref. USGS, 1984a.

flow records for this station are available from 1942 to the present. A maximum flow of 14,700 cfs was measured by the USGS on June 17, 1963 (USGS, 1984a). Table C.1.3 contains mean and maximum discharges for the Little Wind River at this station. Monthly average flows at this station for a 34-year period are given in Table C.1.4. Table C.1.5 lists historical peak flows for both the Wind and Little Wind Rivers.

The Wind River is the main source of water for Riverton's municipal uses during the spring and summer (April through October). The water is taken from an irrigation ditch at the city's water treatment plant 2.5 miles north of the tailings site, and the ditch taps the river several miles northwest (upstream) of the site. During the fall and winter, the city's only source of water is its well system which taps the confined aquifer of the Wind River Formation (Scott, 1987). The waters of both the Wind and Little Wind Rivers are used locally for irrigation and livestock watering.

A geomorphic evaluation by Sergent, Hauskins, & Beckwith (SHB, 1985) states that evidence of extensive channel migration by the Wind and Little Wind Rivers can be seen by viewing historical sets of aerial photographs. These photographs show paleo-channels from the Wind River on or near the tailings site and meander scars from the Little Wind River within 0.42 mile of the site. The thalweg of the largest paleo-channel from the Wind River (hereafter referred to as the meander scar), is 2,100 feet southwest of the site.

The geomorphic report describes the Wind River as having a mixed load channel typical of rivers in which the bedload forms a significant part of the total load. It has an irregular, single-phase meandering pattern that locally is semi-confined by the valley sides. Meander length and amplitude, sinuosity, gradient, and the degree of anabranching vary over distances on the order of 1 to 2 miles. The average gradient increases from about 7 feet per mile near Boysen Reservoir to 15 feet per mile near the site. Average sinuosity typically ranges from 1.1 (sinuous) to 1.3 (meandering) although it is locally higher. Common bars and islands result from cutoff meander loops (SHB, 1985).

In contrast, the Little Wind River has a suspended load channel typical of rivers in which the bedload forms a small part of the total load. The single-phase meandering channel has variable but high sinuosity, averaging about 1.9 between the junctions with the Wind and Popo Agie Rivers. The average gradient for this reach is about 4.3 feet per mile (SHB, 1985).

The geomorphic evaluation of the tailings site area also assessed the possibility that the channels of the Wind and Little Wind Rivers could move toward the site. Geolo-

Table C.1.3 Mean and maximum discharges for the Little Wind River near Riverton, Wyoming (Station No. 06235500)

Water year (Oct-Sept)	Mean discharge (cfs)[a]	Maximum discharge (cfs)[a]
1942	524	3,850
1943	743	4,510
1944	765	6,120
1945	694	4,990
1946	460	3,020
1947	914	9,360
1948	477	2,970
1949	554	5,080
1950	738	4,590
1951	678	4,780
1952	755	7,180
1953	411	5,180
1954	422	3,760
1955	327	1,960
1956	561	5,120
1957	825	7,330
1958	509	6,060
1959	313	2,930
1960	236	1,160
1961	339	2,920
1962	642	6,540
1963	558	12,800
1964	528	5,070
1965	846	8,740
1966	306	1,020
1967	872	8,560
1968	608	5,740
1969	621	6,770
1970	488	3,780
1971	826	7,520
1972	697	5,450
1973	785	4,300
1974	701	4,340
1975	631	4,280
1976	469	2,620
1977	237	1,670
1978	623	4,860
1979	441	3,830
1980	689	4,880
1981	410	4,480
1982	520	3,530
1983	1,020	8,300

[a]Cubic feet per second.

Ref. USGS, 1984a.

Table C.1.4 Monthly average flows, Little Wind River near Riverton, Wyoming (Station No. 06235500)

Month[a]	Average (cfs)[b]	Maximum (cfs)[b]	Minimum (cfs)[b]
October	325	429	238
November	274	345	183
December	209	261	165
January	180	228	145
February	220	448	158
March	257	370	187
April	337	609	213
May	1,064	2,677	370
June	2,420	4,666	1,140
July	1,028	2,145	380
August	270	546	160
September	277	494	164

[a] Water years 1950-1983.
[b] Cubic feet per second.

Ref. USGS, 1984a.

Table C.1.5 Historical peak flows, Wind and Little Wind Rivers at Riverton, Wyoming[a]

Wind River at Riverton, Wyoming		Little Wind River near Riverton, Wyoming	
June 14, 1933	9,510	June 11, 1965	9,550
June 8, 1957	9,550	June 22, 1947	9,820
June 24, 1967	9,550	Feb. 11, 1962	10,300
May 29, 1913	10,900	June 17, 1963	14,700
May 28, 1928	10,900		
June 17, 1911	11,100		
July 25, 1923	11,400		
June 8, 1921	12,200 cfs		
June 14, 1906	12,300 cfs		
June 15, 1935	13,300 cfs		

[a]Peak flows are measured manually in the vicinity of the established gauging stations and, therefore, may differ from maximum discharges recorded at the gauging stations. Flows are in cubic feet per second (cfs).

Ref. USGS, 1984a.

gic evidence indicates that the Wind River could migrate laterally across its floodplain within a 2,000-year period. The extent of possible channel migration is unpredictable; however, the rate of migration could exceed 0.5 mile per 1,000 years. The present channel is 1 mile north of the tailings site. It also appears that aggradation (channel filling) or large-scale flooding could result in avulsion, or rapid channel shift, of the Wind River across the floodplain. The effect of Boysen Reservoir on the long-term behavior of the Wind River near the site is difficult to predict. Accumulation of sediment in the reservoir could result in a raising of the base level of the river and consequent channel aggradation. The Little Wind River is more stable and more deeply incised, and the potential for its migration toward the site is much less (SHB, 1985).

C.1.1.2 Dry Cheyenne alternate disposal site

The Dry Cheyenne alternate disposal site is within the Wind River basin on an east-facing slope at the head of a small, ephemeral tributary to Dry Cheyenne Creek. Surface-water flows occur only during rainfall and snowmelt. Dry Cheyenne Creek, located 3.5 miles northeast of the site, is also ephemeral and is about 200 feet lower in elevation than the site. No data on historical flows are available for the tributary or Dry Cheyenne Creek.

C.1.1.3 Borrow sites

The Little Wind borrow site is 3 road miles south of the tailings site on a terrace south of, and 60 to 80 feet above, the Little Wind River. Surface-water information for the Little Wind River at this borrow site is the same as that provided for the tailings site. Small ephemeral tributaries of the Little Wind River drain the borrow site, but flows occur only during rainfall and snowmelt. No data on historical flows are available for this borrow site.

Borrow site 2 is located immediately north of the tailings pile. Surface-water information for this borrow site is the same as that provided for the tailings site.

Borrow site 10 is 13 road miles southeast of the tailings site on a north facing slope near the head of a small ephemeral tributary to Kirby Draw. Surface-water flows occur only during rainfall and snowmelt, and earthen dams have been built across the small drainages northeast and southeast of the borrow site to impound the flows for livestock and wildlife. No data on historical flows are available for the tributary or Kirby Draw.

The Boulder Flats borrow site is 27 road miles southwest of the tailings site on a terrace north of and above the North Popo Agie River. The land surface slopes gently to the southeast toward the river, and the Reynolds Ditch taps the river west of the site and courses generally due east to dead-end south of the site. This ditch is used to provide river water for irrigating small agricultural plots, pastures, and gardens during the spring and summer.

C.1.2 FLOOD ANALYSIS

C.1.2.1 Riverton tailings site

A flood analysis has been performed to assure that the remedial action design for the uranium mill tailings site at Riverton, Wyoming, satisfactorily addresses short- and long-term flood protection. Short-term flood protection simply defines the extent of the 500-year flood and the impact, if any, on the stabilized tailings or on remedial action construction activities. The primary purpose of this part of the analysis is for compliance with the U.S. Department of Energy's (DOE) floodplain and wetlands environmental review requirements of Title 10, Code of Federal Regulations, Part 1022 (10 CFR Part 1022). To accomplish the objective of long-term flood protection, the standard design approach for the Uranium Mill Tailings Remedial Action (UMTRA) Project is to determine the magnitude and potential impacts resulting from a Probable Maximum Flood (PMF) event. If a design for this event is not practical, then alternative design events or solutions are assessed.

The use of the PMF as the design flood event to achieve long-term control of uranium tailings is not clearly defined. The U.S. Environmental Protection Agency's (EPA) standards (40 CFR Part 192, Subparts A, B, and C) require that control of the uranium tailings must be effective for 1,000 years (to the extent reasonably achievable) and, in any case, for at least 200 years. The standards do not specifically state that a PMF event must be used for design in order to achieve the stated containment life. An analysis of exceedence probabilities for various events with respect to the containment life (Junge and Dezman, 1983) suggests that design events with a very long return period (e.g., 10,000 years) must be used to meet a long-term containment objective. However, the limited statistical data that are available cannot be extrapolated accurately to such long return periods. The generally accepted alternative, therefore, is to use extreme events such as the PMF for design. Since a PMF event by definition is the worst event possible, a tailings disposal system designed to withstand such an event would have an infinitely small risk of failure and, thus, would meet both the intent and long-term containment objective of the EPA standards.

The PMF analysis first requires the use of Hydrometeorological Report No. 55 (NOAA, 1984) to determine the appropriate Probable Maximum Precipitation (PMP) that could occur over the various drainage basins. The analysis then involves the consecutive use of the U.S. Army Corps of Engineers HEC-1 (COE, 1981) and HEC-2 (COE, 1982) models. The HEC-1 model is designed to simulate the runoff response of a drainage basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. It is utilized to determine the PMF flows resulting from a PMP event. Then a determination of stream hydraulics, resulting in water surface elevations and velocity gradients at the tailings site, is developed for the PMF flows using the dynamic HEC-2 model.

500-year flood

As stated above, an estimate of the 500-year flood is used primarily for compliance with 10 CFR Part 1022. However, it is also helpful for comparison with the maximum recorded historical floods and the PMF estimates. This comparison emphasizes the extreme magnitude and rarity of a PMF event. Flood flow frequencies out to the 500-year flood event are easily obtained with historical data and utilization of the Log Pearson Type III method as outlined in Bulletin No. 17B of the Hydrology Subcommittee (DOI, 1981b).

The WATSTORE Data Retrieval System used by the USGS contains flow records for gauging stations and also has the capability of automatically performing the peak flow frequency analysis for station data. The model analyzes the data following the guidelines in Bulletin 17B (DOI, 1981b). Flood flow frequency forecasts that were obtained from WATSTORE (USGS, 1984b) are summarized in Table C.1.6.

A HEC-2 analysis was performed separately for the upper 500-year flood estimates for the Wind and Little Wind Rivers. A 500-year flood flow of 18,164 cfs was used for the Wind River with computed water surface elevations in the vicinity of the tailings site ranging from 4,940 feet to 4,944.5 feet above mean sea level. The resulting water surface elevations are not high enough to result in flow over the scarp directly north of the road running along the northern boundary of the site nor are they high enough for flow to break into the meander scar southwest of the site. The computed flow levels would approach within 2,000 feet of the edge of the tailings pile and within 800 feet of the north boundary of the tailings site.

A 500-year flood flow of 24,233 cfs was used for the Little Wind River with a computed water surface elevation adjacent to the tailings site of approximately 4,930 feet above mean sea level. This results in a distance of 3,500 feet between the boundary of the site and the limit of the 500-year floodplain on the Little Wind River.

As shown in Figure C.1.4, these results indicate that the tailings site would not be impacted by 500-year flood events from either river. In addition, the cleanup of the

Table C.1.6 Flood flow frequency forecasts, Wind and Little Wind Rivers at Riverton, Wyoming

Recurrence interval (years)	Annual exceedence probability	Flow rate (cfs)[a] 95% confidence limits Lower	Upper
Wind River flood flow frequency			
10	0.1	9,399	11,541
50	0.02	11,441	14,672
100	0.01	12,156	15,822
200	0.005	12,801	16,881
500	0.002	13,568	18,164
Little Wind River flood flow frequency			
10	0.1	7,629	10,218
50	0.02	10,377	15,349
100	0.01	11,573	17,810
200	0.005	12,796	20,448
500	0.002	14,463	24,233

[a]Cubic feet per second.

Ref. USGS, 1984b.

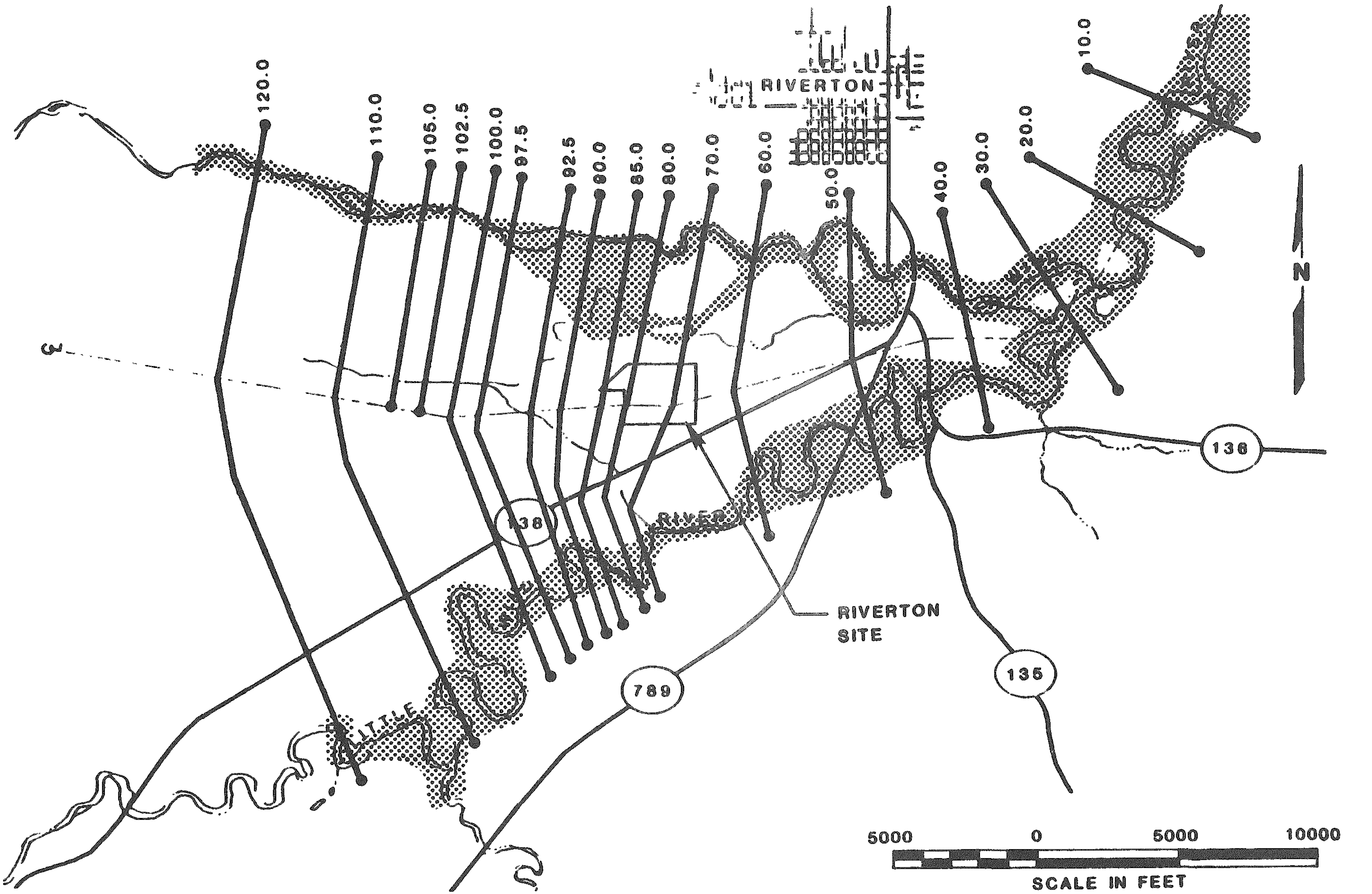


FIGURE C.1.4
500-YEAR FLOODPLAIN, RIVERTON SITE

windblown tailings and the activities at borrow site 2 for the Dry Cheyenne alternative would not occur within the 500-year floodplains.

PMF hydrologic analysis

Prior to the use of the HEC-1 model, the analysis required determination of appropriate general storm PMP amounts over the drainage basin. For the purpose of the HEC-1 analysis, the drainage basin above the confluence of the Wind and Little Wind Rivers was divided into 11 sub-basins, as shown in Figure C.1.5.

The Wind River drainage basin was divided into six sub-basins:

W1 - Upper Wind River sub-basin.
W2 - Middle Wind River sub-basin.
W3 - Bull Lake sub-basin.
W4 - Dry Creek sub-basin.
W5 - Enos sub-basin.
W6 - Lower Wind River sub-basin.

The Little Wind River drainage basin was divided into three sub-basins:

LW1 - Upper Little Wind River sub-basin.
LW2 - Middle Little Wind River sub-basin.
LW3 - Lower Little Wind River sub-basin.

The remaining sub-basins were:

B1 - Beaver Creek sub-basin.
PA1 - Popo Agie sub-basin.

The PMP determinations for each sub-basin were made according to the techniques published in Hydrometeorological Report No. 55 (NOAA, 1984). This report provides all-season general storm PMP estimates for durations from 1 to 72 hours for the region between the Continental Divide and the 103rd Meridian. For the non-orographic portions of eastern Montana, Wyoming, North and South Dakota, Colorado, New Mexico, and western Texas, estimates are available for area sizes from 10 to 20,000 square miles. For orographic regions of these states east of the Continental Divide, estimates are available for areas from 10 to 5,000 square miles. At present, the report does not address a spring PMF with snowmelt.

A step-by-step procedure for computing a general storm PMP is presented in Hydrometeorological Report No. 55 and was used for this analysis. The first step required determination of the 1-, 6-, 24-, and 72-hour 10-square-mile average PMP over each sub-basin. Table C.1.7 lists the calculated PMP amounts for this first step.

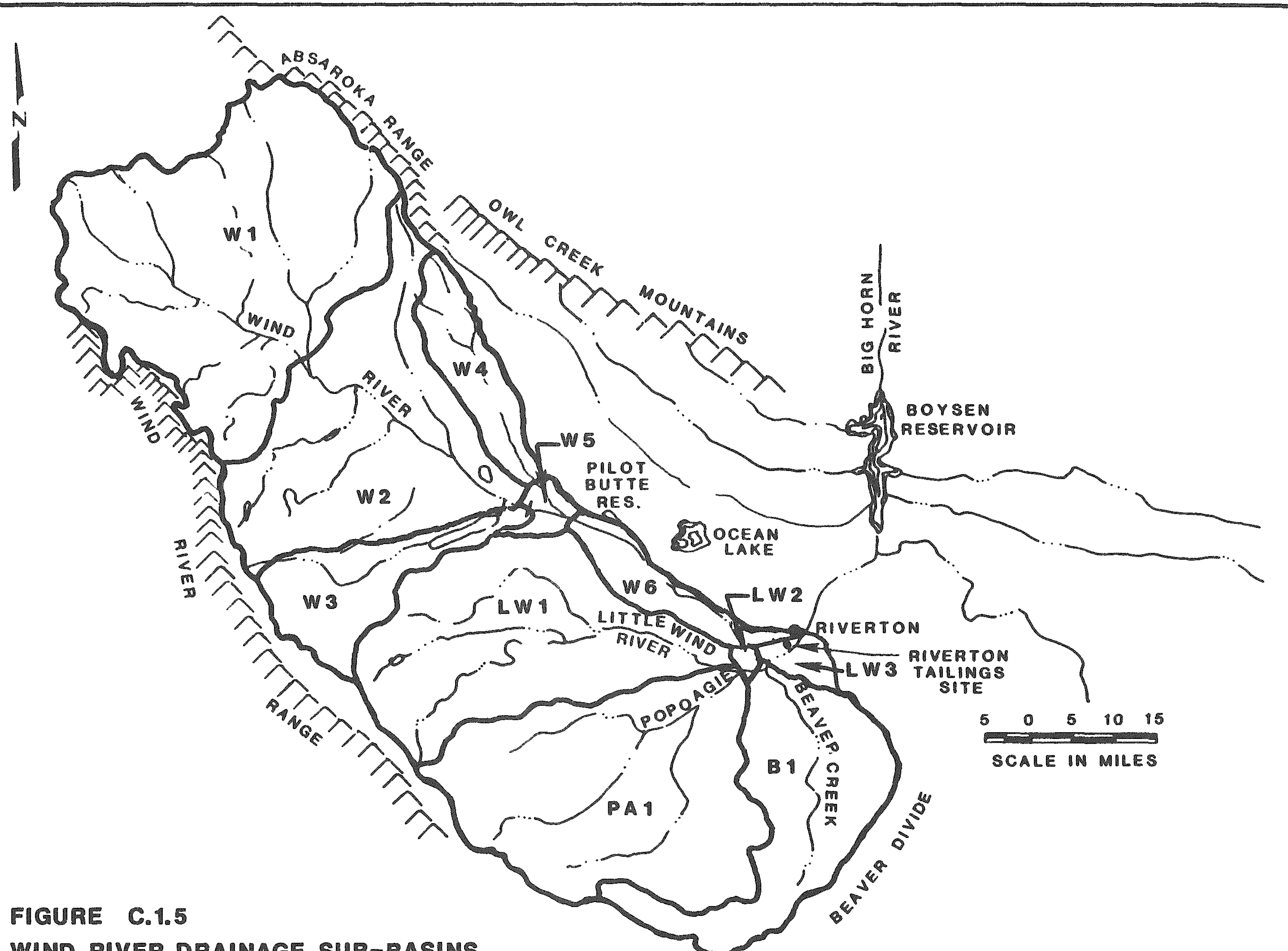


FIGURE C.1.5
WIND RIVER DRAINAGE SUB-BASINS ABOVE RIVERTON, WYOMING

Table C.1.7 Average PMP amounts per drainage sub-basin

Drainage sub-basin	10-square-mile general storm PMP (inches)			
	1-hour	6-hour	24-hour	72-hour
Wind River				
W1	7.6	12.7	20.5	27.3
W2	9.2	15.1	24.7	33.1
W3	9.8	16.9	27.1	34.2
W4	7.9	12.8	21.0	27.2
W5	8.7	14.7	22.5	29.0
W6	8.8	14.8	23.2	29.3
Little Wind River				
LW1	10.1	17.0	26.6	34.4
LW2	8.5	14.4	23.0	27.0
LW3	8.5	13.5	21.0	25.0
Beaver Creek				
B1	8.4	14.5	23.0	29.7
Popo Agie River				
PA1	10.0	17.1	26.7	34.3

The next step required selection of the appropriate sub-region and subdivision that contains each sub-basin in order to select the appropriate set of depth-area-duration relations for the full 4,300-square-mile drainage area above the site. The entire area lies within sub-region A with over 80 percent of the drainage area within the orographic subdivision. The remaining area lies within the minimum non-orographic and sheltered orographic subdivisions (NOAA, 1984). The sub-basin lying within different subdivisions was areally weighted to determine the appropriate areal reductions (as a percent of the average 10-square-mile PMP amount) to apply to the average PMP amounts from the first step. The areally-reduced PMP amounts for the sub-basins are shown in Table C.1.8.

After reducing the average PMP estimates, the results were plotted on linear graph paper as amount versus duration with smooth curves of best fit drawn. The PMP amounts for the remaining, incremental 6-hour durations from 0 to 72 hours were then interpolated from the curves. The incremental PMP amounts at each 6-hour period were then derived by subtracting each durational amount from the amount at the next longer duration.

In order for the HEC-1 model to compute the flood hydrograph for a PMP, it is necessary to specify the temporal distribution of the precipitation. The 6-hour incremental rainfall amounts developed in the previous step should be arranged in a sequence that will result in a reasonably critical flood hydrograph. This is performed when no predominant rainfall pattern is evident from past storms or has not been developed. Recommended guidelines for developing the temporal distribution are published in Hydrometeorological Report No. 52 (NOAA, 1982). These guidelines are listed as follows:

- Arrange the individual 6-hour increments such that they decrease progressively to either side of the greatest 6-hour increment. This implies that the lowest 6-hour increment will be at either the beginning or the end of the sequence.

- Place the four greatest 6-hour increments at any position in the sequence except within the first 24-hour period of the storm sequence. During major storms (exceeding 48-hour durations), maximum rainfall rarely occurs at the beginning of the sequence.

Several sequences were evaluated for the Wind River drainage basin. The distribution that resulted in the largest hydrograph was one in which the four greatest 6-hour increments were placed in the middle 24-hour period of the 72-hour storm sequence. This temporal distribution was used throughout the remainder of the analysis.

Table C.1.8 Areally reduced PMP amounts per drainage sub-basin

Drainage sub-basin	10-square-mile general storm PMP (inches)			
	1-hour	6-hour	24-hour	72-hour
Wind River				
W1	1.8	5.6	11.8	17.3
W2	2.3	6.9	14.7	21.6
W3	2.5	7.8	16.3	22.6
W4	1.8	5.5	11.6	16.5
W5	1.6	5.2	9.8	13.9
W6	1.1	4.0	7.2	10.0
Little Wind River				
LW1	2.4	7.4	15.2	21.6
LW2	1.1	3.9	7.1	9.2
LW3	1.1	3.6	6.5	8.5
Beaver Creek				
B1	2.0	6.5	13.4	19.0
Popo Agie River				
PA1	2.5	7.8	15.9	22.4

Several other parameters were required in order to run the HEC-1 model. These parameters were as follows:

- o Hydrograph time interval.
- o Soil infiltration rate.
- o Lag times for each sub-basin.

It was concluded that a time interval of less than 1 hour would be too small for a PMF analysis. Therefore, the 72-hour storm was divided into 1-hour increments. The 1-hour PMP amounts were obtained by equally dividing each 6-hour increment into 1-hour amounts.

The COE recommends the use of the map of "Soil Infiltration by Generalized Soil Groupings" (MBIAC, 1966) for PMF analyses. From the soil infiltration map, the Wind River drainage basin is comprised of three soil groupings as summarized in Table C.1.9. Since over 80 percent of the basin is covered with medium textured soil, a conservative soil infiltration rate of 0.5 inch per hour was used for the entire basin.

Table C.1.9 Wind River drainage basin soil groupings

Generalized soil infiltration groupings	Associated infiltration rate (inches per hour at saturation)	Percent of drainage basin covered
Clay and clay pans - slow permeability and intake	0.05 to 0.20	9
Moderately fine textured-moderately slow permeability and intake	0.20 to 0.60	9
Medium textured - moderately permeable and moderate intake	0.60 to 2.00	82

Ref. MBIAC, 1966.

Lag times for each watershed were initially computed using the empirical relationship contained in Design of Small Dams (DOI, 1977) as follows:

Lag time = $0.6T_C$

T_C = time of concentration in hours = $\left(\frac{(11.9)L^3}{H}\right)^{0.385}$

where

L = length of longest watercourse in miles.

H = elevation difference in feet.

This relationship generally gives longer, less conservative lag times than what might actually occur. These times were used in an initial run to establish a lower bound for the PMF. The result was a PMF of 656,000 cfs at the confluence of the Wind and Little Wind Rivers. In order to establish an upper bound, a velocity of 15 feet per second (fps) was estimated for the routing sections, and new lag times were calculated by dividing the channel lengths by the velocity. The result was a PMF of 942,000 cfs.

In order to determine a better estimate of channel velocity, cross-sections at each channel length were estimated using USGS quadrangle maps. The slope of the reach at each cross-section was also estimated. These values, along with the peak flow for each hydrograph derived in the previous run, were entered into Manning's Equation, and values for velocity were calculated. The velocities were used to recalculate the routing lag times.

The resulting flow amounts from this analysis were used as input to the HEC-2 model and are summarized in Table C.1.10.

Table C.1.10 PMF runoff summary, Wind and Little Wind Rivers at Riverton, Wyoming

	Flow in cfs[a], time in hours[b]			
Description	Time to peak	Wind River flow	Little Wind River flow	Combined flow at confluence
Little Wind River peak	45	123,000	557,000	680,000
Combined peak	47	239,000	481,000	720,000
Wind River peak	51	403,000	214,000	617,000

[a]Cubic feet per second.
[b]Hours in the 72-hour hydrograph.

In order to check the conservativeness of these magnitudes, a comparison was made to charts published in Maximum Flood Flows in the Conterminous United States (Crippen and Bue, 1977). These charts are based on maximum recorded flood flows within regions and indicate peak discharge versus drainage area. The Wind River basin is located in Region 13. The calculated peak PMF flows can also be compared to the historical peak flow (Table C.1.5) and the forecasted 500-year flood flows (Table C.1.6). These comparisons are summarized in Table C.1.11.

PMF hydraulic analysis

The selection of cross-sections for the HEC-2 analysis can become extremely complex when modeling occurs near the confluence of tributary streams.

Boundary geometry for the analysis of flow in natural streams is specified in terms of ground surface profiles (cross-sections) and the measured distances between them (reach lengths). Cross-sections are located at intervals along a stream to characterize the flow carrying capability of the stream and its adjacent floodplains. They should extend across the entire floodplain and should be perpendicular to the anticipated flow lines. Occasionally it is necessary to arrange cross-sections in a curved or dog-leg alignment to meet this requirement. Efforts were be made to obtain cross-sections that accurately represent the stream and floodplain geometry (COE, 1982).

Complicating this process is the fact that preliminary results indicate that interflow from the Wind River to the Little Wind River occurs upstream of the site without being fully combined flow. This means that the flow has three directions and water surface elevations within this area. The situation is further complicated by varying flood levels in each tributary stream.

The alignment of cross-sections chosen to best model the complex flow patterns around the Riverton site is shown on Figure C.1.6. The cross-sections are characterized by dog-leg alignments and extensions across the floodplains of both rivers. In order to assure the most valid range of results, it was very important to recognize divided flow versus fully combined flow across an entire cross-section.

If fully combined flow was not entirely evident, then the different flow combinations were restricted to specific areas within the cross-section. Figures C.1.7, C.1.8, and C.1.9 represent the three HEC-2 model flow areas used in the analysis. This allowed specific modeling of the Wind River, Little Wind River, and meander scar channels while keeping the entire combined flow cross-section intact.

Table C.1.11 Flood flow comparison summary, Wind and Little Wind Rivers at Riverton, Wyoming

Drainage basin	Drainage area (square miles)	Peak flows (cfs)[a]				Ratio of PMF to		
		Recorded[b]	500-year[c]	Region 13[d]	Calculated PMF[e]	Recorded	500-year	Region 13
Wind River	2,300	13,300	18,164	275,000	403,000	30	22	1.5
Little Wind River	2,000	14,700	24,233	275,000	557,000	38	23	2.0
Combined rivers at confluence	4,300	--	--	350,000	720,000	--	--	2.0

[a]Cubic feet per second.
[b]Table C.1.5.
[c]Table C.1.6.
[d]Ref. Crippen and Bue, 1977.
[e]Table C.1.10.

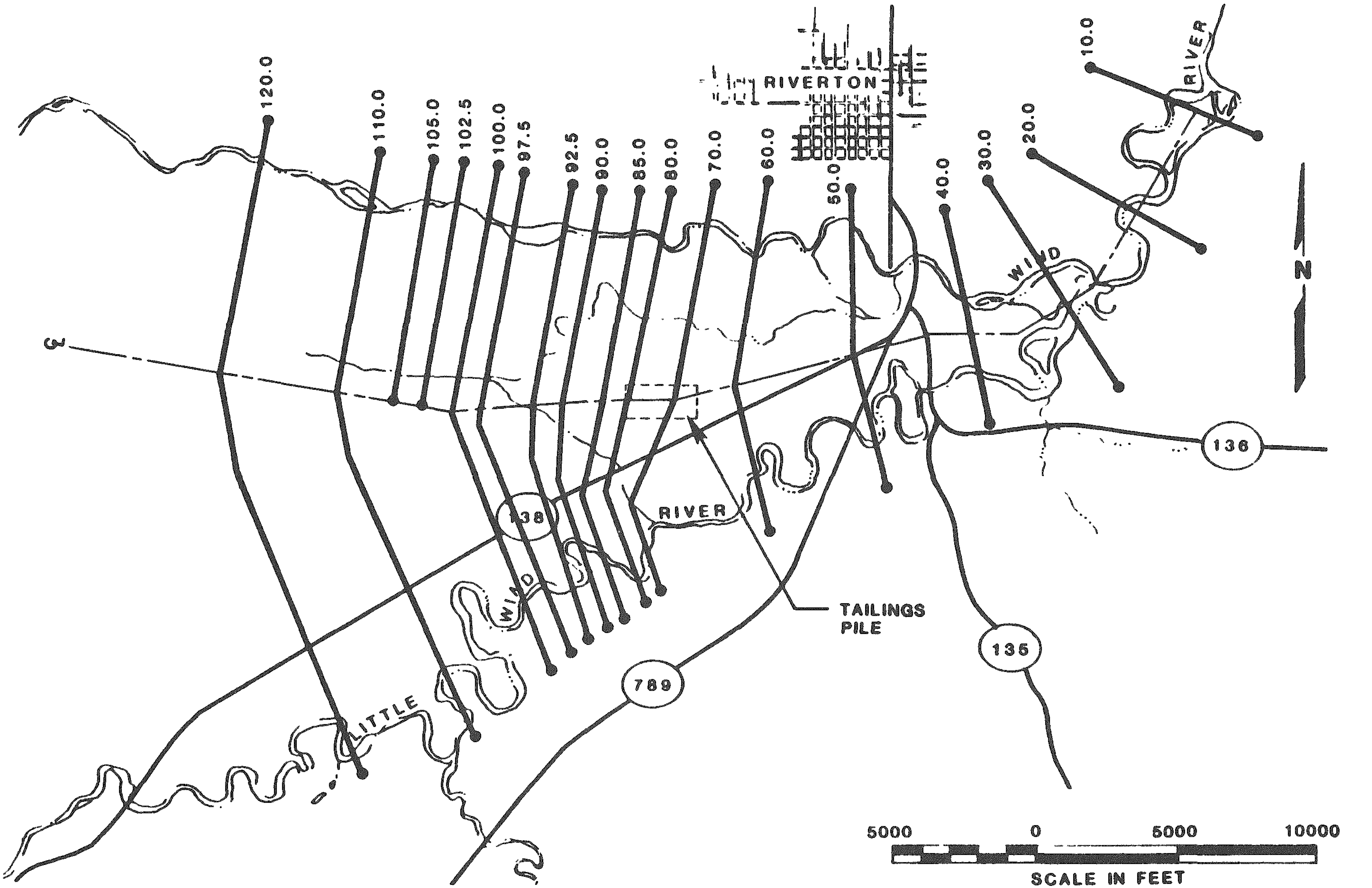


FIGURE C.1.6
HEC-2 MODEL CROSS-SECTIONS, RIVERTON SITE

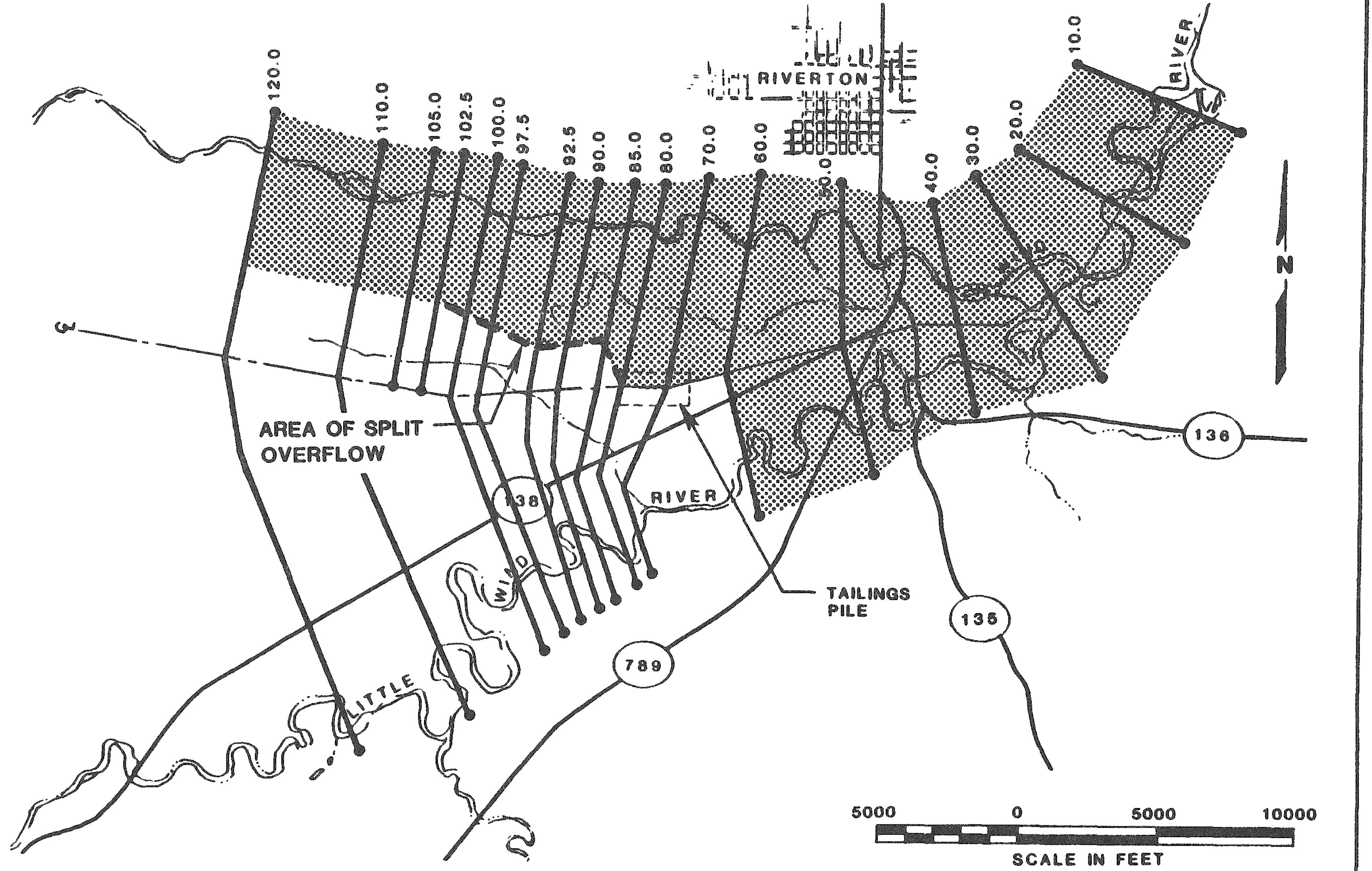


FIGURE C.1.7
WIND RIVER, HEC-2 MODEL FLOW AREA, RIVERTON SITE

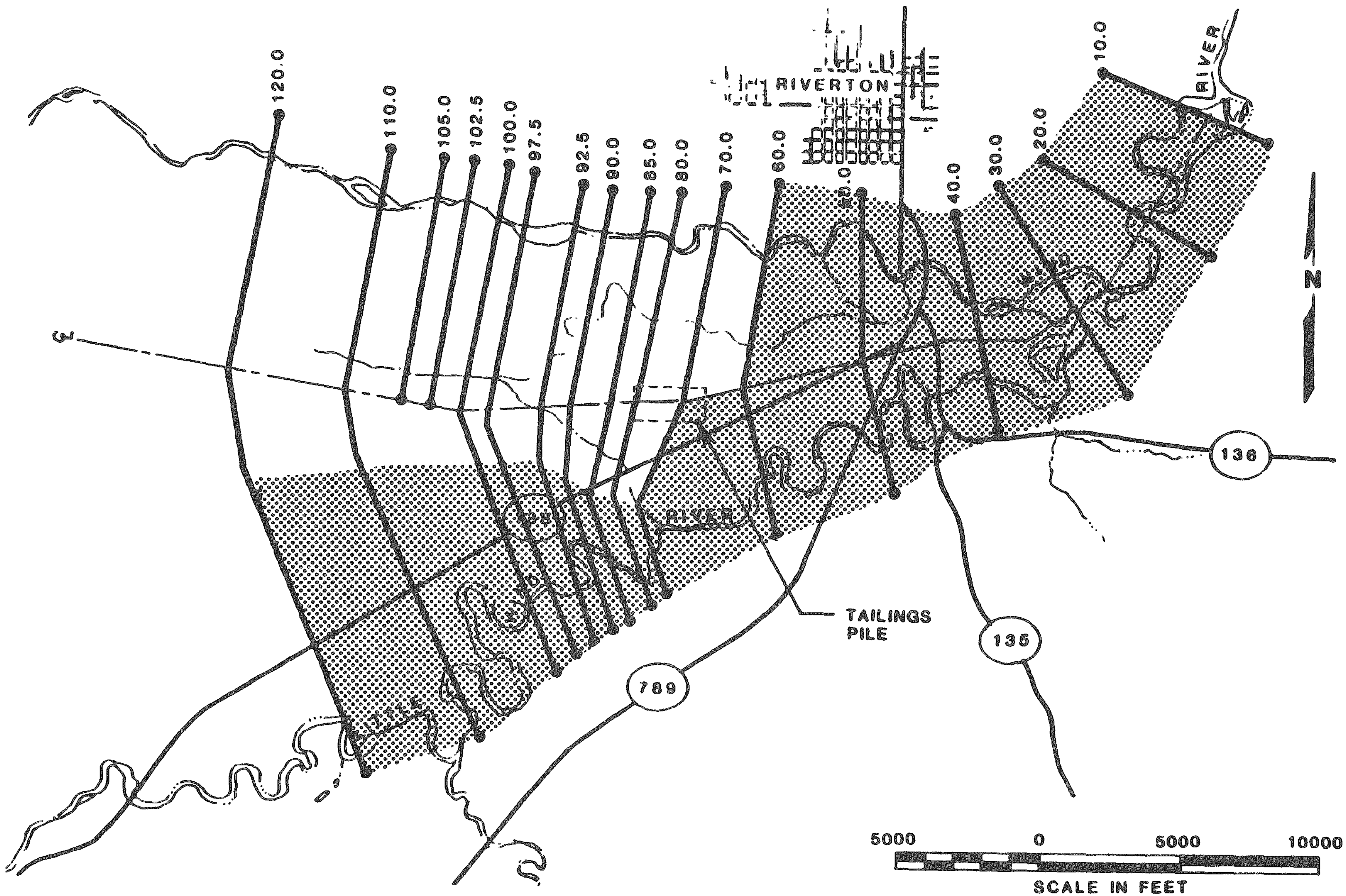


FIGURE C.1.8
LITTLE WIND RIVER, HEC-2 MODEL FLOW AREA, RIVERTON SITE

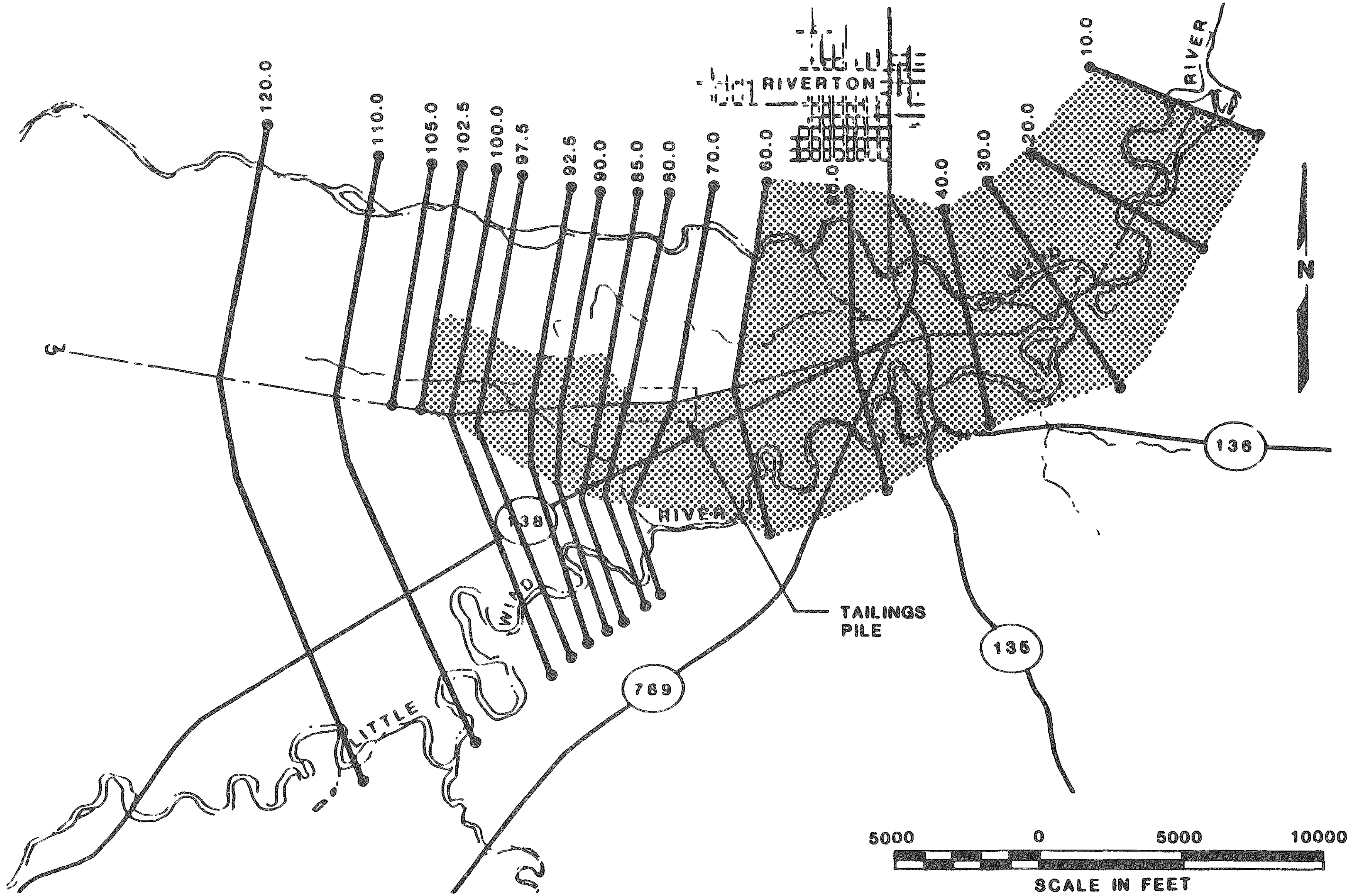


FIGURE C.1.9
MEANDER SCAR, HEC-2 MODEL FLOW AREA, RIVERTON SITE

In developing the cross-sections, the only major difficulty was that 2-foot contour topography maps were not available except for the site and a small area nearby. Outside of the area of the site, the only available maps were the USGS 7.5-minute quadrangle series with 20-foot contour intervals. However, the field studies from the geomorphic evaluation (SHB, 1985) provided information on scarp heights of the terrace levels and bank heights of the river channels. Also available was an aerial photograph in which the scarps and meander scars were clearly visible. A combination of all the above information was used in estimating the cross-sections across the floodplain.

As stated previously and shown in Figure C.1.10, the results indicate that the PMF would completely surround the tailings pile. However, interflow between the Wind and Little Wind Rivers does not become fully combined until downstream from the site. As the flow in the Wind River increases, it eventually splits upstream of the pile to partially flow down the meander scar southwest of the site. At this location, there are actually three different flow directions: flow east down the Wind River, flow southeast down the meander scar intersecting with the Little Wind River, and flow slightly northeast down the Little Wind River. Figure C.1.11 illustrates these flow directions. The Little Wind River, however, is fairly entrenched on the south side of the valley and does not overbank or spread out until downstream from the site.

In order to model this situation effectively, several different flow combinations with flow levels above and below those listed in Table C.1.10 were analyzed. This allowed different types of data curves to be formulated for the various flow combinations. These curves allow for an assessment of critical areas, regardless of the flow combination, and also provide an indication of how sensitive the flow regime behaves in response to changes in flow. The various flow designations used on these curves are identified on Figure C.1.11, and the roughness coefficients used in the analyses are 0.025 for areas covered by 5 feet of water or greater and 0.05 for overbank areas above a 5-foot depth.

It was initially recognized that at high levels of flow in the Wind River, the flow would split around the tailings pile with a portion flowing down the meander scar to the Little Wind River. Therefore, Wind River flow could affect both sides of the tailings pile. On the other hand, flow in the Little Wind River would not combine fully with the Wind River until downstream of the tailings pile. The Little Wind River would, therefore, not directly affect the Wind River side of the tailings pile except from a potential backwater effect.

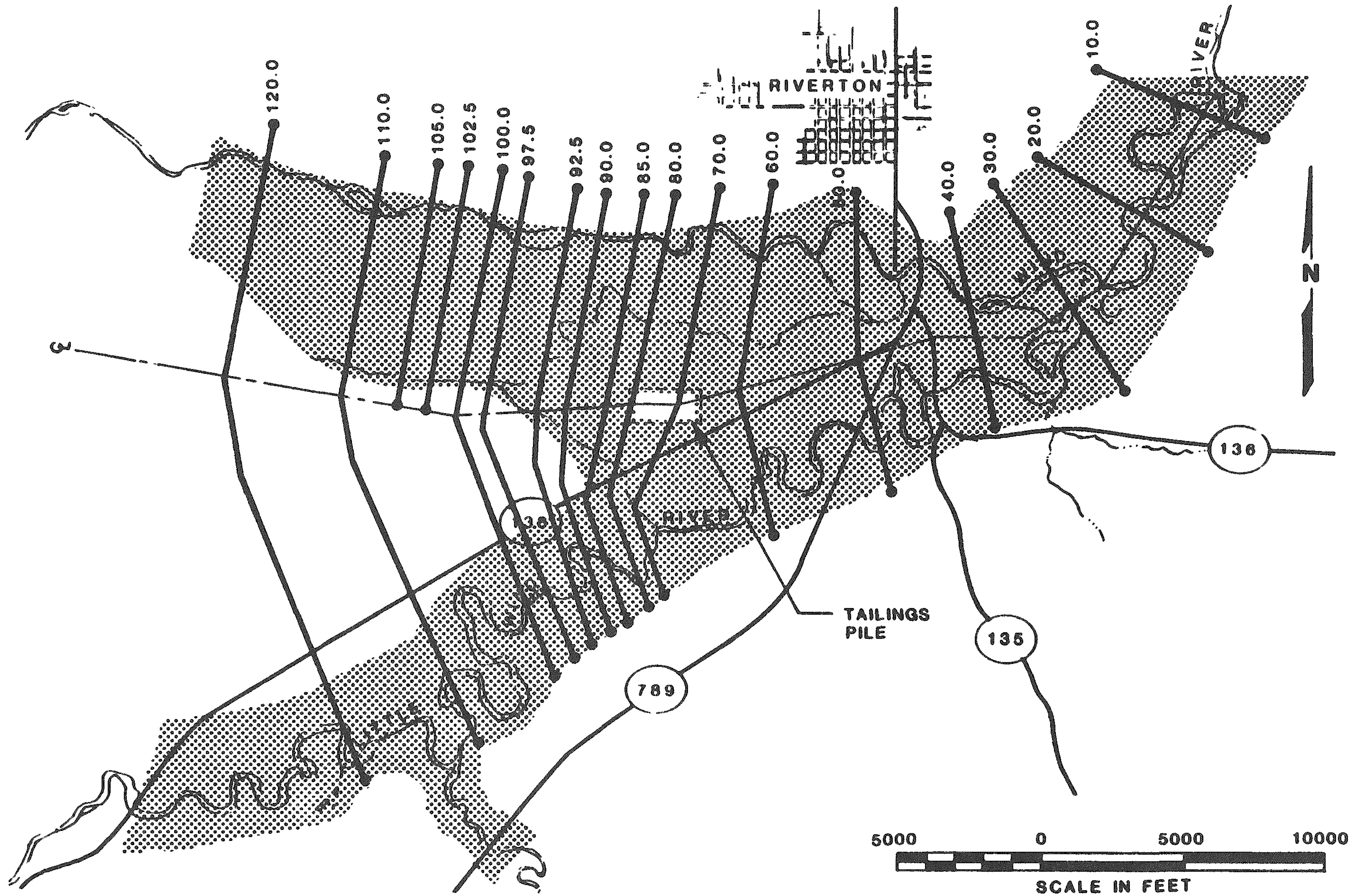


FIGURE C.1.10
PMF FLOODPLAIN, RIVERTON SITE

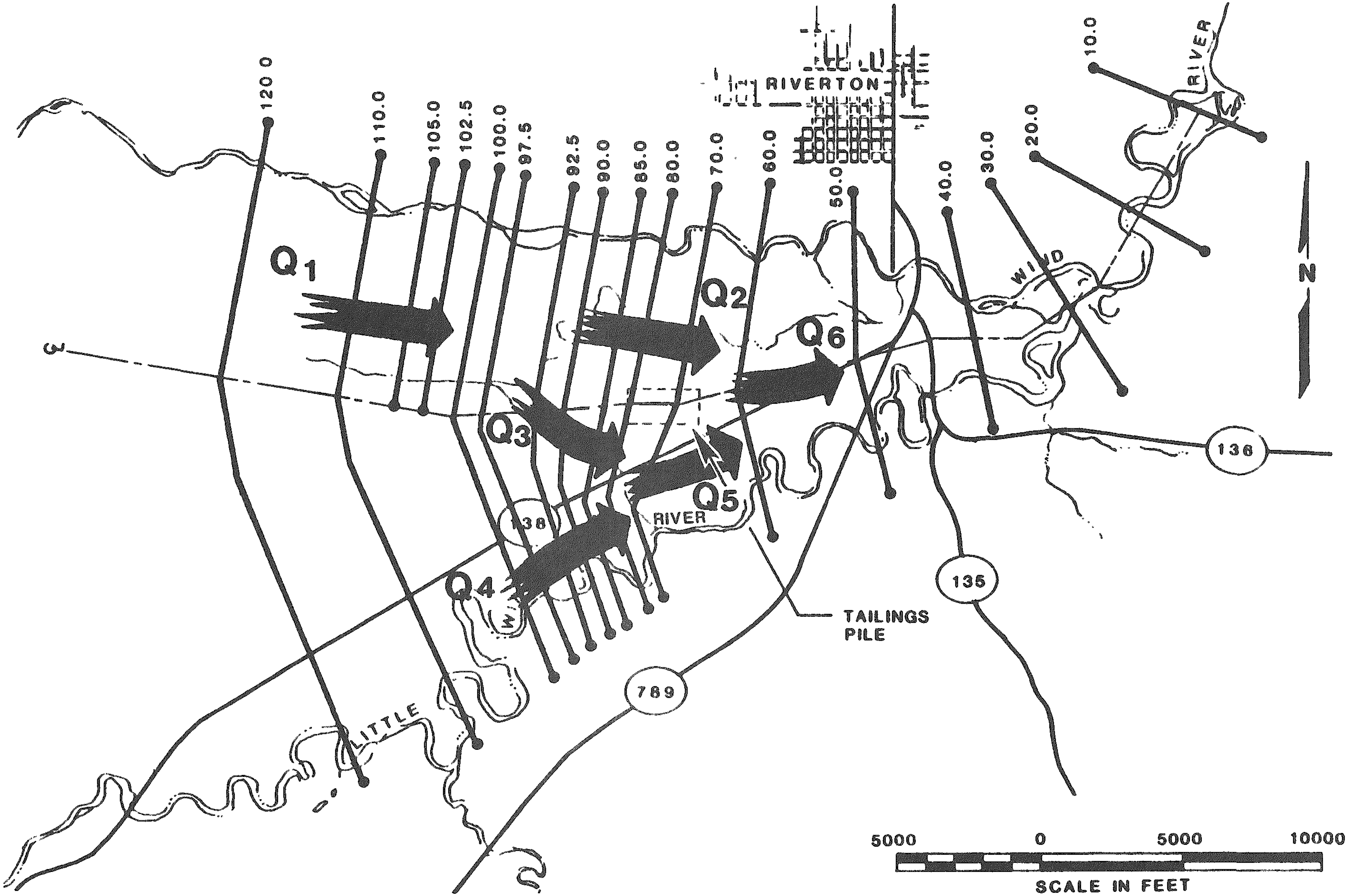


FIGURE C.1.11
SPLIT AND COMBINED FLOW DESIGNATIONS, RIVERTON SITE

The analyses began by determining the split flow relationship in the Wind River channel and the meander scar with different flows in the Wind River. This relationship is shown in Figure C.1.12 and assumes no increase in flow at the confluence due to contribution from the Little Wind River. Figures C.1.13 and C.1.14 were developed for this flow condition to show the depth of flow at the edge of the tailings pile and the mean channel velocity for stations 70 and 80. Additional analyses were performed that increased the flood level at the confluence of the rivers in order to model any effect from the Little Wind River. The results were negligible in changing the Wind River split flow combinations as shown in Figure C.1.12. However, there was a definite effect on flow depths and mean channel velocities as shown in Figures C.1.15 and C.1.16. The increased flow at station 60 reflects flow contribution from the Little Wind River and tends to produce a backwater effect of increased depth and decreased energy slope at station 70. However, the decreased velocity and gradient at station 70 tend to increase the potential for a hydraulic jump or supercritical flow condition at station 80. As a result, the depths decrease at station 80 and the velocities increase for increases in Q_6 (total flow downstream of the pile).

The remaining analyses concentrated on the flow effects on the south side of the tailings pile resulting from the combination of the flows in the meander scar and the Little Wind River. Several values of Q_1 (Wind River flow) varying from 200,000 cfs to 600,000 cfs were used in combination with a range of Little Wind River flows (Q_4) varying from zero to 800,000 cfs. The initial situation modeled the meander scar for the different levels of flow splitting out of the Wind River without contribution from the Little Wind River. The depth of flow at the south edge of the tailings pile and the mean channel velocities for stations 70 and 80 are shown in Figures C.1.17 and C.1.18.

At this point, the range of Little Wind River flows (Q_4) were added to the different levels of flow in the Wind River. Figure C.1.19 illustrates the depth at the south edge of the pile versus the total flow (Q_6) downstream of the pile. This figure portrays a band of data points for each station at each constant value of Q_6. The bands of data represent the variance in depth depending on the different combinations of Q_3 and Q_4 to maintain a constant value of Q_5. The figure indicates a maximum range in the difference of less than 2 feet. The maximum depths at the pile occur when the flow in the meander scar is maximized.

Figures C.1.20 and C.1.21 indicate the mean channel velocities south of the pile for the various combinations of flow shown on Figure C.1.19. The curves show that for any flow level of Q_3, the mean flow velocities would

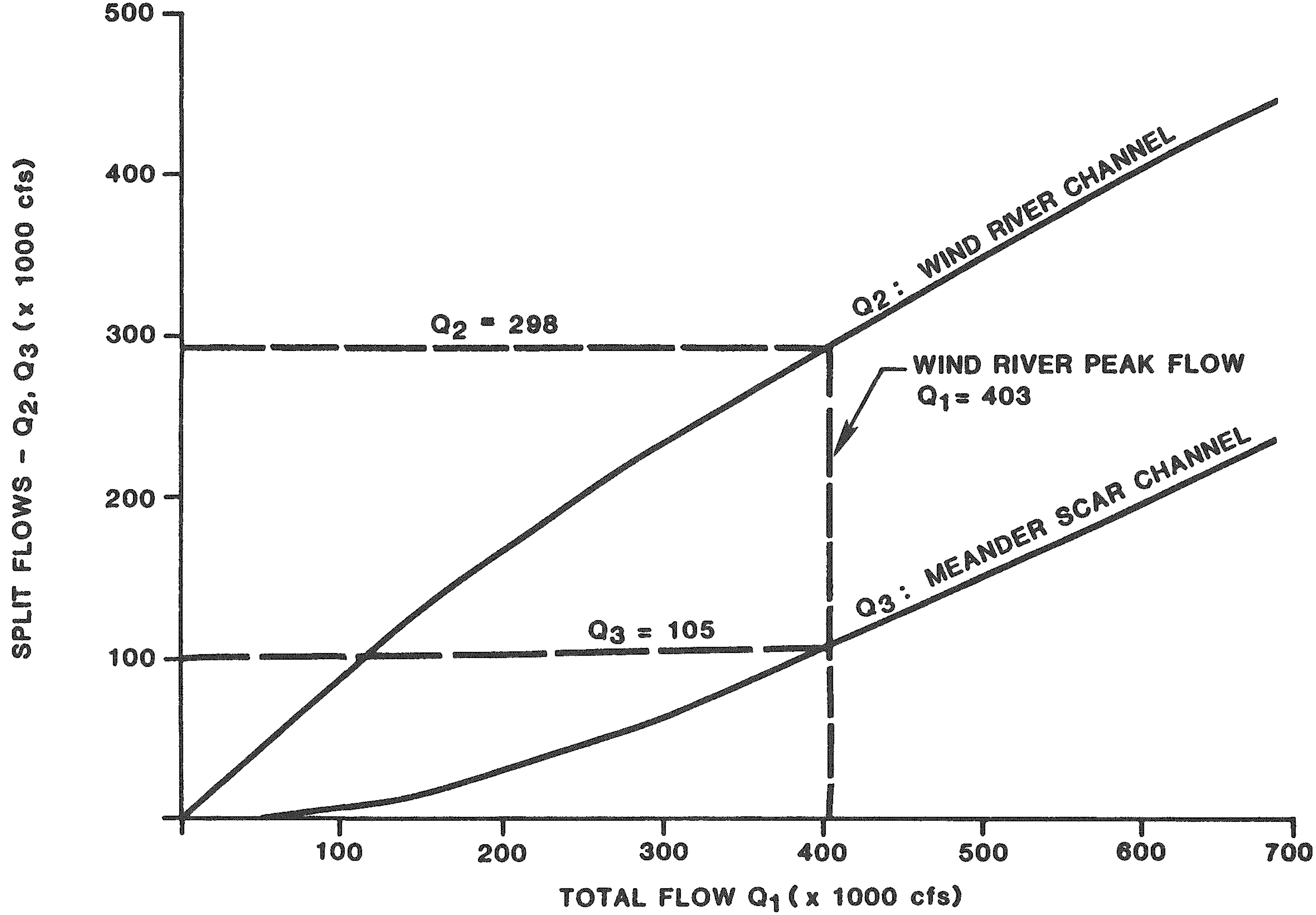


FIGURE C.1.12
WIND RIVER CHANNEL, Q_2 AND Q_3 vs. Q_1

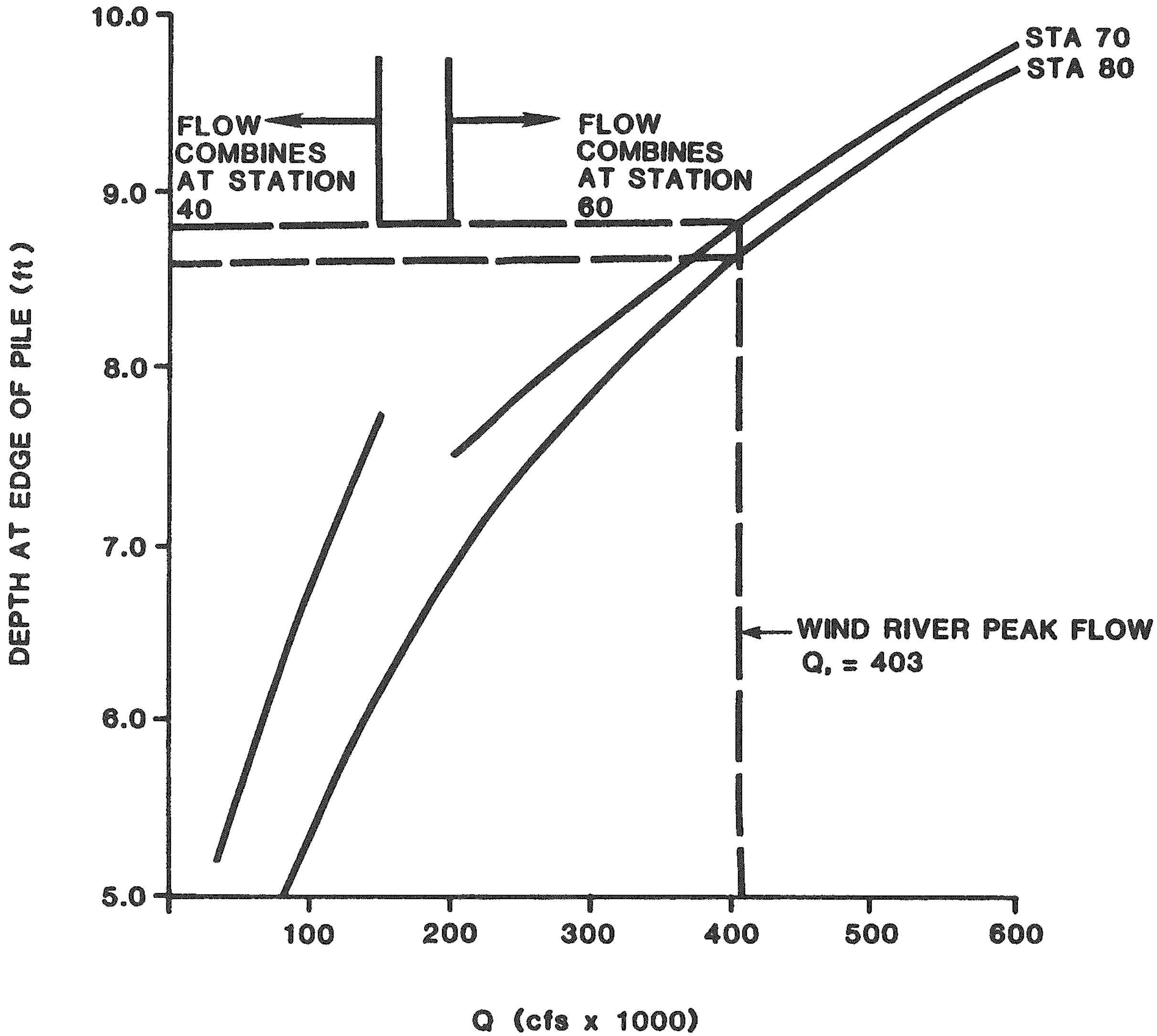


FIGURE C.1.13
WIND RIVER DEPTH AT PILE vs. Q_1

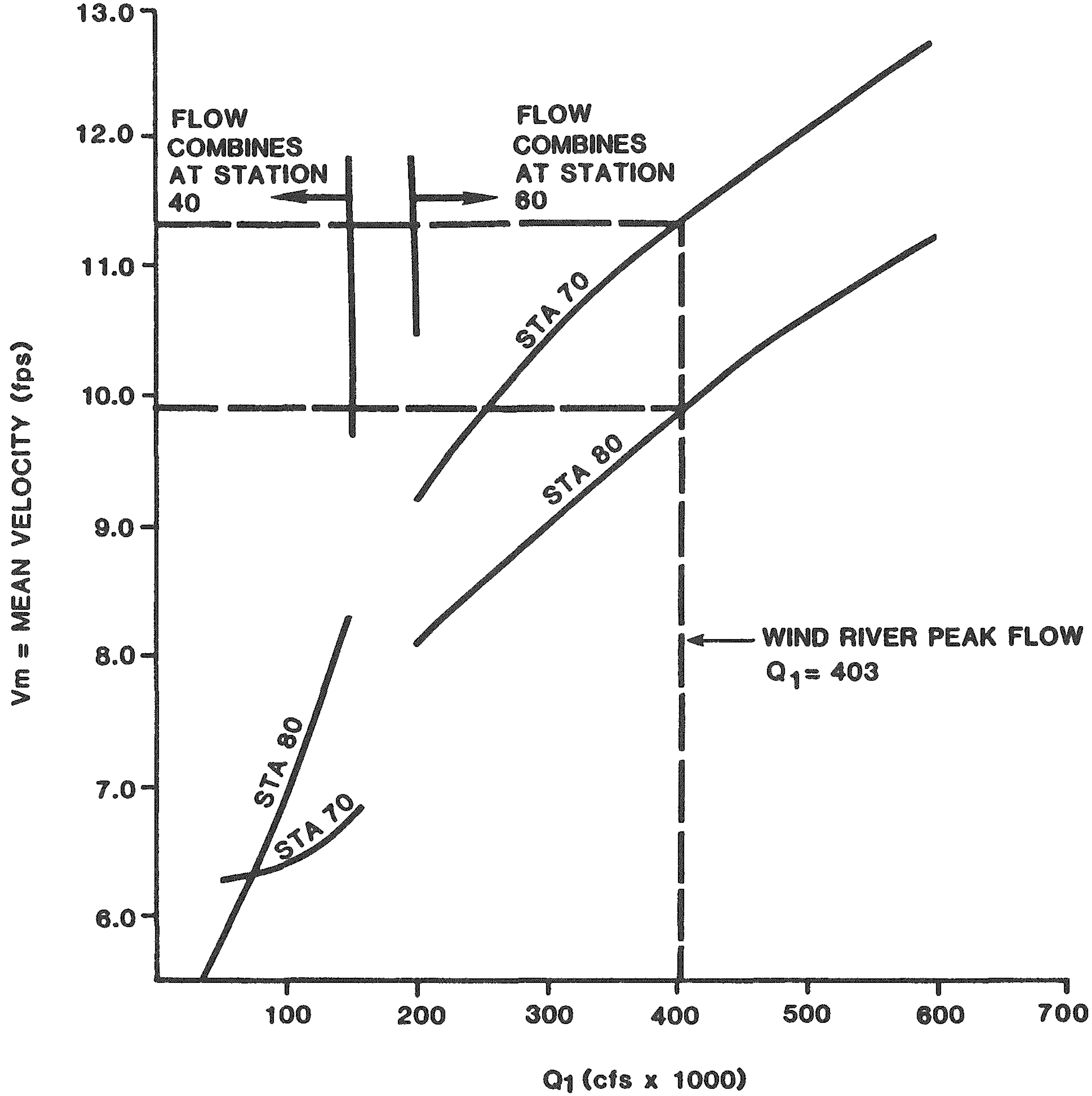


FIGURE C.1.14
WIND RIVER MEAN VELOCITY vs. Q_1

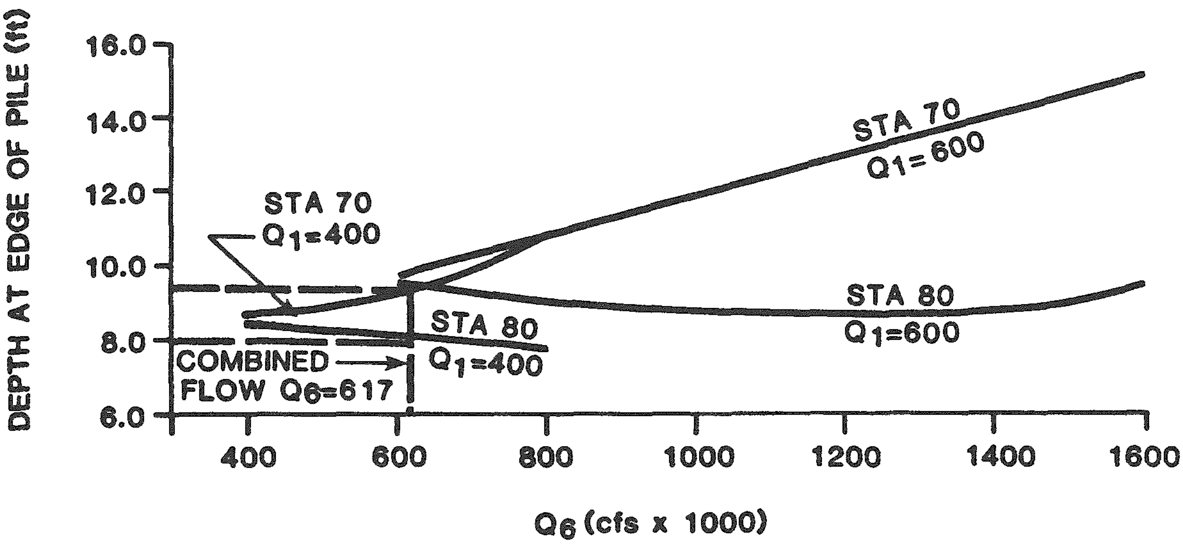


FIGURE C.1.15
WIND RIVER DEPTH AT PILE vs. Q_6

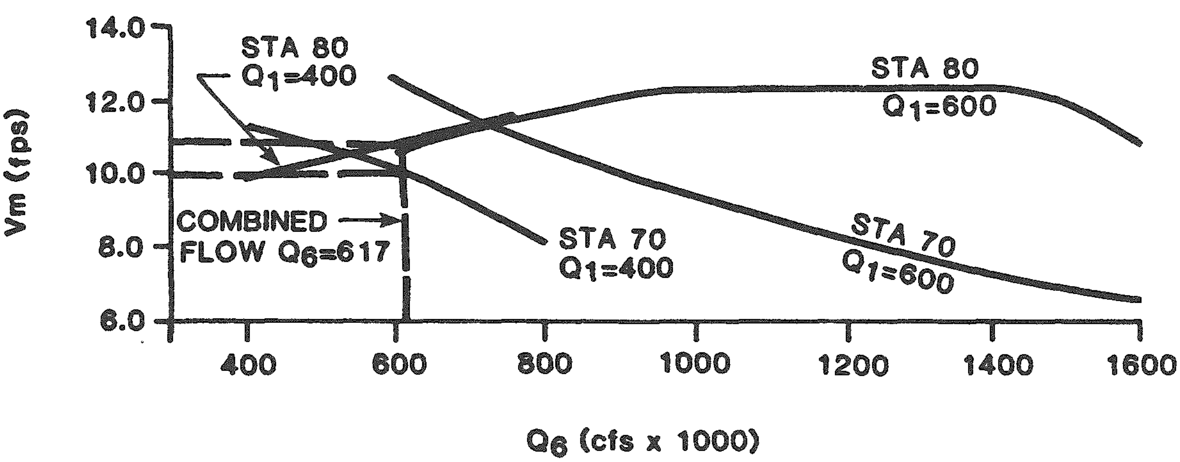


FIGURE C.1.16
WIND RIVER MEAN VELOCITY vs. Q_6

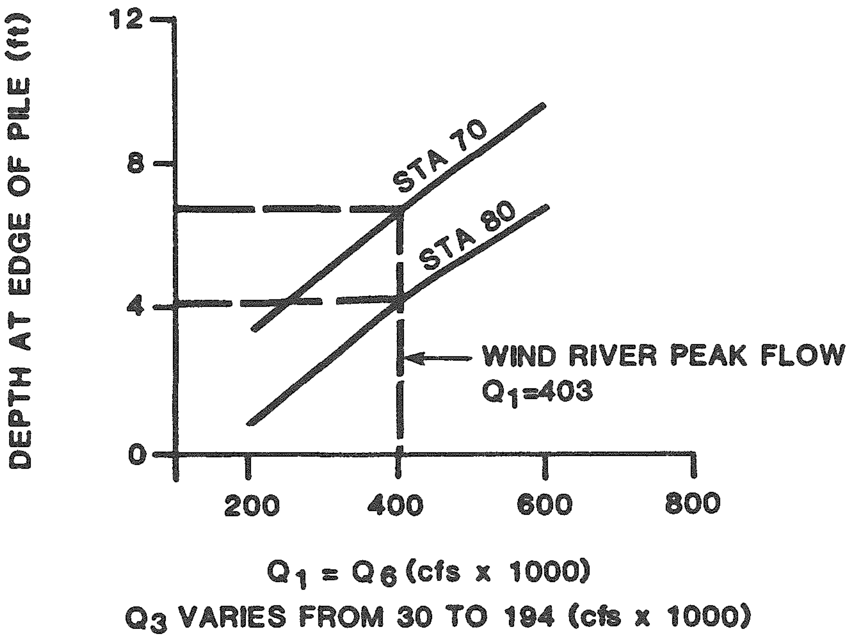


FIGURE C.1.17
MEANDER SCAR DEPTH AT PILE vs. Q_1

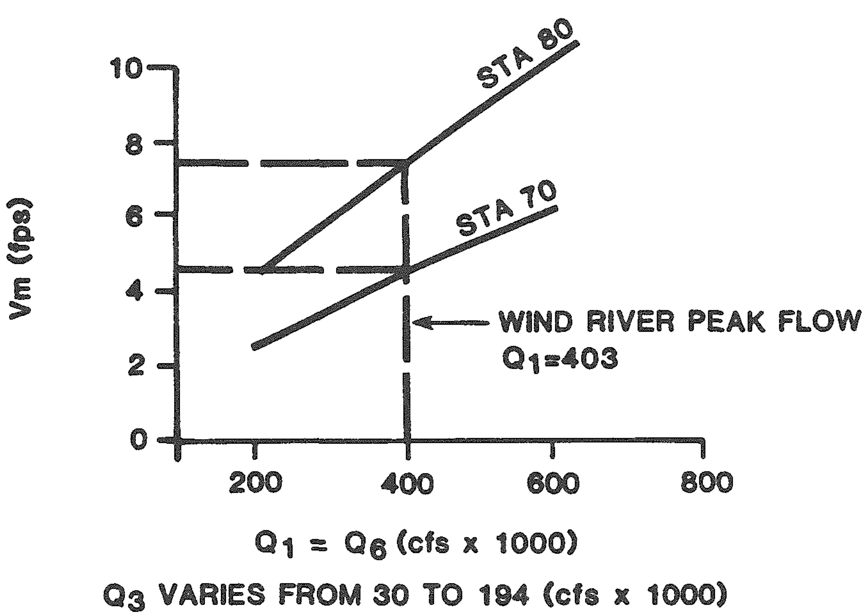


FIGURE C.1.18
MEANDER SCAR MEAN VELOCITY vs. Q_1

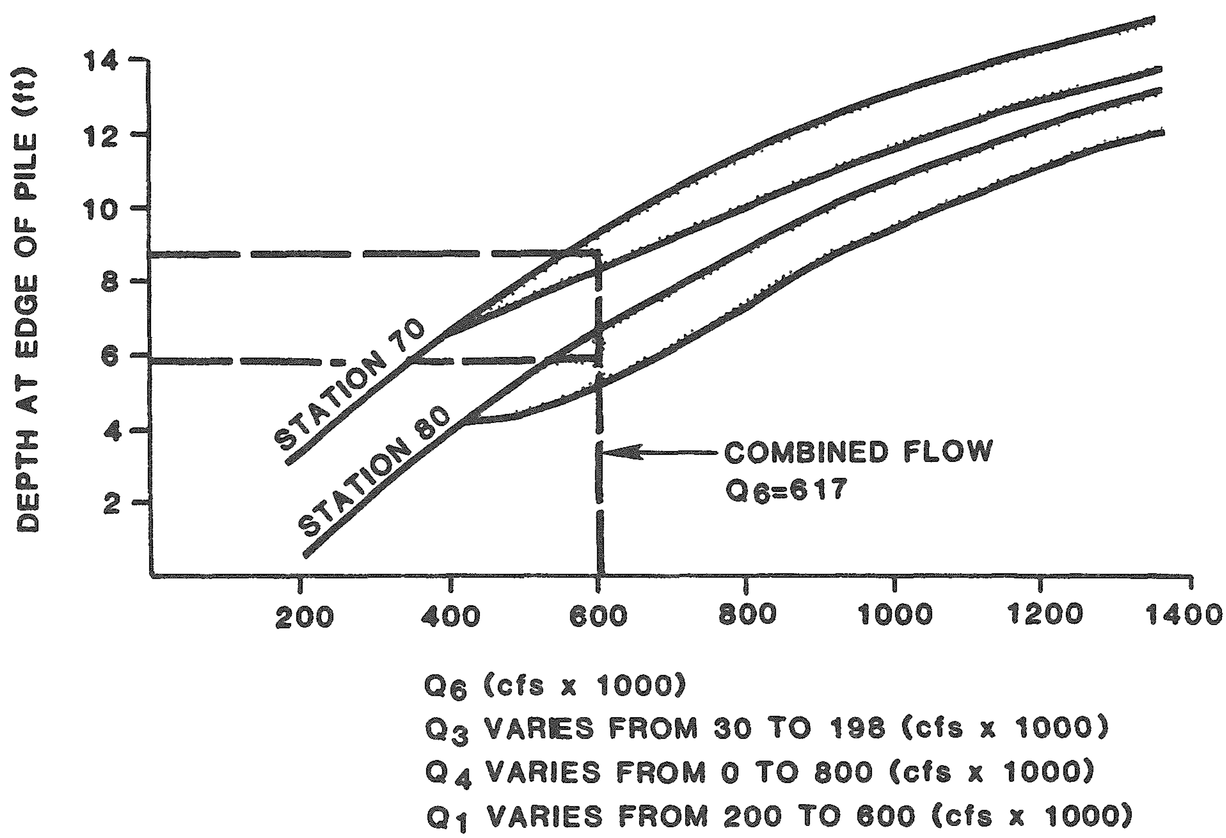


FIGURE C.1.19

MEANDER SCAR DEPTH AT PILE vs. Q_6 COMBINATIONS

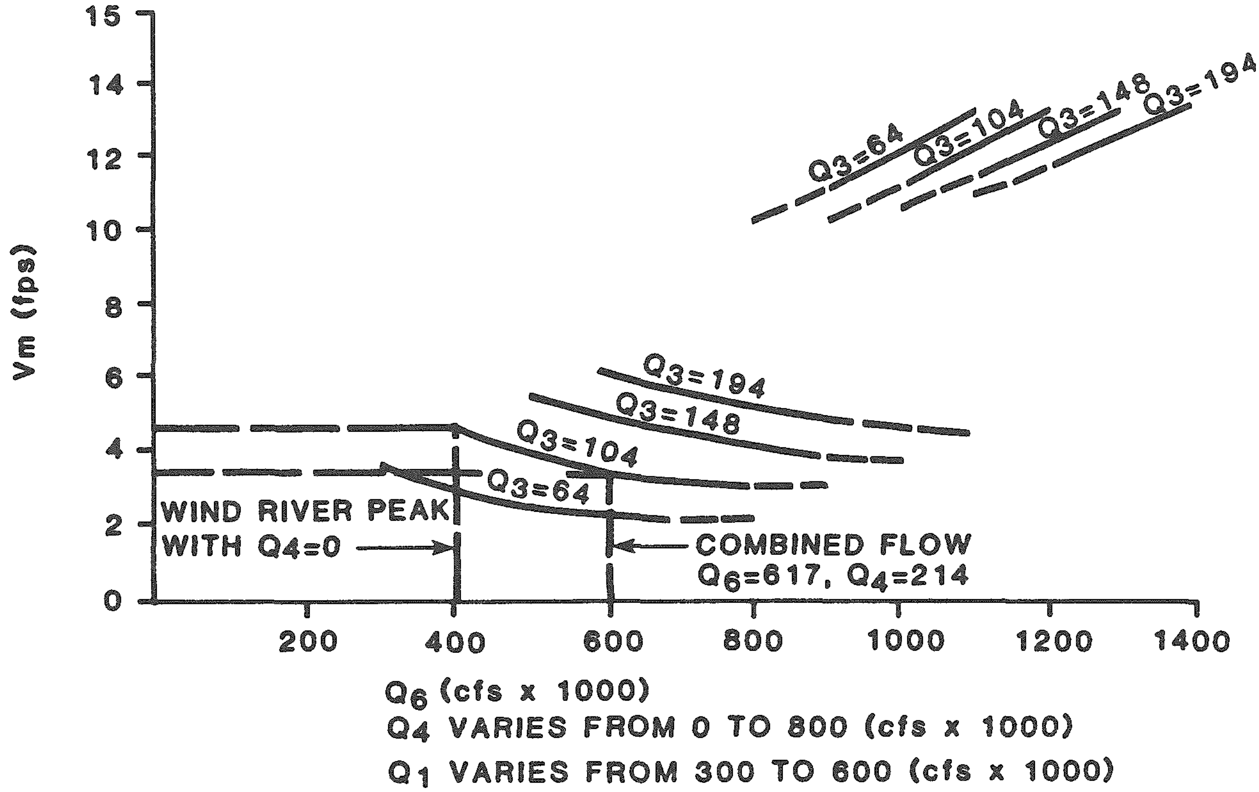


FIGURE C.1.20
MEANDER SCAR MEAN VELOCITY AT STATION 70 vs. Q_6

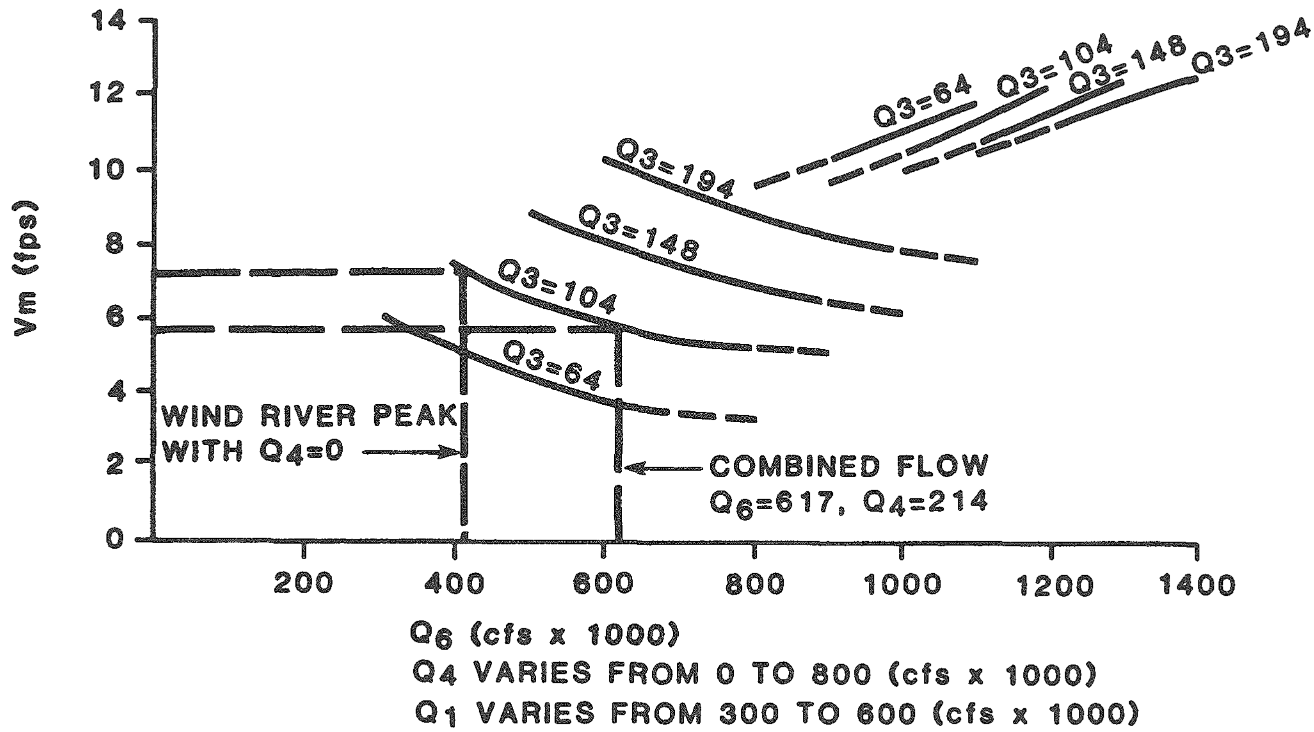


FIGURE C.1.21
MEANDER SCAR MEAN VELOCITY AT STATION 80 vs. Q_6

decrease as the flow from the Little Wind River is increased. This is a result of a decrease in the energy gradient due to a backwater effect. It is pointed out that if Q_4 becomes large enough, however, a drastic increase in the velocities occurs. This marks the area of Little Wind River flow where the flow is large enough to break across the drainage divide at station 85 and become combined flow with the meander scar. At lower levels, Q_4 and Q_3 do not combine until below station 70. Regardless, the PMF flows determined from the HEC-1 analysis are well below this drastic increase in velocities.

The previous analyses reveal that the maximum flood effect of greatest concern occurs on the Wind River side of the tailings pile at the maximum peak of the Wind River. As indicated in Table C.1.10, the maximum Wind River peak flow is 403,000 cfs with the Little Wind River flow at 214,000 cfs. Table C.1.12 is a summary of the depths and velocities that would occur with and without flow contribution from the Little Wind River when the Wind River is at its peak. These values are also emphasized on Figures C.1.12 through C.1.21 by the dashed lines.

These results indicate that water depths less than 10 feet along the sides of the stabilized tailings pile and mean channel velocities less than 15 feet per second (fps) would occur during a PMF. The Wind River side of the pile is a more critical flow situation than the Little Wind River side. An erosion protection barrier placed around the base of the pile and designed for 10-foot depths and 15-fps velocities would adequately protect the pile against the PMF. It would also protect the pile more than adequately against erosion due to long-term river meander.

C.1.2.2 Dry Cheyenne alternate disposal site

No data on historical floods are available for the Dry Cheyenne alternate disposal site. The disposal site is at the head of a small, ephemeral tributary to Dry Cheyenne Creek, and the only surface-water flows are runoff from the site itself. Due to the low annual precipitation, the relatively flat terrain at the site, and the distance from major surface drainages, flood flows would not be expected at this site.

C.1.2.3 Borrow sites

Due to its height above the Little Wind River, flood flows would not be expected to affect the Little Wind borrow site. Calculation of the 500-year flood elevation for the Little Wind River revealed that the Little Wind borrow site is not within the 500-year floodplain of the river.

Table C.1.12 Summary of maximum design flow conditions, Riverton site

Flow channel	Flow combination (cubic feet per second)	Depth at edge of pile (feet)	Mean channel velocity (feet per second)
Wind River	Q_1 = 403,000 Q_4 = 0	8.5 to 9.0	10.0 to 11.5
	Q_1 = 403,000 Q_4 = 214,000	8.0 to 9.5	10.0 to 11.0
Meander scar	Q_1 = 403,000 Q_4 = 0	4.0 to 7.0	4.5 to 7.5
	Q_1 = 403,000 Q_4 = 214,000	6.0 to 9.0	3.5 to 6.0

Borrow site 2 would be immediately north of the tailings pile and would be exposed to the same flood hazards as the tailings site. No data on historical floods are available for borrow site 10; however, due to the very small watershed above the site, flood flows would not be expected. Flood flows would not be expected at the Boulder Flats borrow site due to its height above and distance from the North Popo Agie River.

C.1.3 SURFACE-WATER QUALITY

The State of Wyoming and EPA surface-water quality standards applicable to the remedial action are summarized in Tables C.1.13 and C.1.14.

C.1.3.1 Riverton tailings site

Surface-water quality monitoring has been performed by the USGS at the gauging stations located on the Wind and Little Wind Rivers (locations 22 and 23, Figure C.1.22 and Table C.1.15) from about 1950 to the present. The USGS analyses generally include all of the water quality parameters listed in Table C.1.16. Levels of sulfate exceeded the EPA secondary standard of 250 mg/l during periods of low flow in the Little Wind River (USGS, 1984c).

Two sets of samples were collected by the DOE in March and June, 1984, from the Little Wind River at locations upstream of the tailings site and along the axis and downstream of the contaminant plumes generated in the shallow ground water at the site. These sampling locations are described in Table C.1.15 and shown on Figure C.1.22 (locations 24, 25, and 26). The results of the water quality analyses are listed in Table C.1.17. These results indicate no perceptible contamination of the river water resulting from ground-water discharge into the river. The decrease in major and trace constituents from March to June is probably associated with the increased flow during that period.

Paired values of flow and sulfate concentration were compared for three periods of record for the USGS gauging station on the Little Wind River (location 23 on Figure C.1.22) (USGS, 1984c). These time periods (November 1, 1965, to September 20, 1967; February 1, 1970, to August 1, 1973; and March 26, 1979, to January 3, 1984) relate respectively to a period when plume migration to the river had not occurred, a period when contamination may have reached the river, and a period when contamination had definitely reached the river (as confirmed by drilling and sampling). Linear regressions of the flow versus sulfate concentration and on the logarithms of flow versus the logarithms of sulfate concentration are presented in Figures C.1.23 and C.1.24. These graphs indicate that low-flow sulfate during the last time period may be slightly increased over low-flow sulfate for the first two periods of record. This

Table C.1.13 State of Wyoming surface-water quality standards

Section 21. Toxic Materials.

a. Ammonia - In all Class I, II, and III waters which are designated as cold water fisheries, the concentration of unionized ammonia (as N) shall not exceed 0.02 milligrams per liter (mg/l).

b. Benzedine - In all Class I, II, and III waters the concentration of benzedine shall not exceed 0.0001 mg/l.

c. Chlorine - In all Class I and II waters designated as cold water fisheries, the total residual chlorine concentration shall not exceed 0.002 mg/l. In those Class I and II waters designated as warm water fisheries and in all Class III waters the total residual chlorine content shall not exceed 0.01 mg/l.

d. Others - All other toxic or potentially toxic materials attributable to or influenced by the activities of man shall not be present in any Wyoming surface waters in concentrations or combinations which would damage or impair the normal growth, function, or reproduction of human, animal, plant, or aquatic life. Unless otherwise specified in these Standards, maximum allowable concentrations shall be based on the latest edition of Quality Criteria for Water, published by EPA or its successor agency, and/or more generally accepted scientific information.

   In those cases where maximum allowable concentrations must be determined through bioassay, the appropriate protocol and application factors as outlined in the latest edition of Standard Methods for the Examination of Water and Waste Water or other methods approved by the EPA shall be used.

Section 22. Radioactive Material. In all Wyoming surface waters radioactive materials attributable to or influenced by the activities of man shall not:

a. Be present in any amount which reflects failure in any case to apply all controls which are technologically feasible as determined by the Administrator of the Environmental Protection Agency;

b. Exceed a concentration of 5 picoCuries per liter (pCi/l) of total radium-226 plus radium-228;

c. Exceed a concentration of 8 pCi/l of total strontium-90;

d. Exceed the radiological limits established in the most recent Federal Primary Drinking Water Standards published by the EPA or its successor agency; or

e. Be present in the water or in sediments in amounts which could cause harmful accumulations of radioactivity in plant, wildlife, stock, or aquatic life.

Ref. WDEQ, 1983.

Table C.1.14 Federal drinking water standards

Parameter	Drinking water standards [a]	
	Primary[b]	Secondary[c]
Arsenic	0.05	--
Barium	1.0	--
Cadmium	0.01	--
Chromium	0.05	--
Copper	--	1.0
Fluoride	4.0	--
Lead	0.05	--
Mercury	0.002	--
Nitrate	10.0	--
Selenium	0.01	--
Silver	0.05	--
Zinc	--	5.0
Chloride	--	250.0
Iron	--	0.3
Manganese	--	0.05
pH (standard units)	--	6.5-8.5
Sulfate	--	250
Total dissolved solids (TDS)	--	500
Uranium (health advisory level in picoCuries per liter)[d]	10.0	--
Radium-226 and -228 combined (in picoCuries per liter)	5.0	--

[a]All values in milligrams per liter (mg/l) unless otherwise noted. Dashed lines indicate not applicable.
[b]Primary drinking water standards are contaminant concentrations that affect public health (40 CFR Part 141).
[c]Secondary drinking water standards are for contaminant concentrations that primarily affect the aestnetic qualities relating to the public acceptance of drinking water (40 CFR Part 143).
[d]Ref. Cothern et al., 1983.

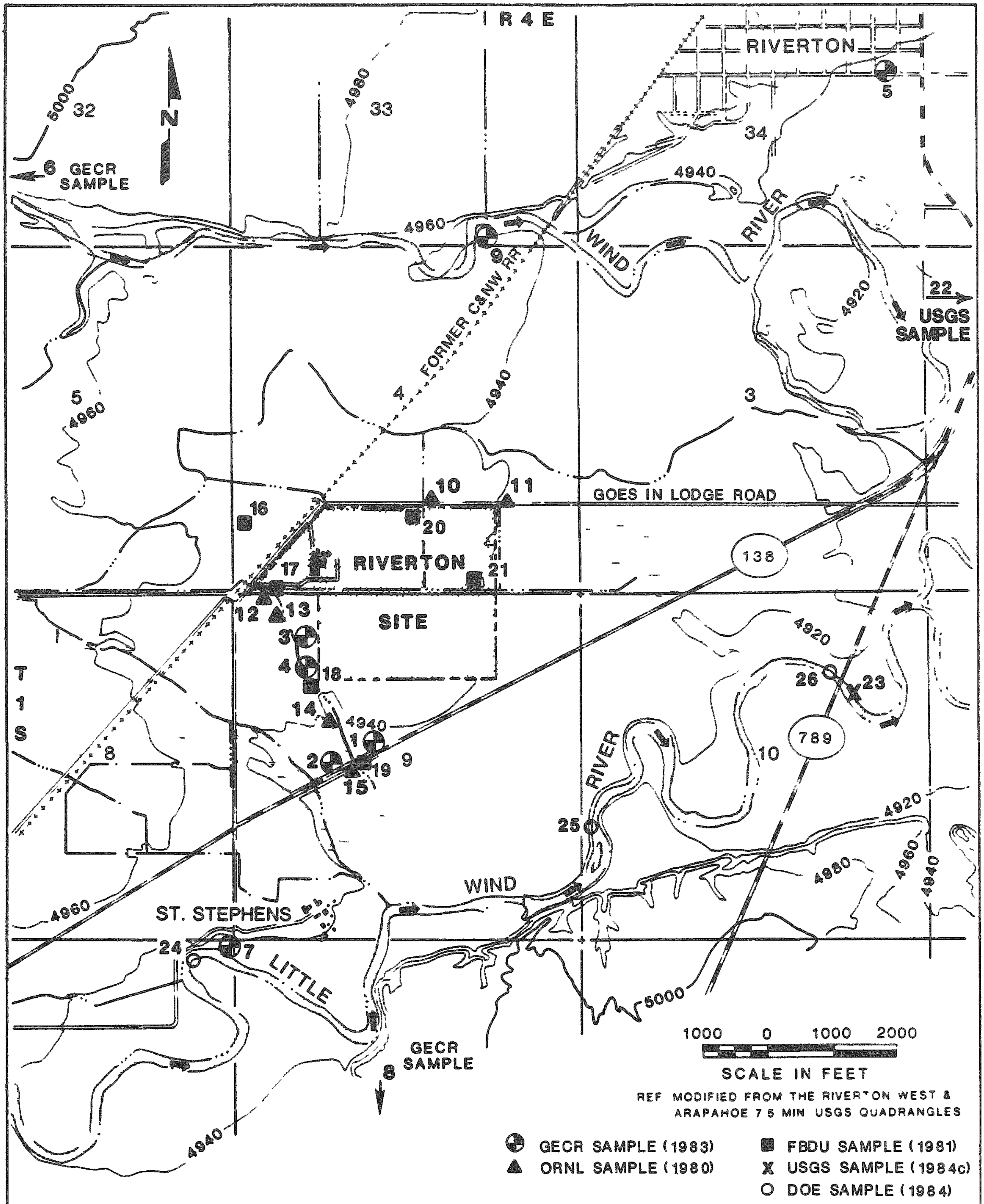


FIGURE C.1.22
APPROXIMATE SURFACE WATER SAMPLE LOCATIONS FOR RIVERTON AREA

Table C.1.15 Descriptions of Riverton surface-water sample locations

Location number[a]	Location identification	Location description
1	RIV 134, GECR	Slew on north side of road, south of tailings.
2	RIV 19, GECR	Marshy area south of tailings, adjacent to highway.
3	RIV 142, GECR	Small runoff pond adjacent to and west of tailings.
4	RIV 138, GECR	Runoff at southwest corner of tailings.
5	RIV 7, GECR	Ditch in Riverton, 1.9 miles northeast of tailings.
6	RIV 18, GECR	Wind River, 2.5 miles northwest of tailings.
7	RIV 22, GECR	Mouth of ditch entering Little Wind River, 1.0 mile southwest of tailings.
8	RIV 8, GECR	Ice from Beaver Creek, 3.1 miles south of tailings.
9	RIV 15, GECR	Ice from Wind River, 1.2 miles north of tailings.
10	YW5, ORNL	Irrigation canal 450 yards north of tailings.
11	YW6, ORNL	Irrigation canal 20 yards northeast of tailings pile.
12	YW2, ORNL	Ditch 250 yards west of tailings.
13	YW1, ORNL	Northwest side of road, across from main entrance to mill site.
14	YW3, ORNL	Drainage ditch 50 yards southwest of tailings.
15	YW4, ORNL	Drainage ditch 380 yards south of tailings pile near highway.
16	A, FBDU	Ditch northwest and upstream of tailings.

Table C.1.15 Descriptions of Riverton surface-water sample locations (Concluded)

Location number[a]	Location identification	Location description
17	B, FBDU	Ditch northwest and upstream of tailings.
18	C, FBDU	Ditch at southwest corner of tailings.
19	D, FBDU	Ditch south of tailings downstream from tailings at road bridge.
20	E, FBDU	Irrigation canal north of tailings, standing water.
21	F, FBDU	Irrigation canal northeast of tailings, standing water.
22	USGS	Gauging station for Wind River at Riverton, Wyoming (Station No. 06228000).
23	USGS	Gauging station for Little Wind River near Riverton, Wyoming (Station No. 06235500).
24	DOE	Little Wind River, upstream of tailings site.
25	DOE	Little Wind River, along axis of contaminant plumes.
26	DOE	Little Wind River, downstream of tailings site at USGS gauging station.

[a]Location numbers correspond to locations shown on Figure C.1.22.

Ref. FBDU, 1981; GECR, 1983; ORNL, 1980.

Table C.1.16 U.S. Geological Survey water quality parameters

Parameter	Units of measurement
Water temperature	Celsius degrees
Stream flow	Cubic feet per second
Turbidity	Turbidity units
Specific conductance at 25°C	Micromhos
Dissolved oxygen	Milligrams per liter
Total alkalinity as $CaCO_3$	Milligrams per liter
Bicarbonate	Milligrams per liter
Carbonate	Milligrams per liter
Dissolved nitrate	Milligrams per liter
Total phosphate	Milligrams per liter
Total hardness as $CaCo_3$	Milligrams per liter
Dissolved calcium	Milligrams per liter
Dissolved magnesium	Milligrams per liter
Dissolved sodium	Milligrams per liter
Sodium absorbtion ratio	None
Dissolved potassium	Milligrams per liter
Total sulfate	Milligrams per liter
Dissolved fluoride	Milligrams per liter
Dissolved silica	Milligrams per liter
Fecal coliform	Million per 100 milliliters
Dissolved solids	Milligrams per liter
Dissolved solids	Tons per acre-foot
Dissolved nitrate	Milligrams per liter
Suspended solids	Milligrams per liter
Suspended solids	Tons per day

Ref. USGS, 1984c.

Table C.1.17 Surface-water quality analyses, Little Wind River near Riverton, Wyoming

Constituent	Location 24		Location 25		Location 26	
	3/28/84	6/5/84	3/29/84	6/5/84	3/29/84	6/6/84
Al	<0.003	<0.1	<0.003	<0.1	<0.003	<0.01
As	<0.001	<0.01	<0.001	<0.01	<0.001	<0.01
Ba	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cd	<0.0001	<0.005	<0.0001	<0.005	<0.0001	<0.005
Ca	115	28.4	134	34.7	113	31.2
Cr	<0.001	<0.01	<0.001	<0.01	<0.001	<0.01
Cu	0.003	<0.02	<0.001	<0.02	<0.001	<0.02
Fe	<0.03	0.05	0.06	0.05	0.54	0.05
Pb	<0.001	<0.01	<0.001	<0.01	<0.001	<0.01
Mg	115	10.3	72.4	11.0	105	11.6
Mn	0.05	<0.01	0.09	<0.1	0.08	<0.01
Hg	<0.0002	<0.0002	<0.0002	<0.0002	<0.002	<0.002
Mo	<0.001	<0.01	<0.001	<0.01	<0.001	<0.01
Ni	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
K	5.80	1.7	5.26	1.6	3.81	1.4
Ag	<0.01	<0.01	<0.01	<0.021	<0.01	<0.01
Se	<0.002	<0.005	<0.002	<0.005	<0.002	<0.005
Na	125	52.5	156	26.3	113	20.9
V	<0.004	<0.01	<0.004	<0.01	<0.004	<0.01
Zn	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
NH_3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sb	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Cl	27.8	26	29.0	30	26.2	14
CN	<0.001	<0.01	<0.001	<0.01	<0.001	<0.01
F	<0.1	<0.1	<0.1	<0.1	<0.01	<0.1
NO_3	2.6	<0.1	2.3	<0.1	2.1	<0.1
P	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
SO_4	719	102	718	69.2	702	65.4
SiO_2	12.1	3.9	6.5	3.9	7.0	3.6
TDS	1,390	227	1,360	231	1,360	249
Ra-226	0.4±0.3	0.4±0.2	0.5±0.4	0.0±0.1	0.5±0.4	0.2±0.2
Th-230	0.0±0.4	0.0±0.4	0.1±0.5	0.0±0.4	0.0±0.3	1.5±1.0
Pb-210	1.6±1.2	0.0±2.0	1.0±1.1	0.0±1.9	1.7±1.0	0.0±0.8
U	0.0129	0.0027	0.0132	0.0013	0.0127	0.002
Flow[b]	420	1,900	393	1,900	393	1,670

[a]Location numbers correspond to locations shown on Figure C.1.22 and described in Table C.1.15. All units of measurement are milligrams per liter except for Ra-226, Th-230, and Pb-210 which are picoCuries per liter and flow which is cubic feet per second.

[b]Provisional data from the USGS measured at Station No. 06235500 (location 23).

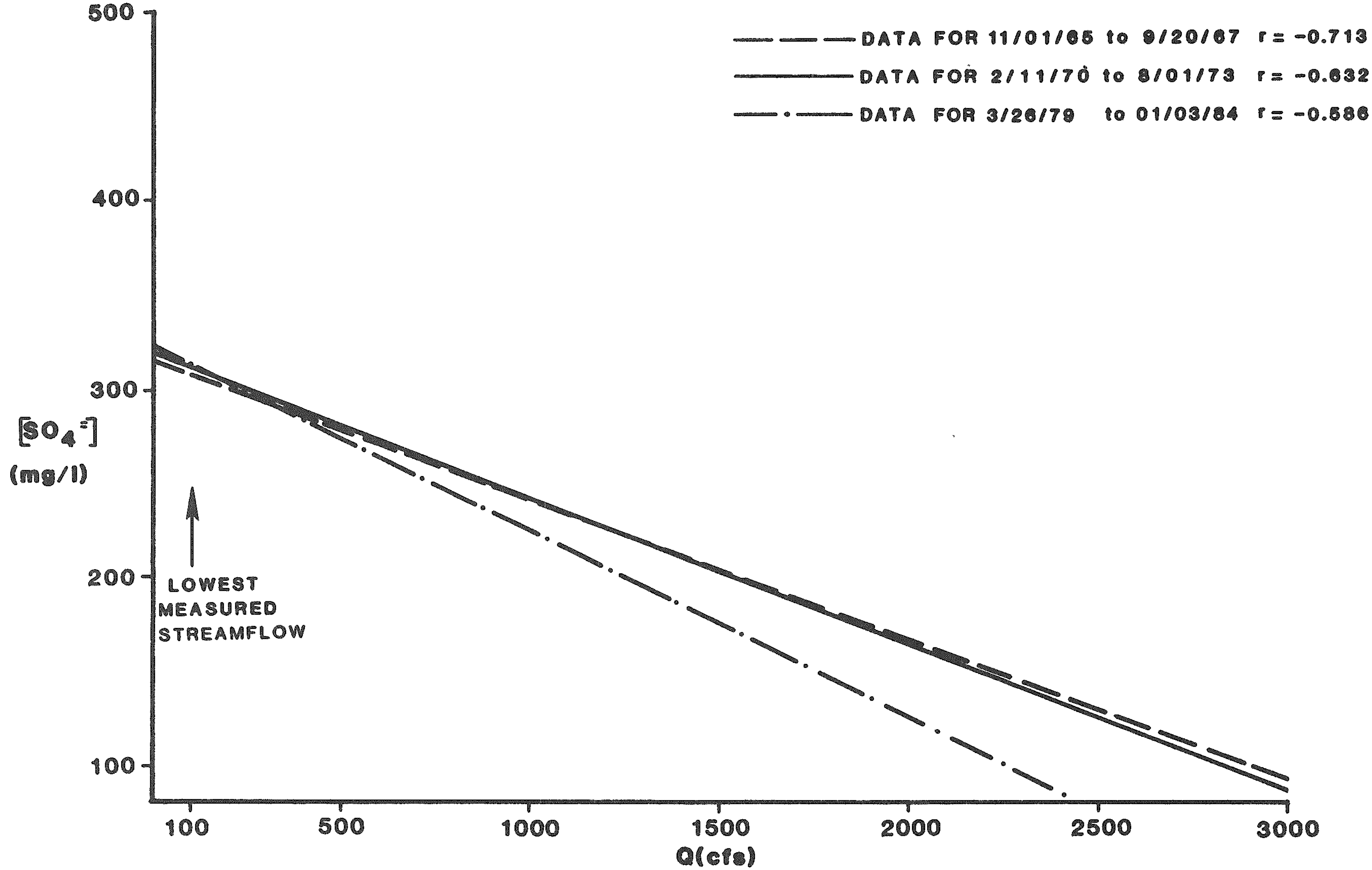


FIGURE C.1.23
LITTLE WIND RIVER, FLOW vs. SULFATE CONCENTRATION

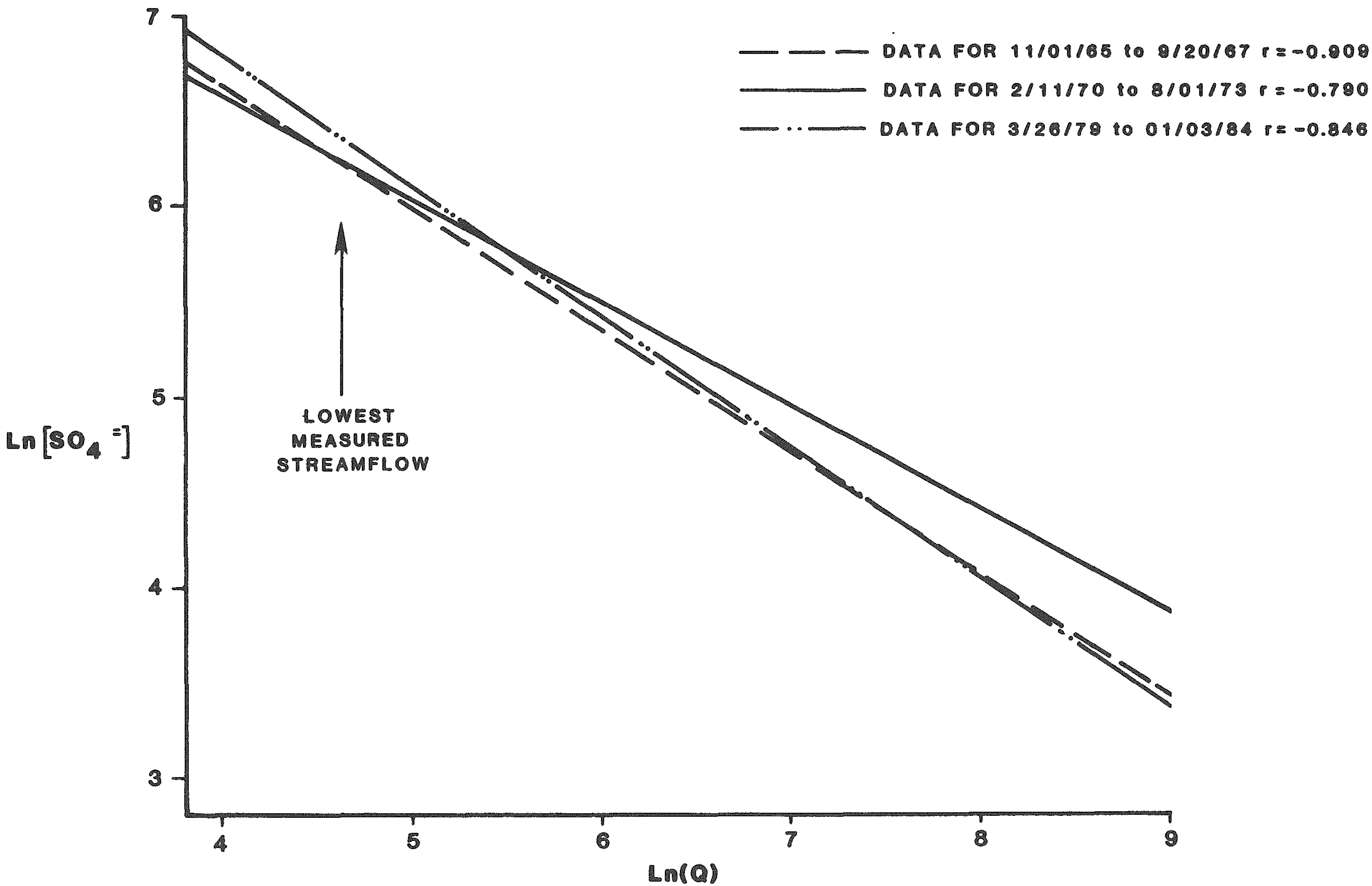


FIGURE C.1.24

LITTLE WIND RIVER, NATURAL LOGARITHMS OF FLOW vs. SULFATE CONCENTRATION

increased sulfate appears to be greatest, about 10 percent, at base flow (approximately 100 cfs) and decreases to equal concentrations of sulfate at flows greater than 220 cfs. Although these data and analyses are not conclusive, they indicate that the concentration of sulfate in the Little Wind River may be slightly increased during periods of low flow due to discharge of contaminated ground water.

A computer simulation of the shallow ground-water flow regime (Section C.2.5.3) confirms the potential for contamination of the Little Wind River water from ground-water discharge during periods of low flow. Based on a steady-state simulation of flow in the alluvial aquifer, the seepage of contaminated ground water into the Little Wind River occurs at a rate of approximately 1.1 cubic meters per second (39 cfs), compared to the total seepage of all ground water into the river of approximately 2.8 cubic meters per second (100 cfs). Although the calculated seepage rate is almost 40 percent of the total seepage, the linear regressions on data collected from location 26 indicate a maximum increase in sulfate of only 10 percent (Figure C.1.24), and the two sample sets taken in March and June, 1984, upstream and downstream of the tailings site indicate no increase of uranium or sulfate in the Little Wind River. In conclusion, although some analyses indicate the potential for surface-water contamination resulting from the discharge of contaminated ground water, the most recent water quality data for the Little Wind River indicate no, or at least undetectable, contamination.

Radiological analyses of surface waters near the Riverton site were conducted by Ford, Bacon & Davis Utah Inc. (FBDU). The FBDU sample locations (16 through 21) and descriptions are provided in Figure C.1.22 and Table C.1.15. Four samples were taken from the drainage ditch that flows intermittently along the western boundary of the tailings pile. Two samples taken upstream from the tailings pile contained 0.206 and 0.141 picoCuries per liter (pCi/l) of Ra-226, while the two samples taken downstream from the pile contained 0.165 and 0.239 pCi/l of Ra-226, showing no appreciable increase in the Ra-226 content. However, samples taken from the irrigation canal that flows along the north edge of the tailings pile indicated an increase in the Ra-226 content from 0.144 (upstream) to 0.404 (downstream) pCi/l (FBDU, 1981). This upper value is still well below the State of Wyoming's allowable concentration for total Ra-226 of 5 pCi/l (Table C.1.13).

Additional analyses of surface waters adjacent to the tailings site were performed by Geochemistry and Environmental Chemistry Research, Inc. (GECR). Figure C.1.22 shows the GECR sampling locations, and location descriptions are provided in Table C.1.15. A summary of the water quality data is provided in Table C.1.18. The GECR analysis showed the waters to be slightly oversaturated with calcite and slightly undersaturated with gypsum (GECR, 1983).

Table C.1.18 Summary of Riverton surface-water quality analyses

Location number[a]	Al	As	Ba	Ca	Cl	Fe	K	Mg	Mn	Na	Si	SO_4	Sr	U	Gross alpha (pCi/l)	pH
1	0.280[b]	--[c]	0.083	0.018	0.620	0.180	31.0	110.0	0.150	0.053	17.0	0.002	1.70	0.020	0.240	8.1
2	--	--	0.044	0.920	0.800	--	21.0	22.0	0.050	0.620	7.50	0.029	0.745	0.012	7.90	7.8
3	--	0.04	0.037	0.910	0.530	0.060	15.0	68.0	1.10	0.054	23.0	0.001	1.30	0.098	0.880	8.3
4	--	--	0.022	0.012	0.012	0.020	18.0	0.720	0.720	0.048	22.0	0.001	1.47	0.021	0.180	8.1
5	--	--	0.026	0.740	0.027	--	3.40	--	--	0.017	8.50	0.023	0.596	0.036	0.220	7.4
6	--	--	0.067	0.490	0.400	--	1.00	--	--	0.200	6.70	0.740	0.301	0.003	3.10	8.0
7	--	--	0.044	0.012	0.130	--	2.90	0.040	0.040	0.011	11.0	0.034	1.43	0.032	0.115	8.1
8	--	--	0.021	0.570	0.160	--	2.30	--	--	0.200	1.40	0.024	0.751	0.003	0.00	8.7
9	--	--	0.069	0.500	0.400	0.040	1.00	--	--	0.200	7.20	0.750	0.298	0.004	4.20	7.4

[a] Location numbers correspond to locations shown on Figure C.1.22 and described in Table C.1.15.
[b] All values in milligrams per liter unless otherwise noted.
[c] Dashed line indicates below detectable limit.

Ref. GECR, 1983.

Some of the surface waters sampled in the area adjacent to the tailings site contained contaminants characteristic of the tailings; however, there were no elevated concentrations of uranium, and the gross alpha activities of the water samples were only slightly above the background level. Contamination of standing water at the base of a dike west of the tailings pile (location 3) is most likely due to runoff from the tailings or to leaching of windblown tailings in the area. The ionic composition of the surface water from the marsh south of the tailings (location 2) also reflects a possible influence from the tailings. The slightly elevated gross alpha activity in the marsh south of the tailings is accompanied by alkalinity lower than the background level (GECR, 1983).

In addition, the potential for ground-water mounding beneath the tailings pile due to local irrigation was assessed because mounding beneath the pile could allow direct contact between ground water and contaminated soils or tailings. Ground-water levels were measured in November, 1982, following the irrigation season and during the irrigation season in July, 1983. There was no appreciable difference in the two sets of measurements beneath the tailings pile; however, a ground-water mound formed south of the pile during irrigation (Section C.2.4.2). The increased water level appearing south of the pile, rather than directly beneath the pile, probably is due to the southward drainage of the irrigation canal and drainage ditch along the northern and eastern boundaries of the tailings site.

C.1.3.2 Dry Cheyenne alternate disposal site

Since surface-water flows are ephemeral at the Dry Cheyenne site, no surface-water quality data are available for this site.

C.1.3.3 Borrow sites

Water-quality information for the Little Wind River at the Little Wind borrow site is the same as that provided for the Riverton tailings site. No water quality data are available for the ephemeral tributaries that drain the Little Wind borrow site. Surface-water quality information for borrow site 2 is the same as that provided for the tailings site. Surface-water flows are ephemeral at borrow site 10, and no surface-water quality data are available for the site. Flows in the Reynolds Ditch at the Boulder Flats borrow site are intermittent, and no surface-water quality data are available for the site.

C.2 GROUND WATER

C.2.1 INTRODUCTION

Due to the ability of ground water to act as a universal solvent and to transport dissolved substances over substantial distances, contamination of ground-water resources by uranium mill tailings has been identified as a primary environmental concern. Although airborne and surface-water contaminants constitute much of the health hazard of uranium tailings, contamination of ground water can not easily be characterized or reversed and may involve transport of toxic chemicals into valuable water reserves that serve long-term population needs. The issue of existing and potential ground-water contamination, particularly with regard to the proposed remedial action strategies, can be addressed only through collection of relevant hydrologic data, data synthesis through analytical or numerical modeling techniques, and evaluation of the predicted quality of the remedial-action decision with respect to protection of ground-water and surface-water supplies. The proposed remedial action alternatives that have been formulated represent potential strategies for containment of contaminated materials and for control of further contaminant movement as required by Title I of Public Law 95-604, the Uranium Mill Tailings Radiation Control Act of 1978.

Section C.2 of Appendix C, Water, presents ground-water data, as well as data analysis and evaluation, for the Riverton tailings site, Dry Cheyenne alternate disposal site, and proposed borrow sites. Results regarding the technical feasibility and the effectiveness of the various remedial actions have been based on evaluation of the data using various analytical and numerical techniques.

C.2.2 WATER USE

C.2.2.1 Unconfined aquifer

Unconfined ground water in the Riverton area can be developed from terrace gravel deposits, river valley alluvium, or the upper sandstone in the Wind River Formation. Unconfined ground water is not the primary source for domestic, municipal, or industrial water supplies in the Riverton area because of the insufficient quantity or poor chemical quality of the water. Development of the unconfined aquifer in the Riverton area has been primarily limited to areas upstream and upgradient from the site (McGreevy et al., 1969). This is due to the natural decrease of the quality of unconfined ground water in the downstream direction and the availability of better quality water in the nearby Wind and Little Wind Rivers and in the confined aquifer. Water obtained from the unconfined aquifer is generally used for irrigation and livestock watering purposes, with yields varying widely from less than 10 gallons per minute (gpm) to over 100 gpm. These wells are not presently metered. Records of current ground-water rights in the Riverton area are on file at the UMTRA Project Office in Albuquerque, New Mexico.

C.2.2.2 Confined aquifer

Figure C.2.1 shows registered wells in the vicinity of the Riverton site which are used to fulfill domestic, irrigation, and livestock watering needs. Well use is provided in Table C.2.1. Clearly, the majority of registered wells are completed in the confined system.

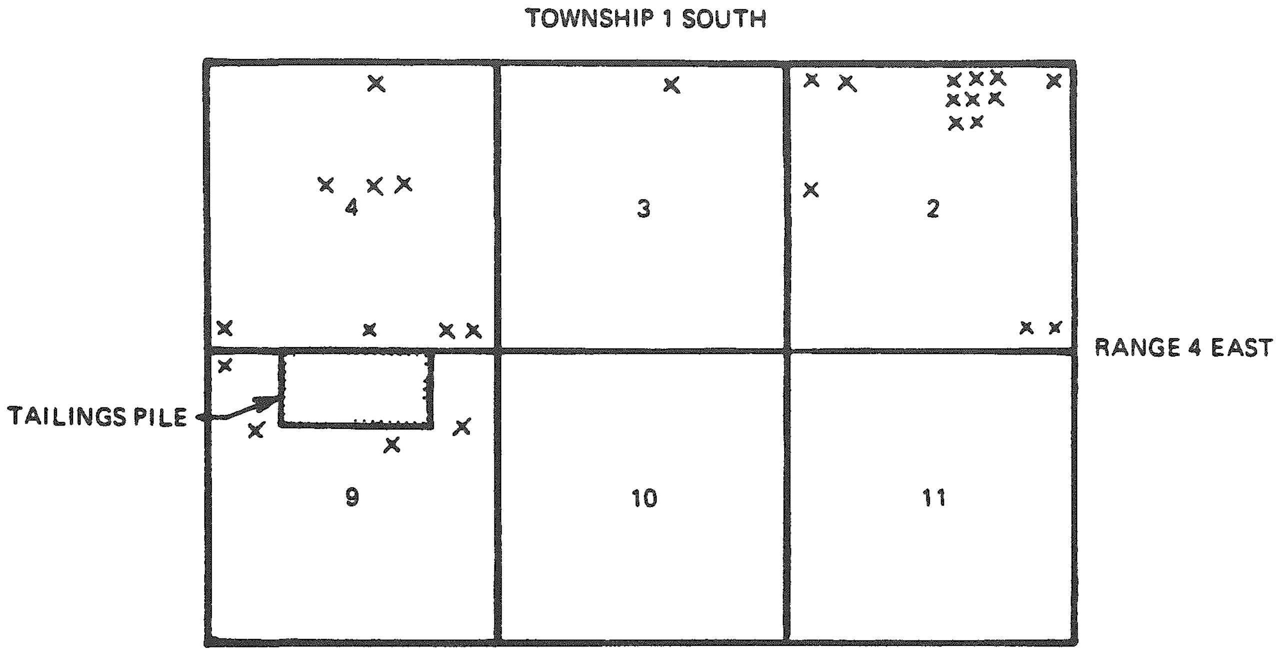
Confined ground water in the Riverton area is developed from the lower sandstone units of the Wind River Formation which represent the major source of water for rural, domestic, municipal, and industrial use in the vicinity of Riverton. All domestic and industrial wells sampled by the DOE were completed in the confined aquifer (Table C.2.1), although some of the wells may be open through the unconfined aquifer. In the Riverton area, wells completed in the confined aquifer are commonly 400 to 900 feet deep (Anderson and Kelly, 1976).

The city of Riverton maintains and operates 15 wells which are completed in the confined system at depths of 500 to 800 feet. These wells can yield up to 500 gpm. Municipal well locations are given in Table C.2.2. The municipal well field is the major ground-water development in the Riverton area. Total water rights established for city wells 2 through 14 amount to 4.5 million gallons per day. Discharge from all individual wells is now metered to provide a record of the total volume of water pumped, which can be used to estimate the average discharge rate. Total annual pumpage is currently in the range of 575 to 600 million gallons. However, even this rate of pumpage is barely adequate to fulfill peak daily pumping requirements during the high demand of summer months (Anderson and Kelly, 1976). In 1985, Bernard Scott of the city of Riverton indicated that the long range plans are to obtain municipal water from the Wind River upstream of the water treatment plant. There are two reasons for this proposed change:

- o Although the water derived from the Wind River sandstone is very soft, the high sodium content is a medical concern.
- o The cost of expanding the well field is prohibitive because to avoid influence between wells, new wells would be outside city limits and the cost of running mains to these wells would be exorbitant.

The change to greater surface-water use and lesser ground-water use was originally planned for the 1990s. Due to the decline in growth associated with lower levels of mining and gas and oil development, the change is now 15 years away (Scott, 1985).

The major non-municipal pumpage occurs at the active sulfuric acid plant at the tailings site which uses 42



Location in Township 1 South, Range 4 East	Name	Static Water Level[a]	Total Depth	Flow in gpm[b]
SE SE Section 4	Mayland #1	SWL 150 ft	265 ft	A 3
SW SW Section 4	Western Nuclear #2	SWL 26	60 ft	P 100
SE SW Section 4	Fremont Minerals #1	MWBZ 385	450 ft	A 100 P 550
SE NE Section 9	Westlake #1	MWBZ 250	267 ft	A 8
SW NW Section 9	Fremont Minerals #2	MWBZ 44 SW 6	63 ft	P 100
NW NW Section 2	KWRL well	MWBZ 185-205 SWL+11	205 ft	A 12
NW NW Section 2	Riverton Auction	SWL 30	45 ft	P 20
NW SW Section 2	Elwood #1	SWL 9	63 ft	
NE SW Section 4	Lucas #1	SWL 10	25 ft	P 6
NW SE Section 4	Raymond #2	MWBZ 300 SWL 15	320 ft	P 15
NE SW Section 4	Bunnies #1	SWL 20	400 ft	P 10
NE NW Section 3	Island #1	SWL 70	160 ft	P 15
SW NE Section 9	Moss #1	SWL 25 ft	160 ft	P 10
SE SE Section 2	Wicker #1	SWL 30	160 ft	P 10
SE SE Section 2	Guthrie #1	SWL 15	50 ft (?)	P 25
NE NW Section 4	Willis #1	completed 12/28/76	200 ft (?)	
NE NW Section 2	Pearl #2		160 ft	
SE SE Section 4	Weber #1		350 ft	
NE NW Section 2	Lummus #1	MWBZ 130-180 SWL 40	180 ft	P 15
NE NW Section 2	Wacks #1	SWL 40	165 ft	P 12
NE NW Section 2	Lye #1		170 ft (?)	
NE NW Section 2	Mahafley #1	MWBZ 145-168 SWL 63	170 ft	P 20
NE NW Section 2	Pebbles #1		160 ft (?)	
NE NW Section 2	Petty #1	SWL 42	170 ft	P 25
NW NW Section 2	Gaines #1		75 ft	

a SWL = Static water level
MWBZ = Main water-bearing zone
b A = Artesian flow
P = Pumped well

REF. FBDU, 1981.

FIGURE C.2.1
REGISTERED WELLS NEAR RIVERTON, WYOMING

Table C.2.1 Domestic well information, Riverton, Wyoming

Well owner	Depth of well (feet)	Distance from tailings site (feet)	Direction from tailings site	Use of well	Sampled by	
					DOE	LBL[a]
Church	80	1435	NW	Not in use		
Larsen	160	1750	NW	Domestic		
Green	135	1505	NW	Domestic		
Willis	Unknown	1435	NW	Domestic		
Roylance	270	1960	NW	Domestic		
Fremont Minerals	385	525	N	Process water	X	
Western Nuclear	50	735	NW	Not in use		X
Western Nuclear	450	945	NW	Not in use		
Kranz	60	1715	NW	Domestic	X	X
Fremont Minerals	63	140	SW	Abandoned		
Rocky Mountain Pre-Mix	12[b]	2205	SW	Abandoned		
Harris	200	245	S	Domestic		X
Moss	200	175	S	Domestic	X	
Goggles #1	100	595	SE	Domestic	X	X
Goggles #2	100	700	SE	Domestic		
Westlake #1	250	1050	E	Domestic		X
Westlake #2	100	1155	E	Domestic		X
Blackburn	360	2695	E	Domestic		
Willow	NA	2695	E	Domestic		
Blomberg	600	280	E	Irrigation		
Blomberg	390	280	E	Irrigation		
Blomberg	390	735	E	Irrigation		
Blomberg	35[b]	2205	E	Livestock		
Blomberg #1	260	1855	E	Domestic	X	X
Clarke	350	1155	NE	Domestic		X
Weber	400	1330	NE	Domestic		
Mayland	255	770	NE	Domestic		
Hilyard	390	1750	NE	Domestic		
Whiteman	290	2800	NE	Domestic		
Raymond	280	1610	N	Domestic	X	X
Lucas	25[b]	1820	N	Irrigation		
Schlotter	360	1505	N	Domestic		X

[a]Lawrence Berkeley Laboratory, Berkeley, California.
[b]Completed in unconfined alluvial aquifer.

Table C.2.2 Riverton, Wyoming, municipal well locations, Township 1 North, Range 4 East

Well number	Section	Quarter
2	35	NW¼NW¼NW¼
3	34	SE¼SE¼NE¼
4	27	SE¼SE¼SE¼
5	27	SE¼SW¼SE¼
6	27	NE¼SE¼SW¼
7	34	SW¼NE¼NW¼
8	34	SE¼NW¼NW¼
9	34	NW¼NW¼NW¼
10	34	NW¼NE¼SW¼
11	29	SW¼SW¼SE¼
12	27	NE¼SW¼NE¼
13	26	NE¼NE¼SW¼
14	29	NW¼NW¼SE¼
15	27	NE¼NE¼SE¼
16	28	SE¼SE¼NE¼

Ref. Anderson and Kelly, 1976.

million gallons a year (Larson, 1987). The plant operates continuously so that the pumping, although operating intermittently at several hundred gpm, is roughly equivalent to a continuous pumping rate of 80 gpm. The golf course west of Riverton uses two, 400 feet deep wells for irrigation with total annual pumpage estimated (based on well discharge rates) to be 13 million gallons (McFarland, 1987). Based on well discharge rates, Anderson and Kelly (1976) estimated that an additional 15 to 25 million gallons are used for suburban domestic supplies pumped from privately owned wells.

Prior to development of the Riverton well field beginning in the 1920s, the artesian pressure in low areas along the Wind River valley was sufficient to produce flowing wells. Intensive development of the area's ground water has affected water levels and artesian pressures. In the immediate vicinity of the city of Riverton, water levels in wells have dropped 60 to 70 feet during the 50-year development period (Table C.2.3). Differential lowering of aquifer pressures within the confined aquifer near Riverton has altered the regional flow pattern, causing diversion of confined ground water from all directions toward the field (Anderson and Kelly, 1976). When the city of Riverton decreases or eliminates its dependence on its well field, artesian pressures above the land surface may be re-established.

Some area residents have complained of falling water levels in confined wells in the suburban subdivision areas west of the city along Riverview Road. Water levels in these wells undoubtedly fluctuate seasonally, largely because of municipal well field operation. In other cases, there is probably mutual interference between closely spaced wells. However, there is no evidence to substantiate claims that water levels outside of the municipal well field are decreasing significantly (Anderson and Kelly, 1976).

Both the chemical and bacteriological quality of ground water in the confined aquifer at Riverton are satisfactory for municipal use without treatment (Anderson and Kelly, 1976). The contamination potential associated with diversion of ground water from the area of the tailings pile to the municipal well field is considered minimal due to the large distance (1.5 to 9 miles) between the field and the pile. Rural ground-water supplies near the pile which are obtained from the confined system presently remain untreated.

C.2.2.3 Dry Cheyenne alternate disposal site

The four wells located in the vicinity of the Dry Cheyenne site, listed in Table C.2.4, are used for watering livestock (Kelly, 1984).

Table C.2.3 Annual pumpage rates and depths to water, Riverton, Wyoming, 1920-1975

Year	Depth to water (feet)	Annual pumpage (millions of gallons)
1920s - 1930s	10-20[a]	Unknown
1951	31	365[b]
1968	55	502
1969	52	557
1970	63	535
1971	65	524
1972	68	530
1973	67	547
1974	75	596
1975	74	573

[a]Depth questionable.
[b]Approximate.

Ref. Anderson and Kelly, 1976.

Table C.2.4 Summary of wells near the Dry Cheyenne alternate disposal site

Well name	Well location	Total depth (feet)	Water-bearing zones (feet)	Yields (gpm)	Static water level (feet)	Total dissolved solids concentration[a] (mg/l)	Remarks
Cash	T34N, R95W, Section 25, NE¼, NW¼	403	245 - 315 320 - 345 388 - 402	3 1 5	235	-- --	Water came in small amounts between shale and sandstone ledges in upper portion; brackish taste
Clay Hill	T34N, R94W Section 12, SW¼, NW¼	225	55 - 70 195 - 220	2 5	40	4,130	Water clear; taste fair; no odor
Oil Springs	T34N, R94W Section 27 SE¼, SW¼	312	106 - 107 260 - 295	2 18	75	5,500	Water clear; taste fair; no odor
Carter #0427	T34N, R95W Section 29 SW¼, SW¼	133	90 - 100 (?) 120 - 130 (?)	5 - 50	20	--	Water quality not tested; used for livestock

[a]Unknown indicated by --.

Ref. Kelly, 1984.

C.2.3 DATA COLLECTION

Data have been collected at the Riverton site for the purpose of evaluating the present and future characteristics of the ground-water regime. From this evaluation, the projected changes in water levels and the present and future rates, characteristics, and concentrations of contaminant migration have been estimated.

C.2.3.1 Data collectors

Various researchers have conducted field studies to estimate the geologic and hydraulic properties of the alluvium and shallow bedrock materials, to determine the distribution of contaminants in the ground water, and to assess the nature and extent of solute transport in the vicinity of the Riverton site. These field studies have been conducted by:

- o Geochemical and Environmental Chemistry Research, Inc. (GECR) in 1982 and 1983.
- o Lawrence Berkeley Laboratory (LBL) in 1983 and 1984.
- o Colorado State University (CSU) in 1982 and 1983.
- o Ford, Bacon & Davis Utah Inc. (FBDU) in 1980 and 1981.
- o U.S. Department of Energy (DOE) in 1983, 1984, and 1985.

The GECR effort involved geochemical characterization of the tailings site and its immediate environment, determination of the contaminant distribution resulting from former milling activities and the tailings, and inference of chemical pathways and transport mechanisms for purposes of identifying criteria for long-term remedial action measures. Samples of soils and water from the tailings pile, its adjacent areas, and the background area were used to define contaminant distributions, geochemical environments, and transport mechanisms at the site. The activities performed by GECR included chemical analyses of:

- o Borehole water samples.
- o Soil, tailings, and cover samples.
- o Water and acid elutriates of soil, tailings, and cover samples.

The primary objective of the LBL investigation was identification of the hydrologic and geochemical regimes in the tailings pile, as well as determination of mechanisms by which important chemical constituents are mobilized and transported into the underlying ground-water flow system.

This necessitated the study of time-dependent changes in fluid potentials within the tailings; the disposition of the shallow water table; the hydraulic conductivity, moisture content, and related properties of the tailings materials; and the rainfall patterns in the vicinity of Riverton over the past 10 years. The activities performed by LBL included:

- o Collection and analyses of water samples from the unconfined aquifer system.

- o Installation of piezometers, and monitoring of the water table elevation in the unconfined alluvial-sandstone aquifer.

- o Monitoring of soil suctions at various depths in, and directly below, the tailings pile.

- o Sampling of soil moisture at various depths in the vadose zone through the tailings pile for geochemical analysis.

- o Analyses of soil moisture samples for major ions, trace metals, and radionuclides.

- o Laboratory determination of saturated hydraulic conductivity, saturability, and other physical properties of representative tailings, cover, and subsoil samples.

- o Radiometric measurements of radionuclide profiles across all material interfaces.

Researchers from CSU investigated the physical properties of the tailings, cover, and subsoil, and collected samples from the unconfined aquifer. These research efforts helped to define existing conditions at the site and identify problem areas that may influence the design of suitable remedial action schemes. The activities performed by CSU involved:

- o Characterization of the materials within the tailings pile with respect to moisture content.

- o Measurements of hydraulic properties of the tailings that are relevant to remedial action at the site.

FBDU work efforts were oriented toward site assessment as it related to the potential for pile stabilization. The FBDU activities included:

- o Drilling of geotechnical boreholes.

- o Extraction of NX cores.

- o Performance of packer tests in the shallow bedrock.

- o Execution of a pump test in the unconfined aquifer.
- o Compilation of data from other researchers.

DOE investigations have focused on synthesis and evaluation of data obtained by GECR, LBL, CSU, and FBDU, as well as collection and synthesis of additional data when it was determined that sufficient information for a comprehensive environmental assessment was lacking. Field studies performed by the DOE included:

- o Extraction of NX cores.
- o Performance of one pump test in the unconfined ground-water aquifer and another pump test in the first confined sandstone layer.
- o Execution of slug and bailer tests.
- o Sampling of ground water in both the unconfined and confined aquifers.
- o Determination of subsurface materials properties using geophysical logging techniques.
- o Determination of local water users.
- o Compilation of previous research results.

No ground-water investigations were conducted by the DOE at the Dry Cheyenne site. However, the Bureau of Land Management (BLM) records contain data for four wells in the vicinity of the site that can be used to estimate general hydrologic characteristics at the Dry Cheyenne site. Investigations at the proposed borrow sites included several borings and test pits that were logged by the DOE.

C.2.3.2 Data collection procedures

Riverton tailings site

The following describes the procedures used by GECR for sampling waters and solids and determining the geochemical conditions at the site (GECR, 1983). Locations of the samples are shown in Figure C.2.2, with corresponding descriptions given in Table C.2.5. The sampling locations included four boreholes through the tailings pile and 1 meter (m) into underlying soils. Care was taken to minimize contamination of samples from the sampling devices and cross-contamination between samples. Accurate representation of the field conditions required immediate measurements of pH and Eh and the preservation of samples.

Sediment samples were collected with a stainless steel scoop and were stored in polyethylene bags. The Eh and pH of the sediment samples were measured before the bags were

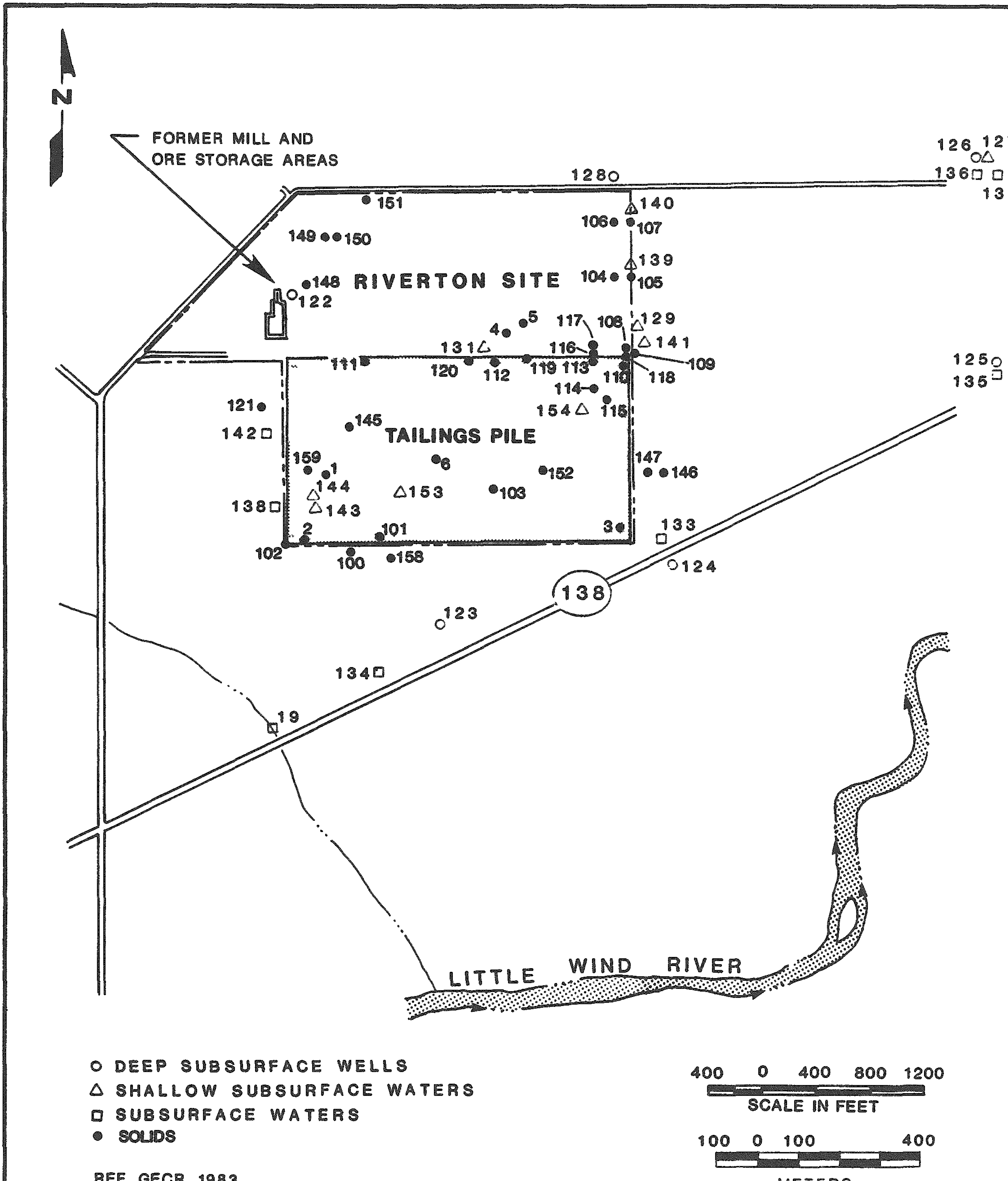


FIGURE C.2.2
GECR WELL LOCATIONS AND SURFACE WATER SAMPLES AT THE RIVERTON SITE

Table C.2.5 Descriptions of GECR Riverton sampling locations

Location or sample number	Area type[a]	Sample type[b]	Description
1	S	SF	Southwest corner of tailings
2	S	SF	Southwest corner of tailings
3	S	C	Southeast corner of tailings
4	A	SF	Sand from bank of ditch north of tailings
5	A	SF	Soils north of ditch north of tailings
6	S	C	Center of tailings
7	B	W,S	Ditch behind USGS gauging station 1.9 miles northeast of tailings
8	B	W	Ice from Beaver Creek 3.1 miles south of tailings
9	B	W,S	6.2 miles north of tailings on Haymaker Creek
10	B	W,S	Small, deep draw 5.6 miles northwest of tailings
11	B	W	4.3 miles north of tailings; 440 feet in depth
12	B	W,S	Ditch 5.6 miles north of tailings (ditch drains septic system)
13	B	W	5.6 miles north of tailings; 279 feet in depth
14	B	W	5.6 miles north of tailings; 98 feet in depth
15	B	W	Ice from Wind River 1.2 miles northeast of tailings
16	B	W	1.2 miles northeast of tailings; 328 feet in depth
17	B	C	Adjacent to Wind River 2.5 miles northwest of tailings
18	B	W,S	Wind River 2.5 miles northwest of tailings
19	A	W,S	Marshy area southwest of tailings adjacent to highway
20	B	W	Developed spring 2.2 miles west of tailings
21	B	W	2.2 miles west of tailings
22	B	W	Mouth of ditch entering Little Wind River 0.9 mile southwest of tailings
100	A	C	Outside of south tailings dike
101	S	C	South edge of tailings pile
102	A	C	Outside southwest corner of tailings dike
103	S	C	Near center of tailings
104	A	C	On western bank of ditch northeast of tailings, midway between tailings & road
105	A	C	Bottom of ditch northeast of tailings, midway between tailings and road
106	A	C	On western bank of ditch northeast of tailings, just south of road

Table C.2.5 Descriptions of GECR Riverton sampling locations (Continued)

Location or sample number	Area type[a]	Sample type[b]	Description
107	A	C	Bottom of ditch northeast of tailings, just south of road
108	A	C	North of ditch at northeast corner of tailings
109	A	C	Bottom of ditch off the northeast corner of tailings
110	A	C	Northeast corner of tailings
111	A	C	North edge of tailings
112	A	C	North edge of tailings
113	A	C	Northeast corner of tailings
114	S	C	Northeast corner of tailings
115	S	C	Northeast corner of tailings
116	A	C	Outside of the northeast corner of tailings
117	A	C	Southern bank of ditch outside northeast corner of tailings
118	A	C	Southern bank of ditch outside northeast corner of tailings
119	A	C	Between tailings and ditch north of tailings
120	A	C	Between tailings and ditch north of tailings
121	A	C	Outside west dike of tailings
122	A	W	Building in mill area
123	A	W	South of tailings and adjacent to highway; 328 feet in depth
124	A	W	Southeast of tailings on south side of highway; 361 feet in depth
125	A	W	0.2 mile east of tailings; 394 feet in depth
126	A	W	Northeast of tailings on north side of road; 318 feet in depth
127	A	W	Northeast of tailings on north side of road; 13 feet in depth
128	A	W	North of tailings on north side of road; 394 feet in depth
129	A	W	Borehole in ditch off northeast corner of tailings
131	A	W	Borehole in dry, sandy ditch just north of tailings
133	A	W	Swampy area just off southeast corner of tailings on north side of highway
134	A	W	Slew on north side of the road south of tailings
135	A	W	Gravel pit east of tailings
136	A	W	Ditch in a grove of trees northeast of tailings
137	A	W	Stagnant ditch near road northeast of tailings

Table C.2.5 Descriptions of GECR Riverton sampling locations (Concluded)

Location or sample number	Area type[a]	Sample type[b]	Description
138	A	W	Runoff at southwest corner of tailings
139	A	W	Borehole in ditch north of tailings
140	A	W	Borehole in ditch north of tailings
141	A	W	Borehole near ditch northeast of tailings
142	A	W	Small runoff pond adjacent to and west of tailings
143	S	W	Borehole in the southwest corner of tailings
144	S	W	Borehole in southwest corner of tailings
145	S	C	Borehole in northwest part of tailings
146	A	C	Adjacent to and east of tailings
147	A	C	Adjacent to and east of tailings
148	A	SF	Mill and ore storage areas
149	A	SF	Mill and ore storage areas
150	A	C	Mill and ore storage areas
151	A	C	Adjacent to and north of mill and ore storage areas
152	S	C	Cover-tailings interface in east part of tailings
153	S	W	Borehole in west-central part of tailings
154	S	W	Borehole in northeast corner of tailings
155	B	SF	0.7 mile southwest of tailings on the north side of road
156	B	SF	1.6 miles southwest of tailings on the northeast side of road intersection
157	B	SF	1.6 miles west of tailings taken on east side of road at intersection of irrigation ditches
158	A	C	South of and adjacent to tailings
159	S	C	West part of tailings
160	B	SF	4.2 miles north of tailings on north side of road
161	B	SF	4.0 miles north of tailings from cut at road
162	B	SF	Intersection 2.8 miles north of tailings
163	B	SF	High terrace 3.0 miles north of tailings

[a]S - source area; A - potentially contaminated area adjacent to source area; B - background area.

[b]W - water sample; S - sediment sample; C - core sample; SF - surface sample.

Ref. GECR, 1983.

sealed. The borehole sediments sampled in December, 1979, were drilled with an 18-inch split tube sampler (ASTM D1586) on a 1.5-inch outside diameter drill rod. The drill rod was driven into the soil with a sledge hammer. The split spoons were opened in the field, and the top 10 to 20 centimeters (cm) were discarded to prevent cross-contamination. Additional sediment samples were obtained from boreholes sampled in June, 1981, which were rotary drilled with a 4-inch outside diameter core sampler. The core was sampled at intervals where the color, moisture content, particle size, or mineralogy changed. The depth of the sample interval was recorded. A one to four, solids to water slurry was prepared from each solid sample, and pH and Eh were measured in the field or in a field laboratory nearby.

Water from within or below the tailings was sampled from piezometers and cased boreholes installed by LBL. Water was pumped from the hole through Tygon tubing into a glass flask with a hand-operated vacuum pump. The borehole water was collected in new polyethylene bottles after rinsing the bottles with the sample water. The bottles were completely filled to exclude air bubbles and sealed. The cations, chloride, and sulfate in the water were stabilized by filtering the sample through a 0.45-micrometer filter and acidifying with nitric acid to a pH less than 2.0.

Both Eh and pH were determined potentiometrically. A combination, platinum saturated, calomel electrode for the Eh measurements was calibrated in Zobell solution. A combination, glass saturated, calomel electrode for pH measurements was calibrated with standard buffer solutions of pH 4.0 and 7.0. The 1-liter sample collected for total gross alpha analysis was not filtered or acidified.

The following describes the procedures used by LBL for field installation of piezometers, suction water samplers, and tensiometers (LBL, 1984). Exploratory drilling was conducted at the Riverton site in June and July, 1981. Figure C.2.3 shows the locations of all LBL boreholes. Continuous 7.6-cm diameter Shelby tube samples were taken through the pile to the top of the alluvium. These holes were then reamed with a 14-cm rotary bit and extended into the underlying alluvium. There were some problems associated with bit penetration in the cobbles beneath the pile and erosion of the borehole by circulating drilling water. Despite these difficulties, casing with a 10-cm inside diameter was installed in RA-2 and RB-2 through the tailings but not into the cobbles, and RC-2 was cased to a depth of 3.9 meters below ground surface or 3.0 meters below the bottom of the pile. The rotary drilling resulted in a hole only slightly larger than the casing, and the tailings were allowed to collapse around the casing without introducing any backfill materials.

The second drilling and sampling program at Riverton took place in July, 1981. A 18.5-cm diameter auger was used to produce a hole only slightly larger than the

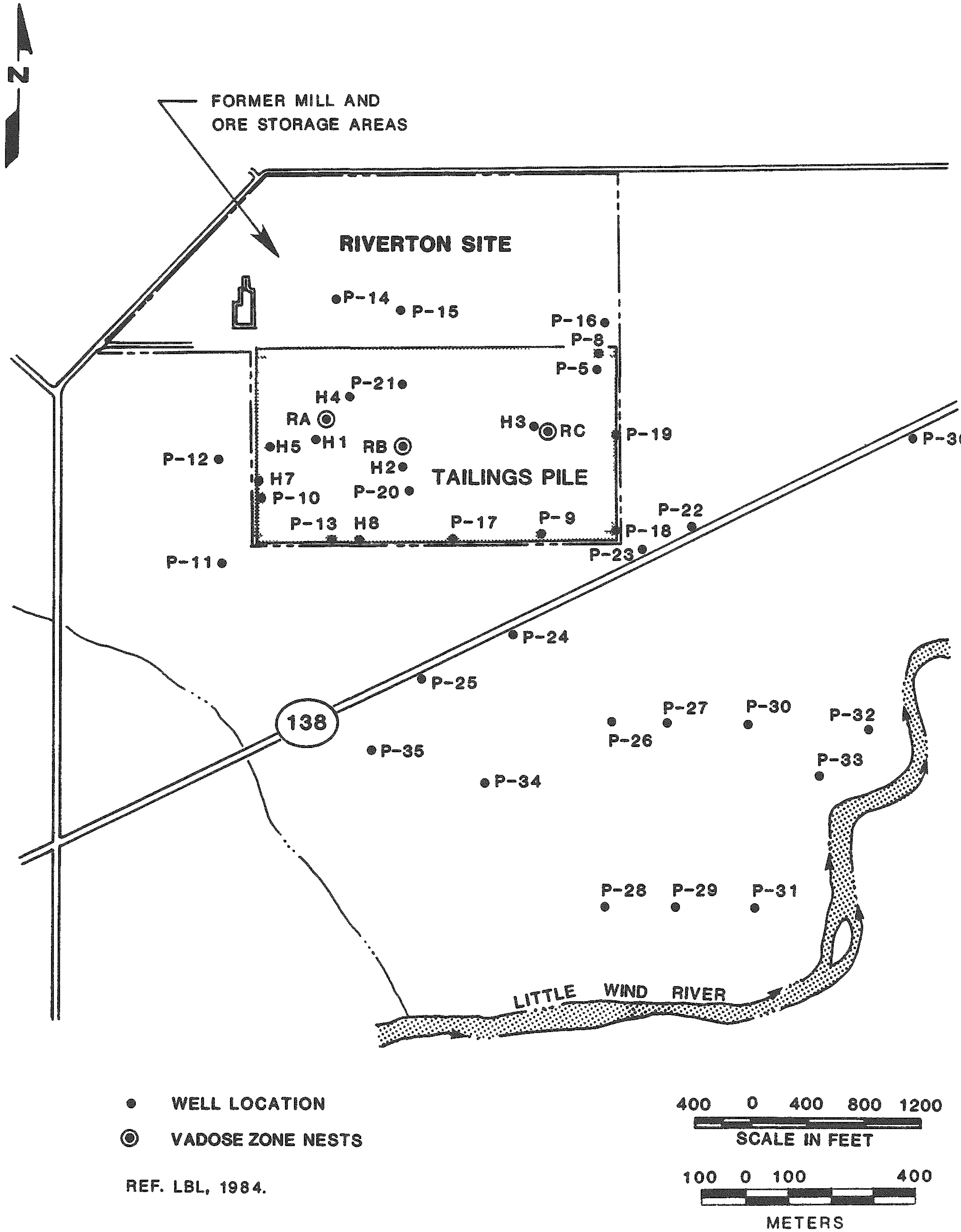


FIGURE C.2.3
LBL WELL LOCATIONS AT THE RIVERTON SITE

couplings on the 10-cm inside diameter casing. The annulus was kept to a minimum and was filled with washed 0.5-cm gravel. Boreholes RA-3, RB-3, and RC-3 were completed through the alluvium with this method. Continuous Shelby tube samples also were taken through the tailings in each of these boreholes before the auger drilling began.

Some of the Shelby tubes were examined with the high-resolution Ge-detector gamma-spectrometer system. The intensity of specific gamma lines provided information related directly to the abundance of particular radionuclides. The relative abundance of uranium-238 (U-238) and radium-226 (Ra-226) was determined for at least one position along each tube by placing the desired section of a tube against the relatively small detector in an unshielded counting geometry in a low background counting room. The lower 1 to 2 cm of materials were extracted from each of these Shelby tubes and then analyzed with the high resolution, Ge-detector gamma-spectrometer for a number of specific radionuclides, including those which are used as indicators for U-238 (thorium-234) and Ra-226 (lead-214 and/or -210).

Materials used to measure activity at the tailings-soil interface were removed from the tube starting at the lower end, working carefully with a narrow-blade spatula. Depth of excavation was registered along the outside of the tube and was never greater than required. Each freshly exposed face was carefully cleaned of loose debris before starting the next sampling. The empty tube section was removed with a pipe cutter after a 3- to 4-cm excavation depth.

Shelby tube samples also were used for laboratory determination of saturated hydraulic conductivity of the tailings. The tube was marked at 1.5 cm above and 1.5 cm below the depth of interest and then cut at the upper mark with a large tubing cutter while the upper section was supported. A thin metal sheet was placed in the cut and used to prevent spillage from the upper tube during its removal. The cut end of the upper tube was then sealed and stored. A labeled, tared sampling ring was centered on the cut upper surface and then driven into the tailings until the upper rims of the ring and Shelby tube were coplanar. The Shelby tube then was cut at the lower mark while the sample was supported, and a metal sheet was placed in the new cut after which the upper portion was removed while supported by the sheet. An annular space of the 3-cm section was then trimmed and stored in a sealed plastic bag that was labeled by location, depth, and date. In the laboratory, the sample surfaces were leveled, and the outer surface of the ring was wiped clean. After weighing, the sample was ready for saturation and measurement of saturated hydraulic conductivity.

Tempe pressure cells (SME #1400A) were modified to allow laboratory measurements of saturated hydraulic conductivity (K_s). The Shelby tube sample was placed in a modified Tempe cell with filter paper and screens at the exposed ends of the tailings. A tare weight of the permeameter was determined. One end-cap was connected to a water filled burette standpipe while the other end-cap was left to atmospheric pressure and placed over a beaker to receive effluent. A minimum of about three pore volumes of water was permeated through the sample before any K_s measurements were made. This brought the sample as close to saturation as is practically achievable in a laboratory.

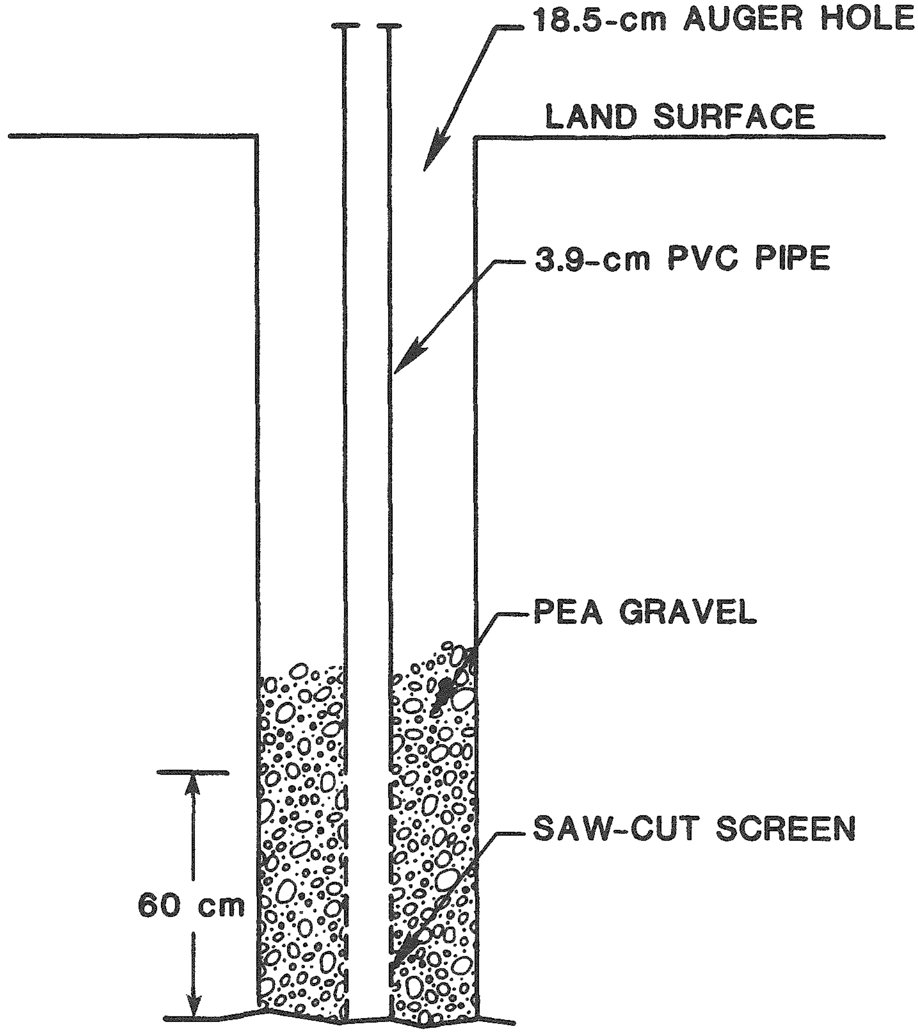
The "falling-head" method was used to obtain a measurement for K_s. After measurement of K_s, the standpipe was disconnected and the saturated permeameter was weighed. The sample was then allowed to desaturate slightly to provide cohesion during preparations for measurements. All effluents were stored temporarily in a 5-gallon carboy.

Measurement of the volumetric water content ratio (water volume V_w per unit bulk volume V_b) as a function of matric suction head was performed in both Tempe cells, as well as in a pressure plate chamber (SME #1500). Drainage curves were measured over a suction range of at least zero to minus 6 meters of water. While the two devices operate under the same principle, there were slight differences in experimental procedures for each method. For suctions larger than 1 bar, the pressure plate extraction method was used.

Piezometers P-11 through P-16 were installed in the alluvium below and around the pile during the second drilling program by using the 18.5-cm hollow stem augers and inserting a 3.9-cm polyvinyl chloride (PVC) pipe down through the hollow stem. The lower 60 cm of pipe was slotted with a hand saw to allow water entry (Figure C.2.4). Piezometers P-1 through P-7 had been previously installed in June using a drive point technique. Piezometers P-8 through P-10 were installed in June by digging holes in the alluvium and installing slotted PVC standpipes. In September, piezometers P-17 through P-21 were installed using hollow stem augers. The locations of the piezometers are shown on Figure C.2.3.

Tensiometers were purchased from Soil Moisture Equipment Corporation (SME) and various lengths (0.5 to 5 feet) of SME Model #2725 ARL tensiometers were used. These tensiometers came with zero to 100 centibar (cb) suction Bourdon gages with adjustable zeroing. To monitor hydraulic potentials at depths greater than 5 feet, extension sections of 5-foot lengths (SME Model #2720 L60) were attached to shorter tensiometers. After assembling the tensiometers and adjusting the initial reading, the tensiometers were filled with distilled water and were ready for installation.

Three types of suction water samplers (SWS) were used to obtain water quality samples from the partially saturated tailings. For sampling at shallow depths of 6 feet or



REF. LBL, 1984.

FIGURE C.2.4
TYPICAL LBL PIEZOMETER

less, SME Model #1900 SWSs were used. At greater depths, two other SWS types were used. One was the pressure vacuum SWS by SME (Model #1920). The other type was a modification of the SME Model #1900. In this modification, extra lengths of PVC pipe were joined to SME Model #1900 samplers to allow use at greater depths. All SWS tubes were rinsed, and the ceramic tips were leached with distilled water prior to installation in the tailings.

The following describes the collection procedures used by LBL to obtain precipitation, piezometer, suction water, and gas samples (LBL, 1984). A precipitation collector was installed at Riverton to obtain the tritium, deuterium, and oxygen-18 contents of the recharge water. The precipitation was collected in double-ply plastic bags suspended in an 18-inch vertical standpipe. A constriction in the lower third of the bag allowed a minimum of atmospheric interaction once the water had flowed down through the narrow orifice. Two separate precipitation samples were collected.

Water was extracted from piezometers completed in the unconfined aquifer using a peristaltic pump. To ensure a representative sample of ground water, at least three well bore volumes were pumped prior to sample collection. Specific conductance was continually monitored until a constant reading was obtained prior to collection. Samples were then immediately filtered through a 0.45-micrometer acetate filter and collected in two 16-ounce Nalgene lock top bottles. The samples for anion analysis were preserved. The isotope and trace metal samples were acidified to a pH of 1.0 using Ultrex grade nitric acid. Temperature, pH, Eh, and dissolved oxygen were measured in unfiltered samples at the well site. Alkalinity titrations were performed on filtered, unacidified samples within 2 hours of collection.

Water samples from the three nests of SWSs in the tailings pile were collected following 24 to 48 hours of applied vacuum using a generator-powered pump. Water was sampled by lowering a vacuum-driven syringe to the base of the porous cups and extracting the fluid contents. These pore fluids were then forced through 0.45-micrometer acetate filters fitted directly on the end of the luger-tipped syringe. Samples were collected from the deeper SWSs by applying a vacuum to one of the exit lines and flushing the sample into an aspirator bottle. Both acidified and unacidified samples were collected, and field pH and Eh were measured.

Deuterium and oxygen-18 samples from shallow wells and SWSs were collected in 2-ounce glass bottles. Tritium samples were collected in 500-milliliter glass bottles. The bottles were flushed with several volumes of water before the final aliquots were collected. The sample bottles were filled completely to preclude potential contamination of isotopic fractions with a gaseous phase. One-gallon samples from selected shallow wells were collected for sulfur-34 analysis. Sulfate was then precipitated in the field using one-normal barium chloride.

Gas samples from several piezometers completed within the partially saturated tailings pile were collected by pumping the wells using a peristaltic pump to inflate 1-liter Teflon gas sampling bags. Approximately 5 liters of gas, or two to three pore volumes, were extracted prior to gas collection.

The following describes the procedures used by CSU for the installation of test borings and for in-situ sampling. Six borings were completed in 1979, and 15 additional borings were made in 1981. The locations of the seven borings where piezometers were installed are shown on Figure C.2.5. The borings were advanced through the tailings and into the cobbly foundation materials. A 4-inch hollow stem auger was used, and samples were retrieved either as split spoon samples (ASTM D1586), Shelby tube samples (ASTM C1587), or California tube samples. The California tube sampler consisted of a driven sample spoon containing 4-inch long brass tube inserts which were 2 inches in diameter. Soil samples recovered from standard split spoons were highly disturbed with respect to in-situ soil structure. California tube samples were less disturbed and were better samples for density and water content evaluation. Bulk samples were also taken for laboratory analyses requiring larger amounts of soil. The PVC standpipe piezometers were installed in seven CSU boreholes for subsequent water level and water quality monitoring (CSU, 1983a). Logs for the CSU boreholes are on file in the UMTRA Project Office. Although ground-water samples were collected and analyzed by CSU, the sampling procedures have not been documented.

Capillary retention curves, or pressure-saturation curves, were constructed with data obtained from intact California tube samples using a porous membrane with an air entry pressure of 6 pounds per square inch (psi) on the bottom of the sample. For these tests, the axis translation technique was used to control the capillary pressure. Capillary pressure is the difference between the air pressure and pore water pressure. Using the axis translation method, pore water pressure was maintained at a value of zero while the air pressure was increased to a greater value, thus simulating capillary pressure by the value of air pressure applied (CSU, 1983a).

The following describes the procedures used by FBDU (1981) for borehole drilling, double packer tests in the cored bedrock, radiometric measurements, and pump testing. Three holes were drilled through the tailings to collect geologic and hydrologic data. A fourth hole was drilled north of the tailings pile to obtain background information but was abandoned because of drilling difficulties. Upon abandonment, the hole was backfilled with cuttings from the hole. The locations of the three boreholes are shown in Figure C.2.6.

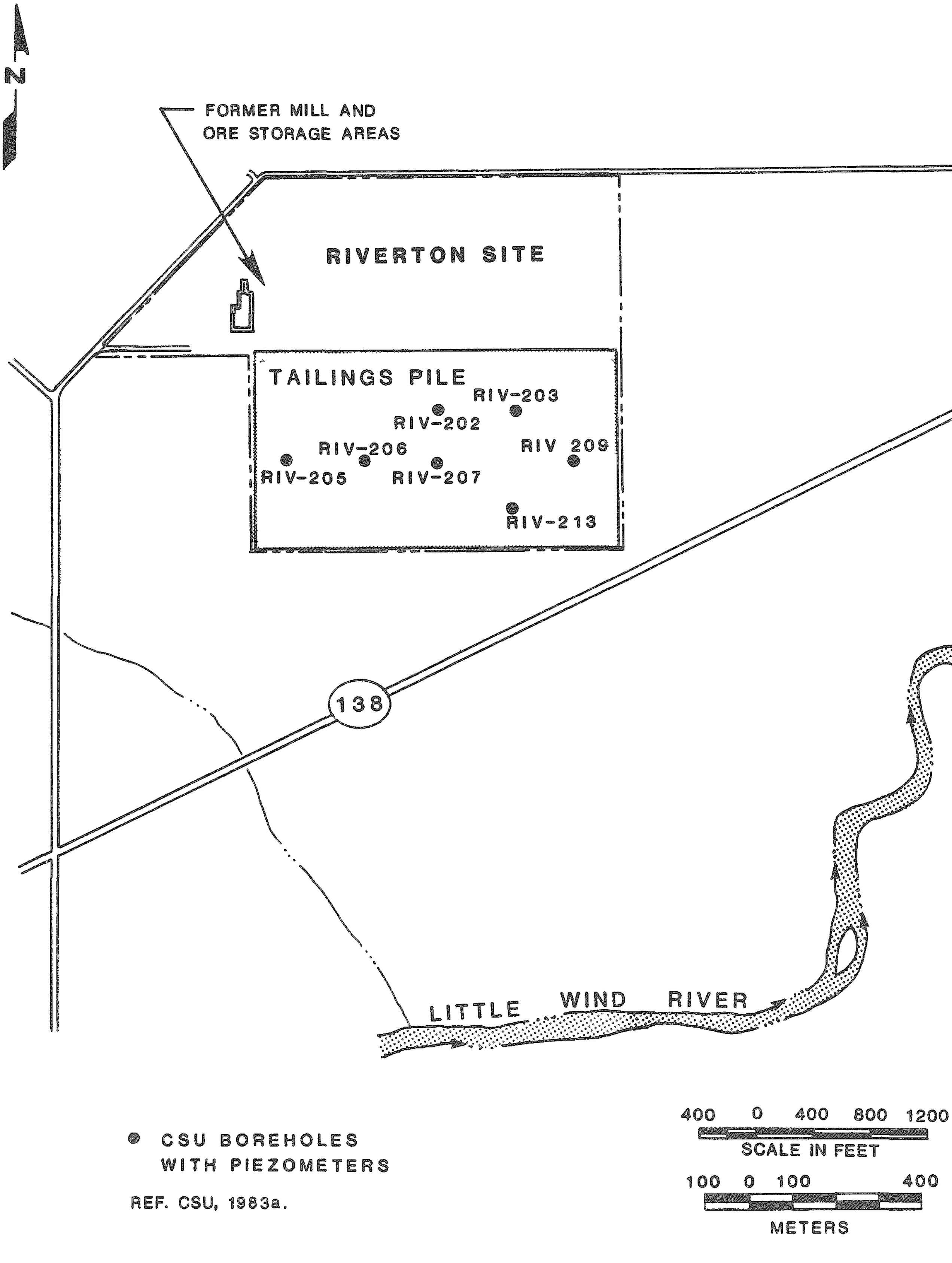


FIGURE C.2.5
LOCATIONS OF CSU BOREHOLES WITH PIEZOMETERS AT THE RIVERTON SITE

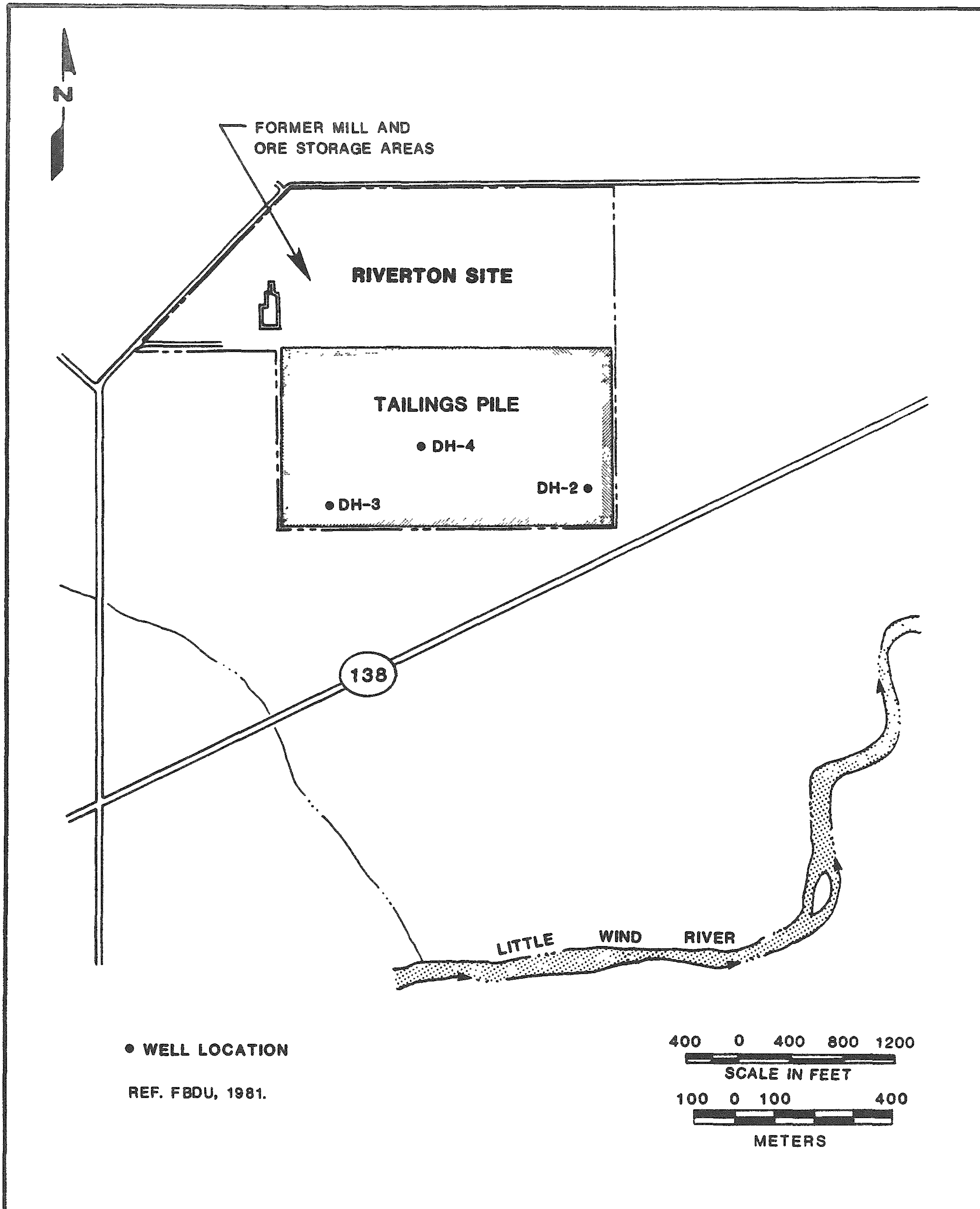


FIGURE C.2.6
FBDU WELL LOCATIONS AT THE RIVERTON SITE

Split spoon samples were obtained at 5-foot intervals from the holes drilled through the tailings. Each hole was advanced during sampling with an auger. Upon reaching refusal with the auger rig, the holes were advanced with a 10-inch tri-cone bit to bedrock, using a biodegradable guar-based drilling fluid to maintain hole integrity. Steel casing of 8-inch diameter then was set to bedrock, and the hole was cleaned to bedrock inside the steel casing with a 7.75-inch tri-cone bit. Radioactivity profiles were measured in these holes with a collimated Geiger Mueller tube. Soil samples were also taken from selected holes for radiometric analyses.

Cores of the bedrock were obtained from each hole with an NX core barrel to a depth of at least 20 feet below the alluvium-bedrock interface. After coring, double packer hydraulic conductivity tests were conducted at selected intervals in the cored section of the holes. Water used for the packer tests was obtained from a deep well completed in the Wind River Formation at the site.

Following completion of the packer tests, the bedrock was reamed a short distance with a 6.75-inch tri-cone bit, and the holes were completed as monitoring wells. Typical well completion details are given in Figure C.2.7. Each well was constructed using 4-inch diameter acrylonitrile butadiene styrene (ABS) casing and a 4-inch diameter, continuous-slot well screen (0.050-inch aperature size). The annulus between the borehole wall and the casing or screen was selectively backfilled with 4- to 8-mesh gravel, bentonite, and cement following placement of the casing. Steel surface casing and a cap were provided to protect against unauthorized intrusion.

After well completion, each well was developed by pumping with a submersible pump to correct any damage to or clogging of the water-bearing sands and gravels that occurred as a side effect of drilling. Pumping continued until the water obtained from each hole was clear, usually for a period of 10 minutes.

As an aid in determining the hydraulic characteristics of the alluvial aquifer, a 7-day pumping test was conducted by Hydro Geo Chem, Inc., in well DH-4 at a constant rate of 0.88 gallon per minute. Drawdown was measured in six observation wells within a 50-foot radius of the pumping well. No well completion records or geologic logs are available for the locations shown in Figure C.2.6.

The following describes the procedures used by the DOE for rock coring, well installation, pump testing, slug testing, and ground-water sampling. The DOE fieldwork was performed during two separate drilling programs. The first drilling site was several hundred feet north of the northern edge of the tailings between the pile and the former

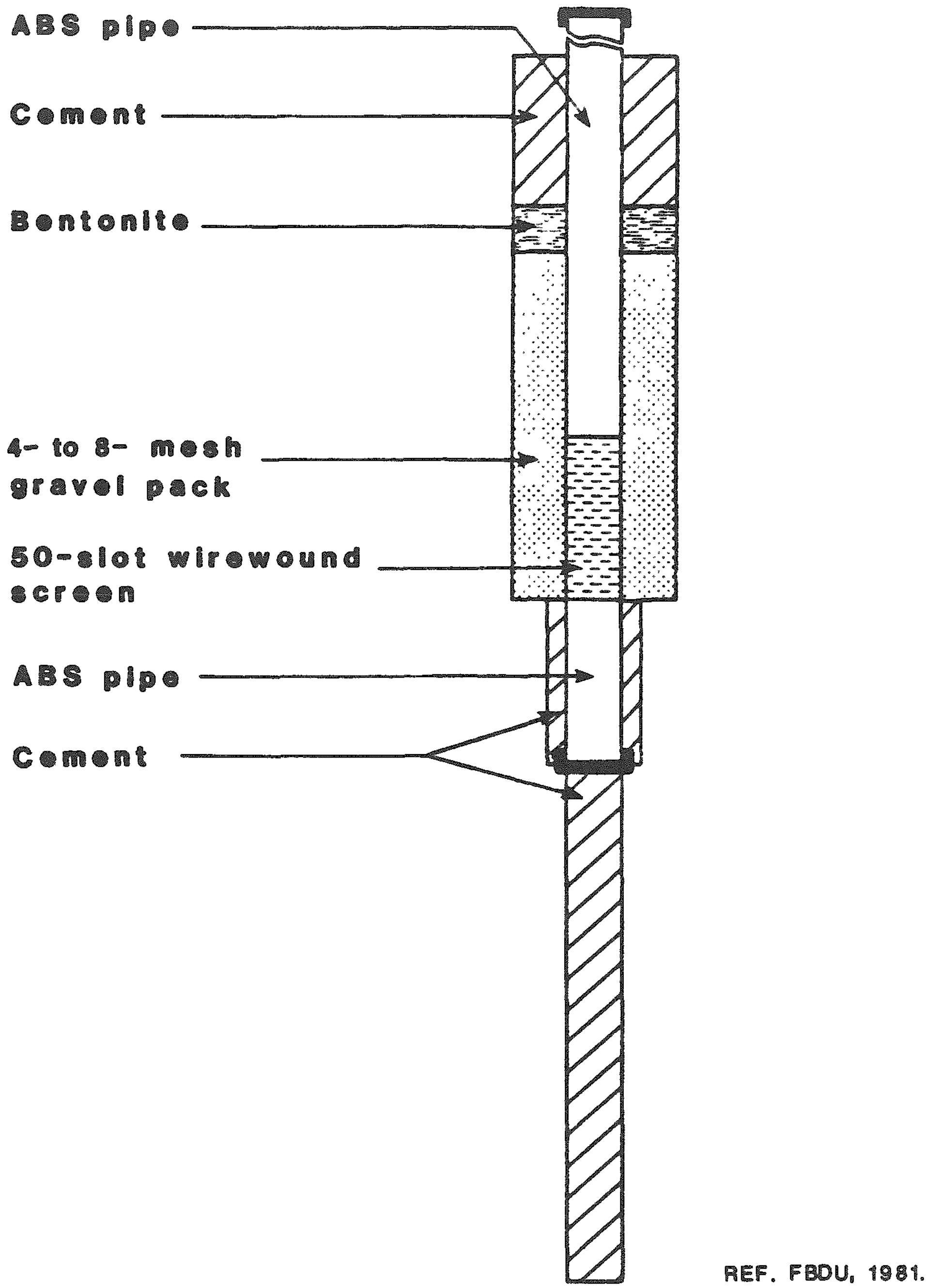


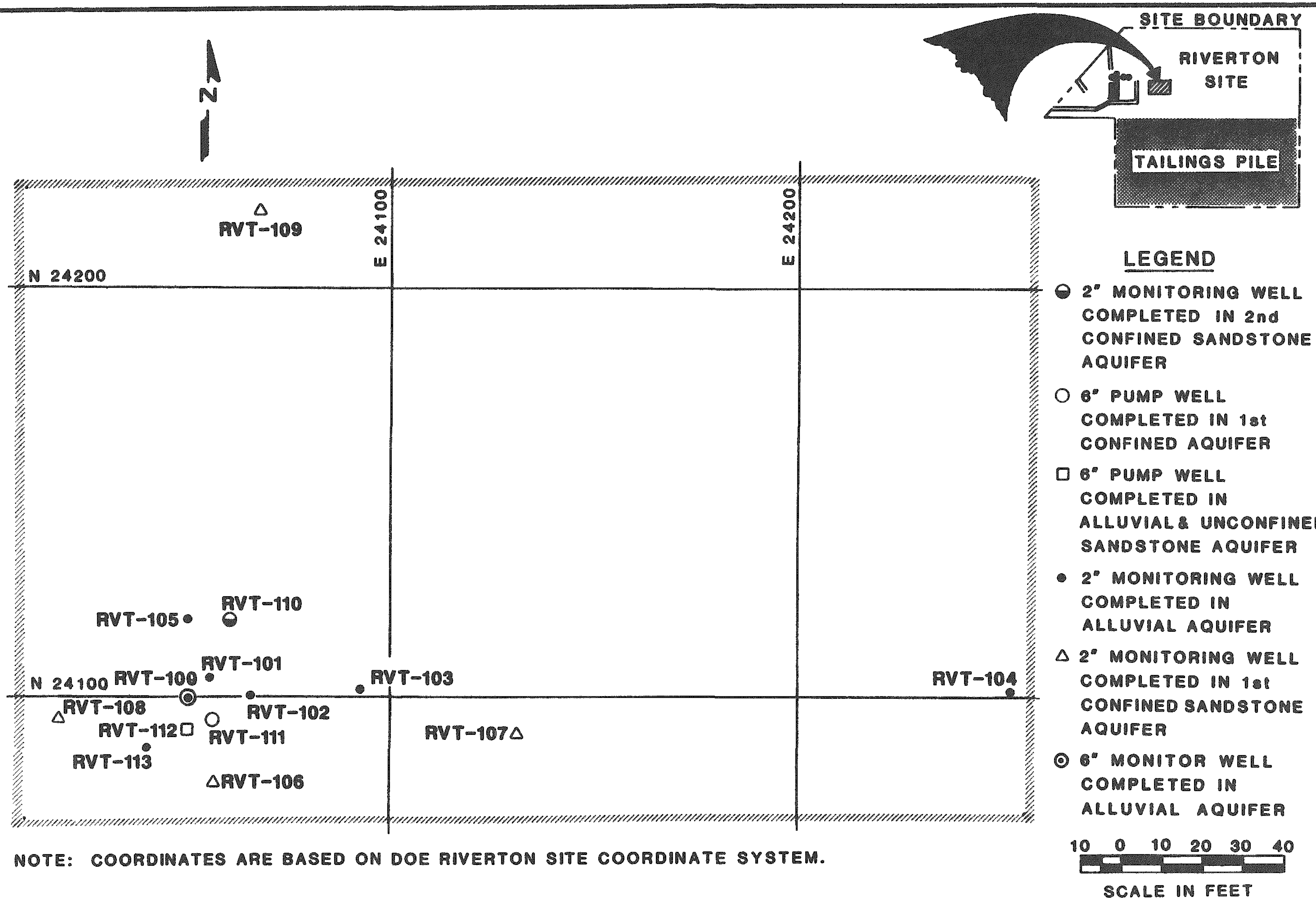
FIGURE C.2.7
TYPICAL FBDU WELL COMPLETION DIAGRAM

ore storage area (Figure C.2.8). Data obtained from fourteen wells at this site included static water levels, water quality samples, geologic logs and cores, and drawdown measurements obtained during two pump tests. In addition, three cores were drilled at this site into bedrock to depths of 65 to 100 feet below the land surface using an NX core barrel. These cores were inspected visually in the field for stratigraphy and degree of saturation, stored in wooden boxes in 10-foot sections, and shipped to Albuquerque, New Mexico, for archiving.

Table C.2.6 lists surface elevations, diameters, depths, screened intervals, and zones of completion for each of the 14 wells. All wells which were constructed for purposes of monitoring drawdown during pump testing consisted of 2-inch, schedule 40 PVC pipe centered in a 6-inch borehole. The casing was threaded and flush-jointed. Two feet of blank casing extending from the bottom of the hole, followed by a slotted well screen 5 feet in length, were installed using devices to assure that they were centered in the hole. The slotted well screen had three rows of slots cut on 120-degree centers, with 0.01-inch wide slots spaced 0.25 inch apart. Some of the borings were partially grouted and redrilled in order to place the well screen within the unit chosen to be monitored. Backfill material for the annular space extending from the bottom of the well to approximately 2 feet above the screened interval consisted of a graded sand that met ASTM C33 requirements for fine aggregate. A 2-foot bentonite seal comprised of bentonite pellets was installed directly above the graded sand backfill. Following installation of the seal, the annular space then was grouted to the surface. The surface grout subsequently was allowed to settle for 24 hours, with additional grout added to bring the grout level to the ground surface.

Observation wells were developed by pumping, bailing, or airlifting until clear water was obtained. The top of each well was then fitted with a flush-jointed threaded cap and protected with a standard 6-inch inside diameter steel pipe 4 feet in length and a locking cap. Figure C.2.9 shows a schematic representation of a typical observation well.

Pump wells were constructed by installing a 6-inch inside diameter standpipe and well screen in a 9-inch borehole. A 6-inch, schedule 40 PVC pipe consisting of 2 feet of blank casing followed by a minimum of 10 feet of slotted screen was centered in the standpipe. The well screen had a slot size of 0.015 inch with an equivalent intake area of at least 10 square inches per foot of screen. Backfill material consisted of well graded sand which fulfilled ASTM C33 fine aggregate gradation standards. Each pump well was protected with a 10-inch inside diameter steel pipe 4 feet in length and a locking cap. A typical pump well is schematically shown in Figure C.2.10. Geologic logs for all 14 wells are on file at the UMTRA Project Office.



NOTE: COORDINATES ARE BASED ON DOE RIVERTON SITE COORDINATE SYSTEM.

FIGURE C.2.8
FIRST DOE DRILLING PROGRAM WELL LOCATIONS, RIVERTON SITE

Table C.2.6 Well information for first DOE drilling program, Riverton site

Well identification	Surface elevation[a]	Top of casing[a]	Well diameter (inches)	Screened interval[a]	Zone of completion	Total depth (feet)
RVT-100	4,946.1	4,946.2	6.0	4,940.1 - 4,932.1	Alluvium	17.0
RVT-101	4,946.2	4,946.6	2.0	4,935.2 - 4,930.2	Alluvium	17.1
RVT-102	4,946.3	4,946.7	2.0	4,936.3 - 4,931.3	Alluvium	17.0
RVT-103	4,946.0	4,946.4	2.0	4,936.0 - 4,931.0	Alluvium	17.0
RVT-104	4,945.3	4,945.9	2.0	4,936.3 - 4,931.3	Alluvium	15.5
RVT-105	4,946.3	4,946.8	2.0	4,936.3 - 4,931.3	Alluvium	17.5
RVT-106	4,946.2	4,945.9	2.0	4,897.2 - 4,892.2	First confined sandstone	56.0
RVT-107	4,946.0	4,946.0	2.0	4,897.0 - 4,892.5	First confined sandstone	67.0
RVT-108	4,946.2	4,946.0	2.0	4,897.2 - 4,892.2	First confined sandstone	56.0
RVT-109	4,945.8	4,946.1	2.0	4,896.8 - 4,891.8	First confined sandstone	58.0
RVT-110	4,946.2	4,946.4	2.0	4,885.2 - 4,880.2	Second confined sandstone	72.0
RVT-111	4,946.1	4,946.9	6.0	4,907.1 - 4,892.1	First confined sandstone	56.0
RVT-112	4,946.2	4,947.3	6.0	4,937.7 - 4,917.7	Alluvium and unconfined sandstone	32.0
RVT-113	4,946.2	4,946.4	2.0	4,925.2 - 4,920.2	First unconfined sandstone[b]	34.0

[a]Feet above mean sea level.
[b]This well has been completed so that it is hydraulically connected with the overlying alluvium.

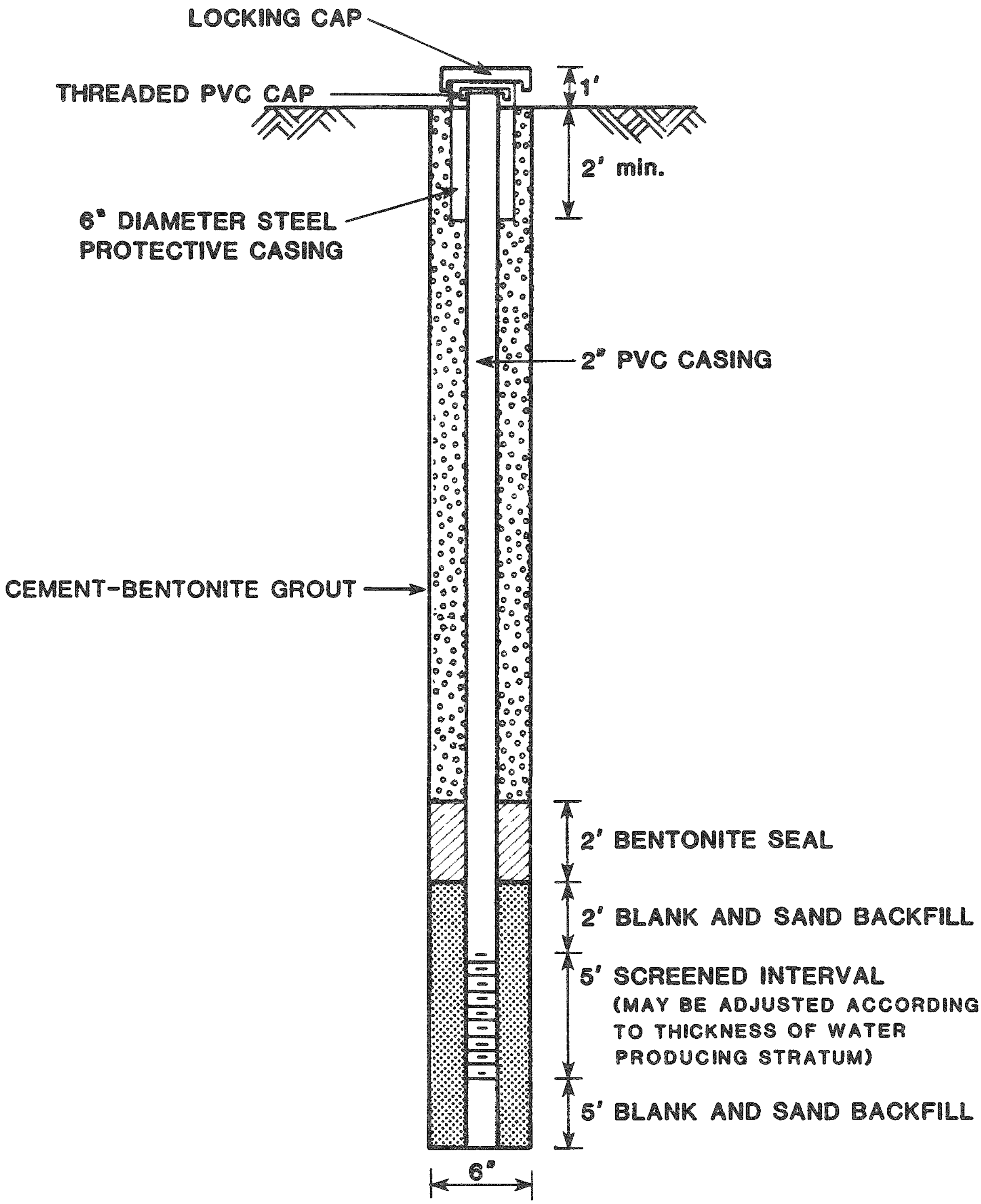


FIGURE C.2.9
TYPICAL DOE OBSERVATION WELL

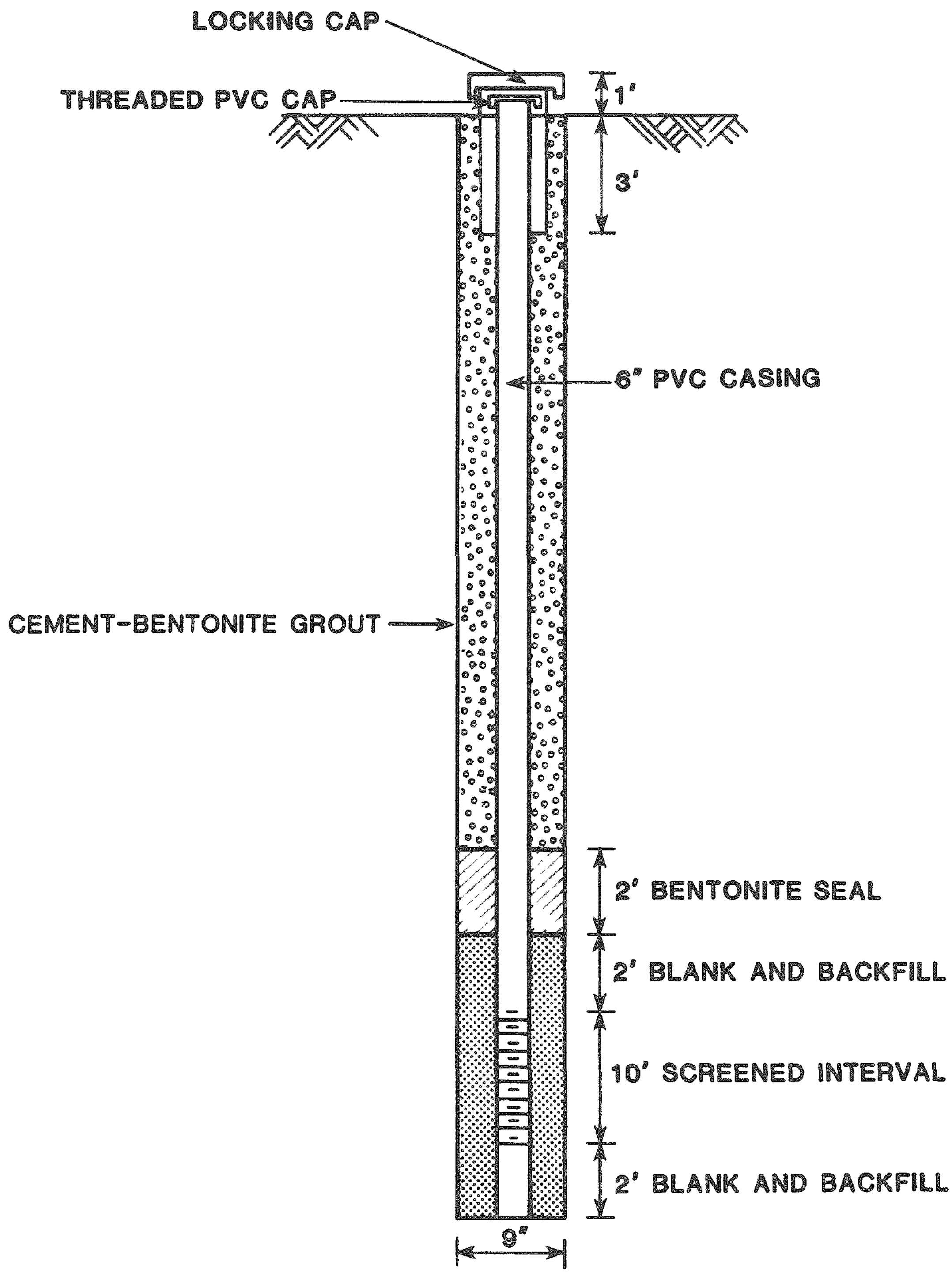


FIGURE C.2.10
TYPICAL DOE PUMP WELL

Two 24-hour pump tests were conducted, one on well RVT-112 which was completed through the entire saturated thickness of the unconfined aquifer and the other on well RVT-111 which was completed through the entire saturated thickness of the first confined layer of sandstone. A submersible pump was used to withdraw sufficient water from each well to achieve measurable drawdown without causing the water level to drop below the well screen. The discharge rate was metered continuously throughout the test. All pumped water was discharged to the ditch surrounding the pile. Water levels were measured prior to, during, and after the tests with water level sounders and periodically checked with steel tapes and blue chalk. During both tests, water samples were collected from the pump well near the beginning, middle, and end of the pumping period.

Slug tests were performed on three of the wells. The procedures used were:

- Measure static water level in the test well.
- Submerge a metal slug of known volume into the well and measure the water level.
- Allow the water level to return to, or close to, the static water level.
- Quickly remove the slug and measure and record the water level every 0.5 minute until complete recovery or close to complete recovery is achieved.

Ground-water samples for water quality analysis were withdrawn with a peristaltic pump and preserved in accordance with EPA recommendations (EPA, 1983). The temperature, pH, alkalinity, and specific conductance of each sample were measured in the field. Field measurements and sample withdrawals were performed in accordance with procedures developed by the DOE. The procedures and records of field sampling procedures for each sample collected are available at the UMTRA Project Office.

The second DOE drilling program was initiated to obtain additional information regarding stratigraphy, potential communication between the confined and unconfined aquifers, the location of the unconfined ground-water divide between the Wind and Little Wind Rivers, and potential contamination north of the tailings site and south of the Little Wind River. Wells that were drilled approximately 2,000 feet southeast of the southeastern corner of the pile and 1,500 feet east of the pile were geologically or geophysically logged and sampled for water quality. In addition, a sampling well was completed in the alluvium south of the Little Wind River. A line of six wells was installed along the abandoned Chicago and North Western Railroad tracks north of the site. Surface elevations, diameters, depths, screened intervals, and zones of completion for the 15 wells are listed in Table C.2.7. Well locations are shown in Figures C.2.11 and C.2.12.

All wells were constructed according to the same procedures used to construct the DOE wells north of the pile. However, four wells located southeast and east of the site were drilled to 200-foot depths in order to obtain a deep core and both geologic and geophysical logs for construction of a stratigraphic profile beneath the site. The borings for these wells were first advanced to the top of bedrock; surface casing was then set and left open. One of the borings was cored to a 200-foot depth, and the remaining three were advanced to 200 feet without coring. The entire bedrock length of each of the four boreholes was then geophysically logged using resistivity, spontaneous potential, natural gamma, gamma gamma, neutron, density, and caliper log techniques. Following the logging procedure, the boreholes were then grouted and redrilled to the desired completion level.

Due to low yield in the pump wells that were completed in the first and the second confined sandstones, pump tests were not conducted at the new drilling site southeast of the pile. A bailer test was performed at a well completed in the shale aquitard for purposes of defining horizontal hydraulic conductivity of the shale. The bailer test procedures used were:

- Measure static water level in the test well.
- Rapidly remove a known volume of water from the well.
- Periodically record the water level until complete recovery or close to complete recovery is achieved.

Packer tests also were performed at the other well completed in the shale aquitard. A double packer system was used to pressure test from a depth of 20 feet to 160 feet using test intervals of 5.92 feet. Air pressures ranged from 110 to 162 psi, and water pressure varied from 2 to 72 psi during the testing procedures.

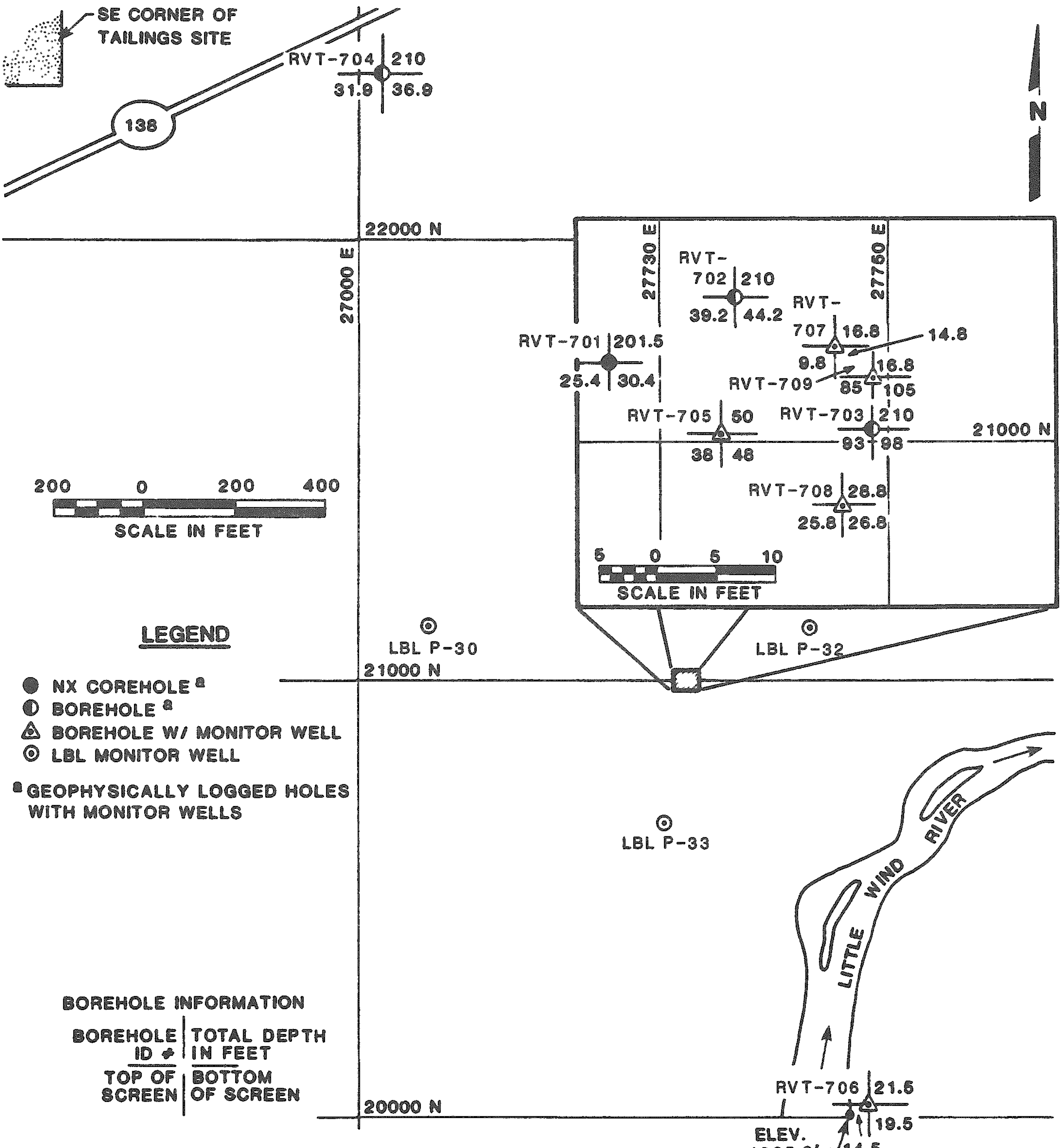
Dry Cheyenne alternate disposal site

Five wells have been drilled in the general vicinity of the Dry Cheyenne site. One well is 1 mile south of the site, and the other four wells are 5 to 8 miles southeast and southwest of the site. The well completion and sampling procedures used at these wells are not known; however, drilling logs are available for four of the wells at the UMTRA Project Office, and limited water quality analyses are available for three of the wells (Kelly, 1984; Packer, 1984).

Table C.2.7 Well information for second DOE drilling program, Riverton site

Well ID	Surface elevation[a]	Top of casing[a]	Well diameter (inches)	Screened interval[a]	Zone of completion	Total depth (feet)
RVT-701	4,930.2	4,930.3	2.0	4,904.9 - 4,899.9	Aquitard below unconfined aquifer	32.3
RVT-702	4,930.2	4,930.7	2.0	4,891.5 - 4,886.5	1st confined sandstone	53.0
RVT-703	4,930.2	4,930.6	2.0	4,837.6 - 4,832.6	2nd confined sandstone	99.6
RVT-704	4,935.1	4,935.6	2.0	4,903.7 - 4,898.7	1st confined sandstone	39.0
RVT-705	4,930.1	4,930.7	6.0	4,892.7 - 4,882.7	1st confined sandstone	49.4
RVT-706	4,931.1	4,931.6	2.0	4,917.1 - 4,912.1	Unconfined aquifer	21.5
RVT-707	4,930.4	4,930.0	2.0	4,920.6 - 4,915.6	Unconfined aquifer	16.7
RVT-708	4,930.3	4,930.6	2.0	4,904.8 - 4,903.8	Aquitard below unconfined aquifer	28.3
RVT-709	4,930.2	4,930.7	6.0	4,845.7 - 4,825.7	2nd confined sandstone	111.0
RVT-710	4,947.2	4,947.4	2.0	4,936.2 - 4,931.2	Unconfined aquifer	20.0
RVT-711	4,943.5	4,943.9	2.0	4,933.1 - 4,928.1	Unconfined aquifer	21.5
RVT-712	4,943.5	4,944.2	2.0	4,933.6 - 4,928.6	Unconfined aquifer	19.5
RVT-713	4,941.6	4,942.2	2.0	4,931.9 - 4,926.9	Unconfined aquifer	16.5
RVT-714	4,941.2	4,941.7	2.0	4,930.2 - 4,925.2	Unconfined aquifer	18.0
RVT-715	4,938.5	4,939.0	2.0	4,927.0 - 4,922.0	Unconfined aquifer	18.5

[a]Feet above mean sea level.



NOTE: ALL WELLS SHOWN ARE DOE EXCEPT WHERE INDICATED.

FIGURE C.2.11

SECOND DOE DRILLING PROGRAM WELL LOCATIONS SOUTH AND EAST OF THE RIVERTON SITE

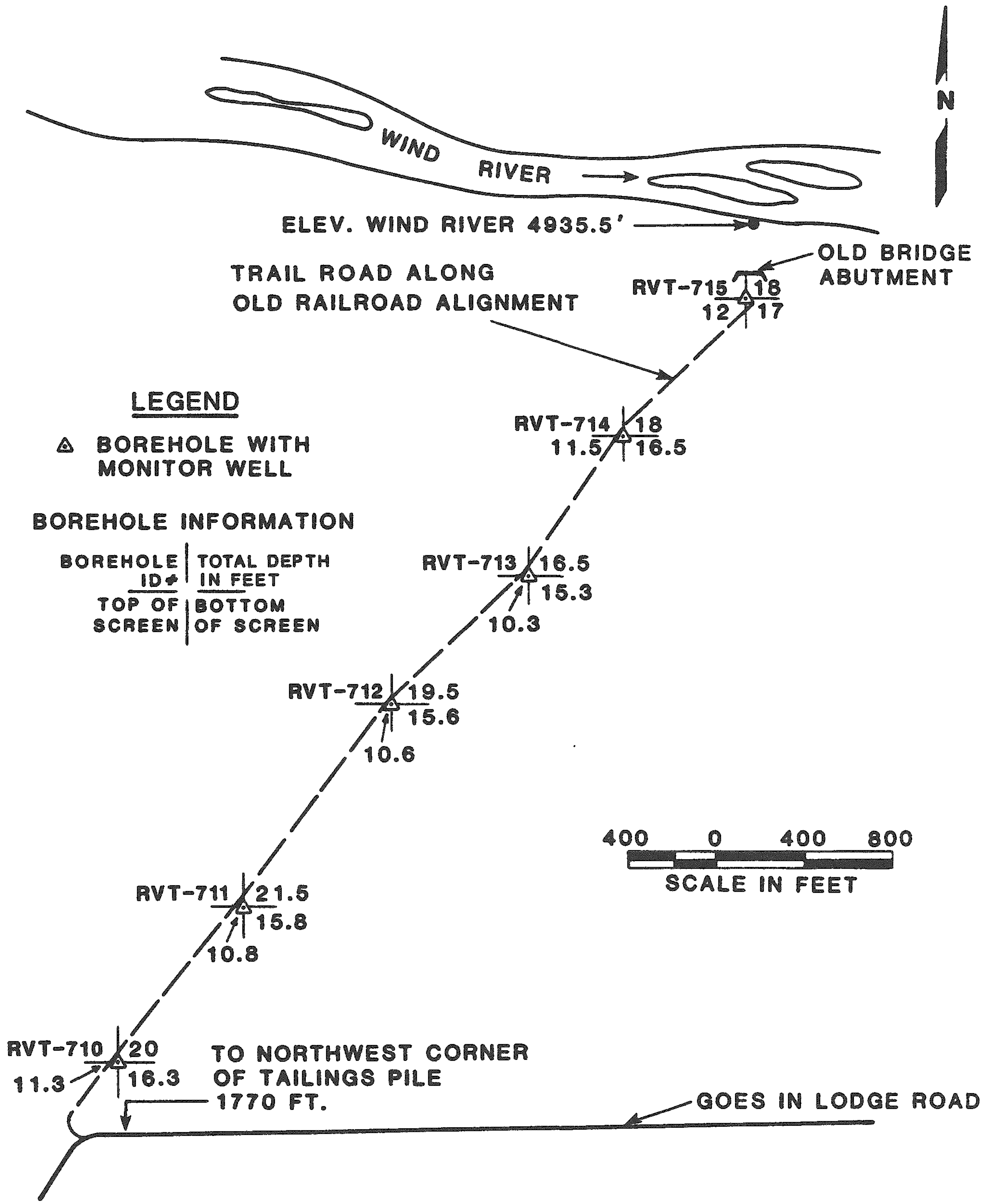


FIGURE C.2.12
SECOND DOE DRILLING PROGRAM WELL LOCATIONS NORTH OF THE RIVERTON SITE

Borrow sites

No hydrologic data were collected at the Little Wind borrow site or borrow sites 2 and 10. Some geochemical data were obtained in the vicinity of borrow site 2 by GECR researchers. Borings and test pits were completed at borrow site 10 to collect geologic data, and the Wyoming Highway Department collected geologic data at the Boulder Flats borrow site. The procedures used and the data collected are on file in the UMTRA Project Office.

C.2.4 DATA SUMMARY

This section summarizes the data collected by the organizations involved in hydrologic investigations at Riverton, Wyoming. Table C.2.8 summarizes the well designations, approximate depths, and locations for each research organization's boreholes at the Riverton site. As site investigations progressed, there was considerable interchange and refinement of collected data in order to accurately evaluate present ground-water characteristics and to model projected future impacts to the ground-water regime.

C.2.4.1 Geology

Riverton tailings site

The Riverton tailings site is on the floodplain bounded on the north by the Wind River and on the south by the Little Wind River. The tailings consist of coarse and finely ground sands and slimes. Although the pile is principally comprised of acid tailings, some carbonate tailings appear to exist toward the east end in a layer near the base of the tailings (GECR, 1983). The carbonate tailings are characterized by the same sands and slimes consistency as the acid tailings. Floodplain deposits consist of a few feet of soil and approximately 15 feet or 4.5 meters of coarse alluvium which, in turn, is underlain by the Wind River Formation. Terrace deposits do not underlie the site but are exposed at higher elevations nearby.

The Wind River Formation of the lower Eocene age underlies all of the Riverton area to a probable depth of 2,000 feet (610 meters). This sedimentary formation consists of a sequence of lenticular, interbedded sandstones, siltstones, and shales with minor amounts of bentonite, tuff, and limestone. The beds are nearly horizontal beneath the site (FBDU, 1981). Tributaries of the Wind River are eroding the Wind River Formation. This formation is uranium bearing in some places and may contribute to the background radiation in the vicinity of the pile (GECR, 1983). A simplified regional stratigraphic column is given in Figure C.2.13.

Directly beneath the tailings pile, borings show a discontinuous layer of foundation materials consisting of

Table C.2.8 Well summary for the Riverton site

Research organization	GECR	LBL	CSU	FBDU	DOE
Study purpose	Hydrogeochemical characterization and chemical transport mechanisms	Contaminant plume definition; geochemical and hydrodynamic modeling	Geotechnical investigation of tailings pile; chemical transport mechanisms	Engineering assessment and draft environmental assessment (EA); hydraulic testing	Plume characterization; aquifer hydraulics
Well locations	No wells constructed	On tailings pile and downgradient of tailings pile to the Little Wind River (Figure C.2.3)	Borings at 700-foot centers on the tailings pile; some piezometers installed (Figure C.2.5)	On tailings pile (Figure C.2.6)	Tailings site (Figure C.2.8); northwest and southeast of tailings pile (Figures C.2.11 and C.2.12)
Approximate depth	No wells constructed	4 to 26 feet	4.5 to 19 feet	Drilled to 45 feet; completed at 20 to 27 feet	Shallow wells at 15 to 20 feet; deeper wells at 55 to 110 feet
Well designations	Sampled existing on- and off-site wells as designated in Figure C.2.2	P series: P-1 through -36 Tensiometer and suction water sampling nests: RA, RB, and RC	RIV series: RIV-200, -203, -205, -206, -207, -209, -213	DH series: DH-2, -3, -4	RVT series: RVT-100 through -113 and RVT-700 through -715
Data collected	Water quality from background, on and adjacent to, and tailings pile. Water-quality samples distance from, adjacent to, and on the tailings pile	Hydraulic properties of tailings samples; water level data; water quality of tailings and ground waters	Borehole logs; mechanical properties of tailings from borehole samples; water quality; water levels	Borehole logs; water-quality data collected by LBL	Boring logs; water levels; water quality; hydraulic tests; geophysical logs

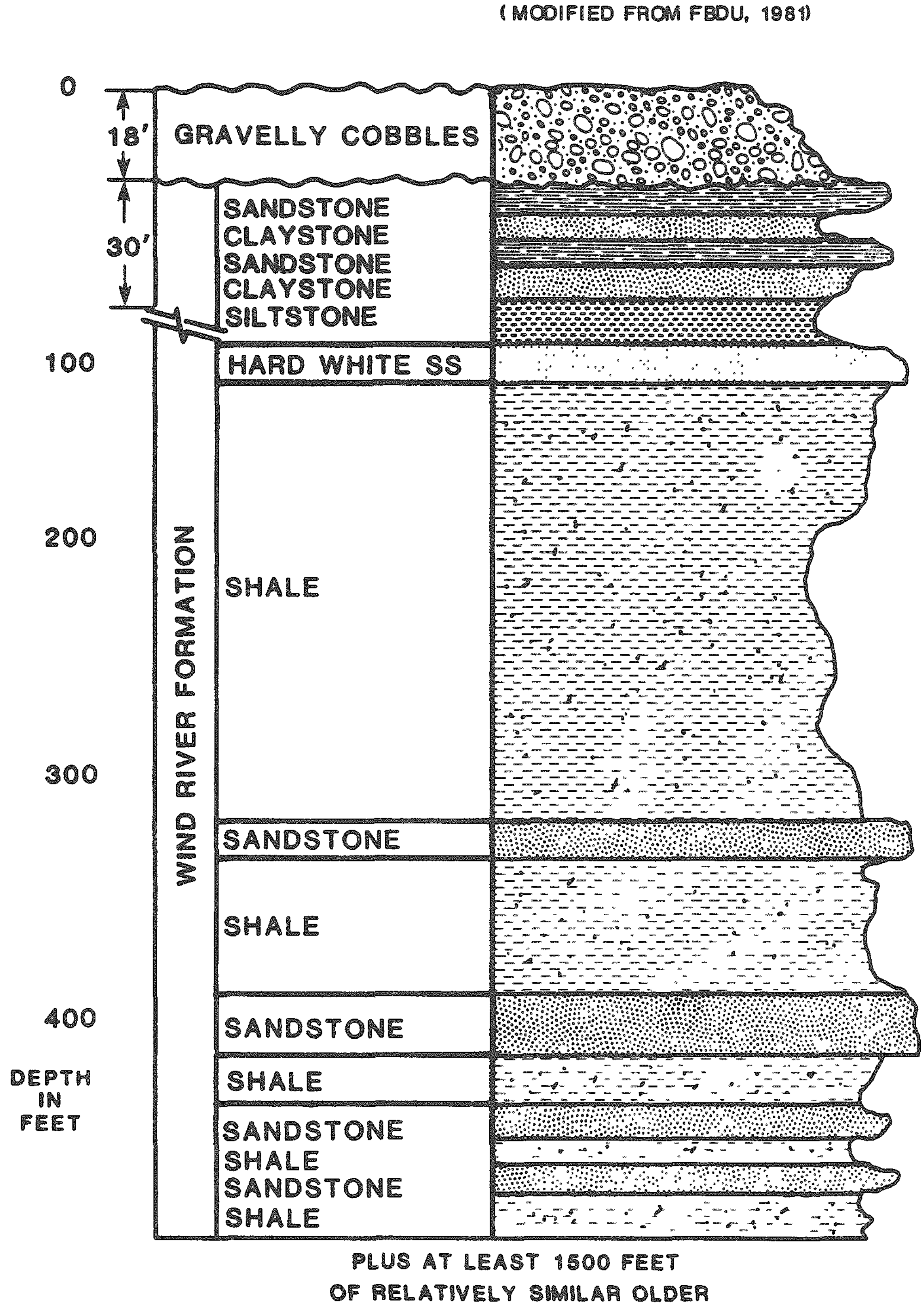


FIGURE C.2.13
SIMPLIFIED STRATIGRAPHIC COLUMN, RIVERTON SITE

brown and gray, silty and clayey sands in layers varying from zero to 3 feet in thickness (original surface alluvium). A deposit of cobbly alluvium underlies the entire pile, and, toward the eastern side, the cobbles are overlain by sandy gravel (CSU, 1983a).

Geologic cross-sections constructed on the basis of geologic and geophysical logs obtained at DOE boreholes RVT-106, RVT-701, and RVT-704 and FBDU borehole DH-2 are shown in Figures C.2.14 through C.2.17. The cross-sections indicate that the alluvium is of approximately uniform thickness over a long distance, with thicknesses ranging from about 14 feet beneath the pile to 18 feet southeast of the pile. The upper sandstone unit of the Wind River Formation is characterized by a maximum thickness of roughly 14 feet at borehole RVT-106 and appears to grade out to zero thickness northwest of borehole DH-2. The shale and siltstone layers which underlie the alluvium or upper sandstone unit appear to be continuous across the study area. The maximum total thickness of these layers is roughly 14 feet beneath the pile. The cores show no signs of fracturing or chemical precipitation within these layers, characteristics which would indicate a significant pathway for vertical ground-water movement. Below the shale and siltstone layers lie 15 to 20 feet of sandstone, followed by alternating layers or stringers of shales, siltstones, claystones, and sandstones. Approximately 60 percent of the upper Wind River Formation appears to be shale, claystone, or siltstone.

Dry Cheyenne alternate disposal site

The Dry Cheyenne site is near the edge of the Wind River Basin and is in an area where the coarse grained sequence of the Wind River Formation predominates. This sequence is characterized by green and gray, largely arkosic sandstone and conglomerate beds which are very well sorted, loosely cemented, and very porous. The coarse grained sequence intertongues with a finer grained sequence. In general, the bedrock does not have well defined outcrops in this area as it is easily weathered and covered with recent deposits (FBDU, 1981).

Due to the presence of the coarse grained facies of the Wind River in this area, most of the soils also are coarse grained and may not be effective for incorporation into a radon barrier.

C.2.4.2 Hydrogeology

Riverton tailings site

Ground water in the Riverton area occurs under both unconfined and confined conditions. An unconfined system exists in the floodplain alluvium, the adjacent terrace

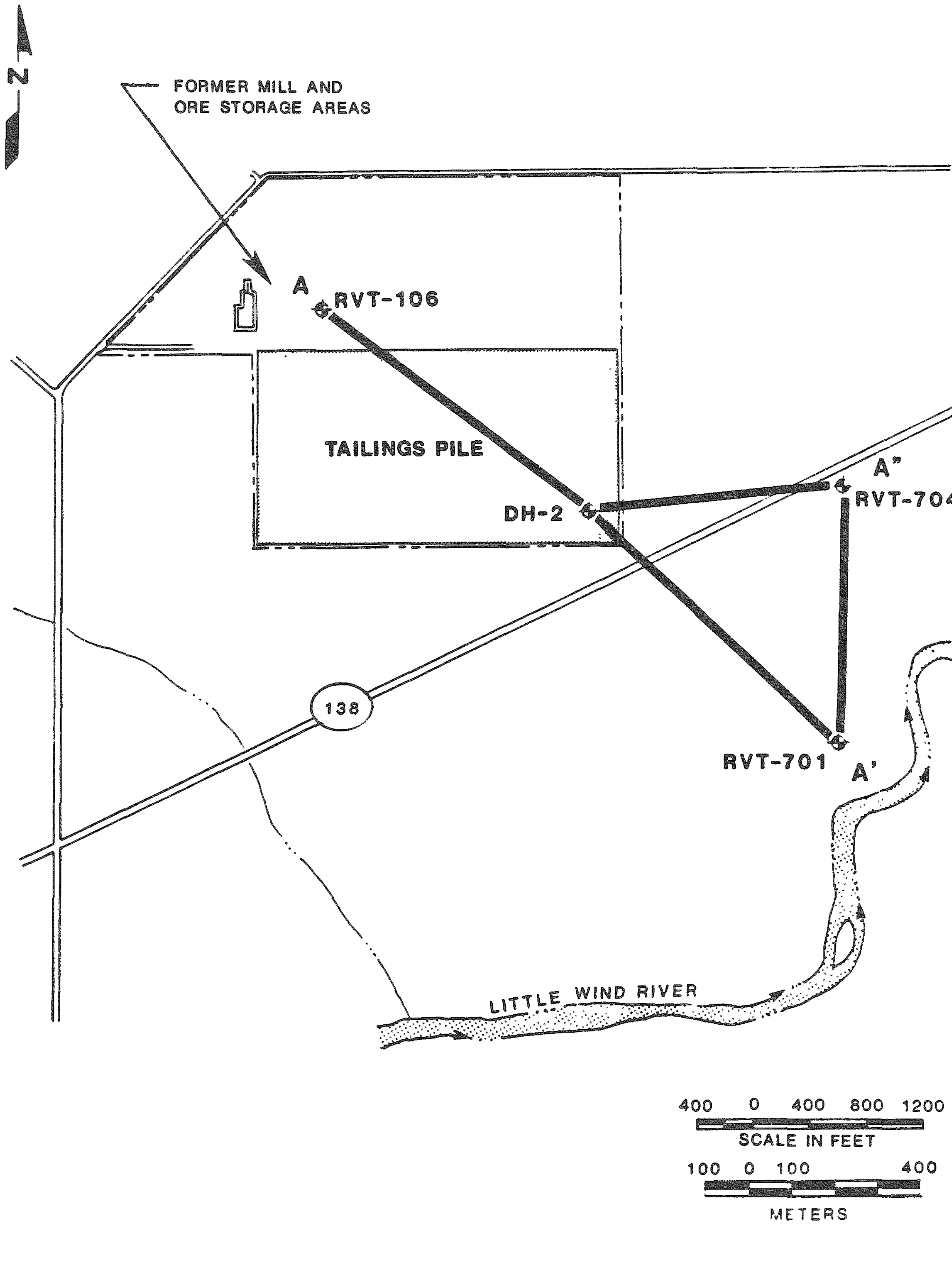


FIGURE C.2.14
LOCATIONS OF GEOLOGIC CROSS-SECTIONS, RIVERTON SITE

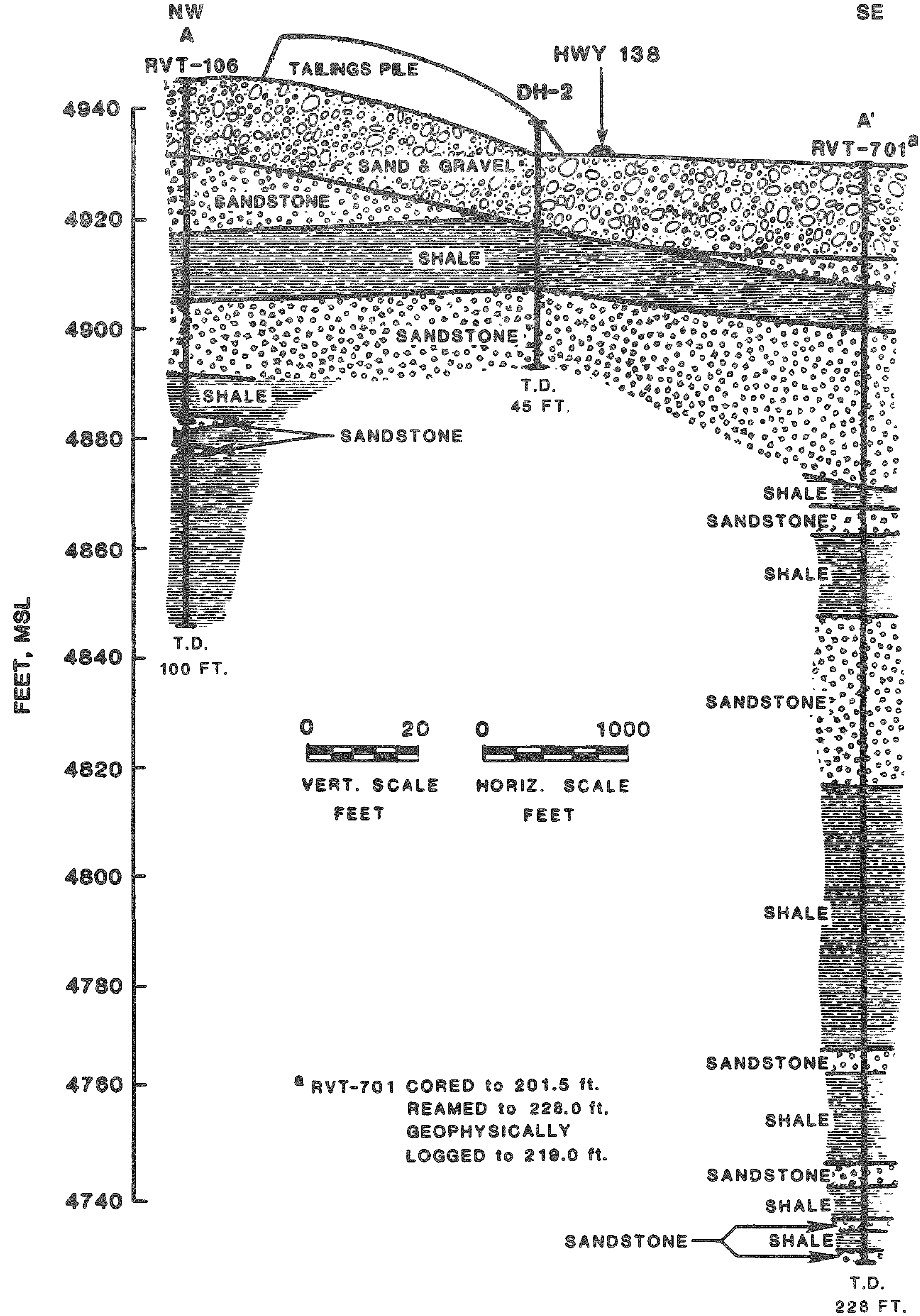


FIGURE C.2.15
GEOLOGIC CROSS-SECTION A-A', RIVERTON SITE

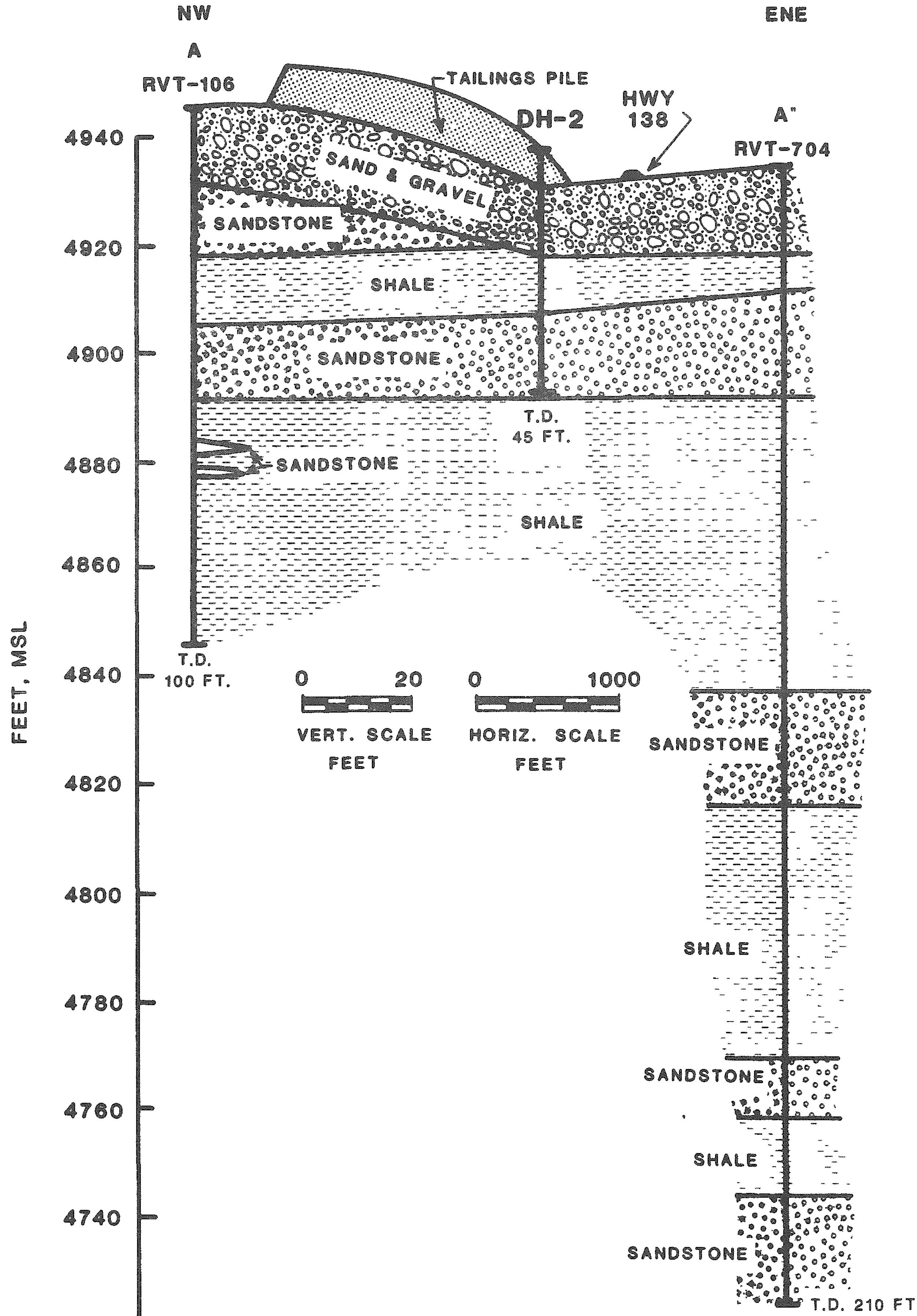


FIGURE C.2.16
GEOLOGIC CROSS-SECTION A-A", RIVERTON SITE

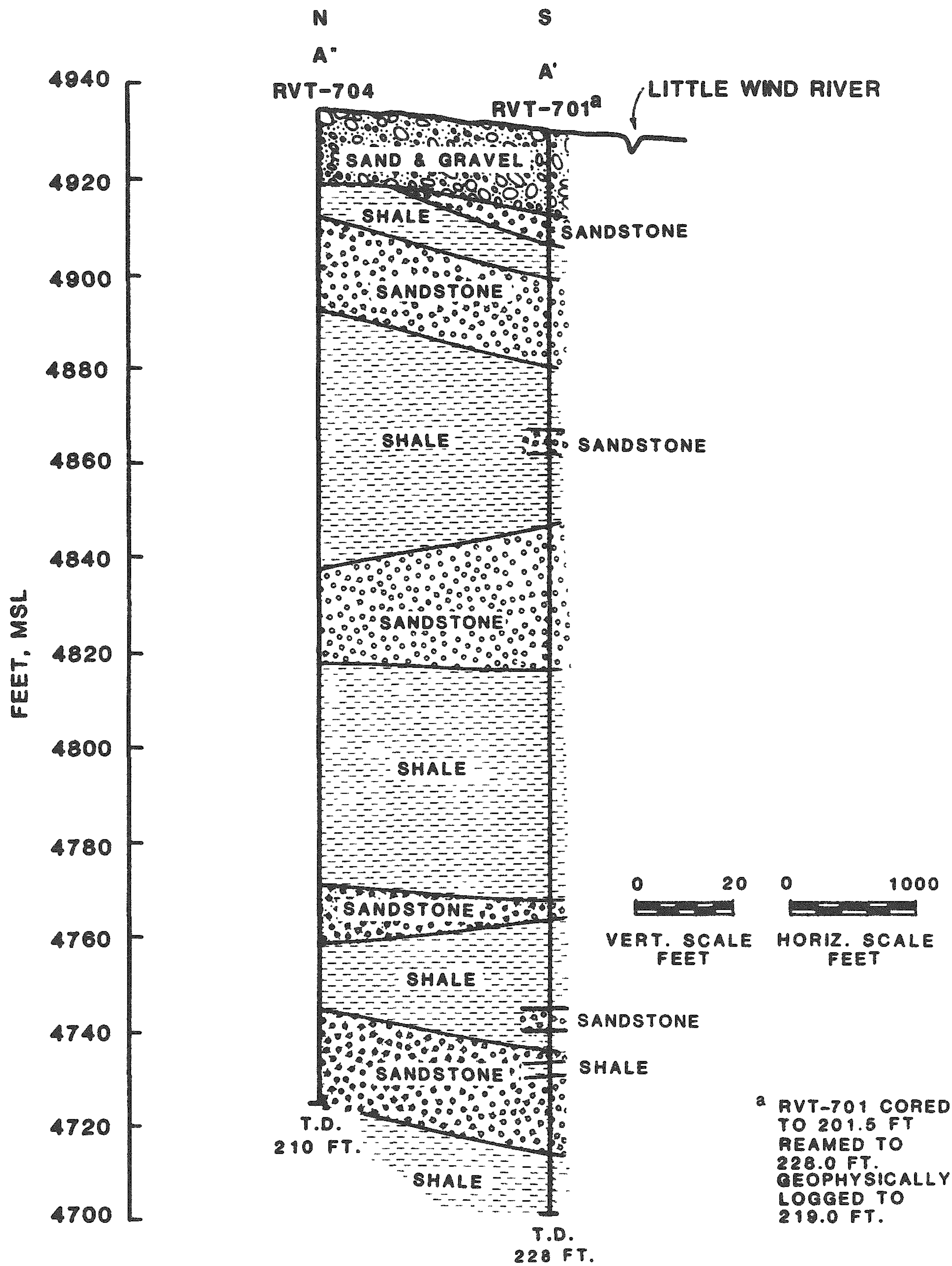


FIGURE C.2.17
GEOLOGIC CROSS-SECTION A''-A', RIVERTON SITE

deposits, and the hydraulically connected upper sandstone of the Wind River Formation. A confined system exists in lower sandstone units of the Wind River Formation. The shales of the formation act as confining layers by restricting vertical movement of ground water (FBDU, 1981).

The unconfined system

The alluvium and overlying soils are roughly 20 feet thick beneath the pile, with a saturated thickness of approximately 14 feet. Recharge to the unconfined system occurs through seepage of precipitation, snowmelt, and surface-water irrigation return flow. Local discharge occurs to the Little Wind River about 2,800 feet downgradient from the site (LBL, 1984). Due to the natural topography and return irrigation flows, much of the area surrounding the site is water-logged following the irrigation season (May through September) (FBDU, 1981). Beneath the site, the water table lies about 6 feet below the natural ground surface. During wetter times of the year, it is conceivable that the water table may rise into the tailings (FBDU, 1981) although water level measurements have not confirmed this.

Contours of water level measurements from 36 LBL piezometers in the alluvial aquifer are shown for November, 1982, and July, 1983, in Figures C.2.18 and C.2.19. The flow direction is predominantly south-southeast toward the Little Wind River, with an average hydraulic gradient of 0.0023. Temporal differences between the two water table configurations directly southeast of the site but not under the pile can be attributed to the greater effects of irrigation return flow on the November water table due to agricultural application of surface waters to the surrounding land during the April to July irrigation season. Water level measurements used to develop the water table maps are listed in Table C.2.9.

The degree of ditch-aquifer interaction need not be quantified because the effects are seasonal and do not appear to influence ground-water levels beneath the pile. Only the long-term, steady state response of the hydraulic system is necessary to define the solute transport characteristics of the aquifer; the influence of drainage and irrigation ditch flow on plume migration is minimal. Water levels south of the pile but not beneath the pile appear to be higher in November than in July. This characteristic of the November water table implies an increased source of recharge just south of the pile. It appears that the irrigation ditches and canals which traverse the site along the northern and eastern edges of the pile probably are contributing to the drainage berm which surrounds the pile (see Figure C.1.2). Under a predominantly southward topographic gradient, the irrigation water entering the berm would tend to collect along the southern edge of the pile and could produce the observed mounding effect south of the pile.

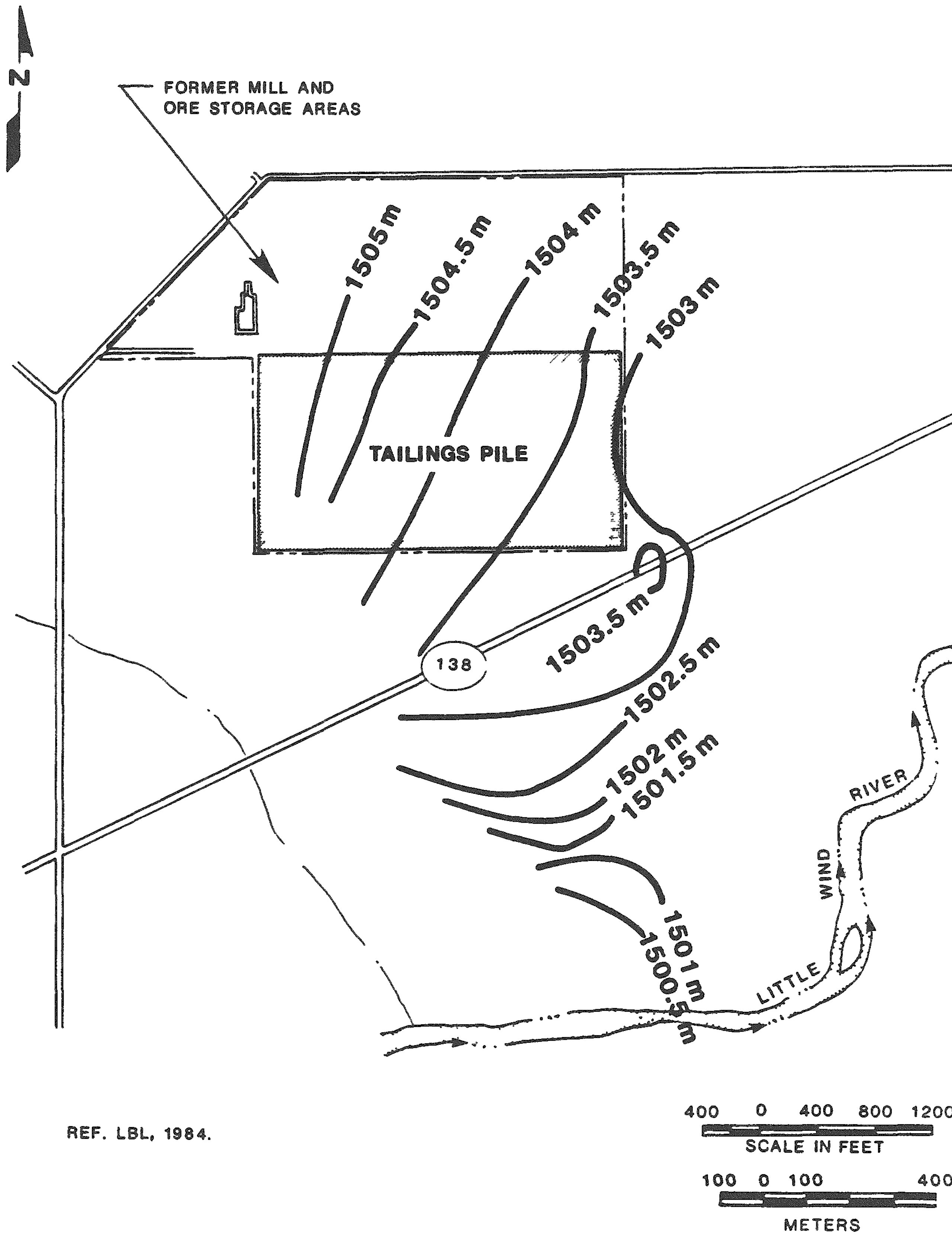


FIGURE C.2.18
WATER TABLE OF UNCONFINED AQUIFER, RIVERTON SITE, NOVEMBER, 1982

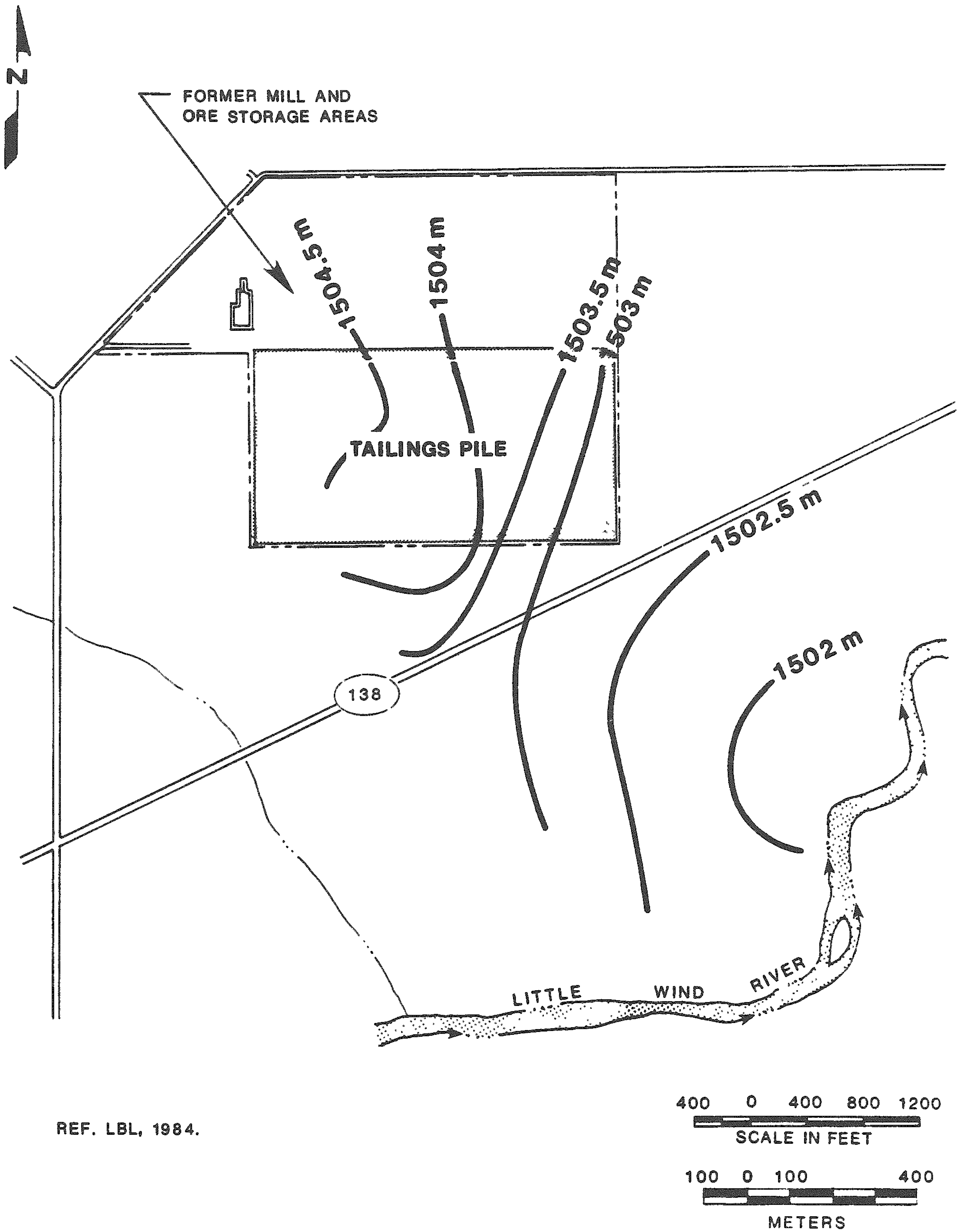


FIGURE C.2.19
WATER TABLE OF UNCONFINED AQUIFER, RIVERTON SITE, JULY, 1983

Table C.2.9 LBL water level measurements in the unconfined aquifer, Riverton site, 1982-1983[a]

Well number	November 3, 1982 Water table elevation[b]	July 15, 1983 Water table elevation[b]	Change in water table elevation[c]
P-8	4,930.92	4,931.05	- 0.13
P-9	4,931.52	--	--
P-14	4,934.01	4,933.87	+ 0.13
P-15	4,938.37	4,935.68	+ 0.92
P-16	4,934.60	--	--
P-17	4,931.94	--	--
P-18	4,934.17	4,934.23	- 0.06
P-19	4,928.95	4,928.69	+ 0.26
P-20	4,927.45	4,927.90	- 0.46
P-22	4,928.72	4,928.66	+ 0.07
P-23	4,932.01	4,931.84	+ 0.16
P-24	4,930.20	4,930.10	+ 0.10
P-25	4,931.09	4,930.86	+ 0.23
P-26	4,928.20	4,927.97	+ 0.23
P-27	4,927.94	4,927.54	+ 0.39
P-28	4,919.80	4,929.31	- 9.51
P-29	4,925.18	4,926.92	- 1.74
P-30	4,920.50	4,926.30	- 5.81
P-31	--	4,927.02	--
P-32	--	4,925.67	--
P-34	4,928.69	4,928.89	- 0.20
P-35	4,928.66	--	--
RA-3	4,935.51	4,935.51	0.00
RB-4	4,934.86	4,934.96	- 0.10
RB-5	4,933.81	4,933.97	- 0.16
RB-6	4,934.56	4,934.79	- 0.23
RB-7	4,933.97	4,934.20	- 0.23
RB-8	4,934.01	4,934.20	- 0.20
RC-3	4,931.18	4,931.45	- 0.26
H-1	4,935.58	4,935.38	+ 0.20
H-2	4,932.17	4,932.89	- 0.72
H-3	4,921.97	4,931.74	- 9.77
H-4	--	4,936.17	--
H-5	4,937.09	4,936.30	+ 0.79
H-7	--	4,935.84	--
H-8	--	4,933.25	--

[a]Dashed lines indicate that water level data were not collected.

[b]Feet above mean sea level.

[c]November water table elevation minus July water table elevation in feet.

The confined system

A confined aquifer system occurs in the lower sandstone units of the Wind River Formation. Interbedded layers and lenses of shale, siltstone, and claystone confine the ground water in the sandstone beds. Because the formation strata are lenticular, interfingered, and varied in thickness, there is some migration from one horizon to another (CSU, 1983a). This migration causes the entire stratigraphic sequence to behave as a single aquifer on a regional scale in response to long-term hydraulic stresses (FBDU, 1981).

Intensive use by the city of Riverton has formed a cone of depression around the city well field 1.5 to 9.0 miles north and northeast of the tailings site (CSU, 1983b). Significant development of the confined aquifer has also occurred at the tailings site. Figure C.2.20 shows the equipotential surface in the deeper confined sandstones as represented on USGS Map HA-270 (Whitcomb and Lowry, 1968). This regional potentiometric surface indicates that flow in the sandstones is predominantly to the northeast and may be influenced by pumping from the municipal well field, as shown by the sharp upgradient flexures. The magnitude of the gradient, as indicated by Figure C.2.20, is 3.6×10^{-4}.

A local representation of the potentiometric surface in the first confined sandstone was obtained using information from three wells completed in the confined aquifer for which top of casing elevations and depth to water measurements were available. Because only three unique potentiometric measurements could be obtained from the DOE wells at the three drill sites shown in Figure C.2.21, a plane was fit through the three potentiometric elevations. The equation describing head as a function of distance is:

$$h = -0.0022x + 0.00091y + 4967.55$$

where

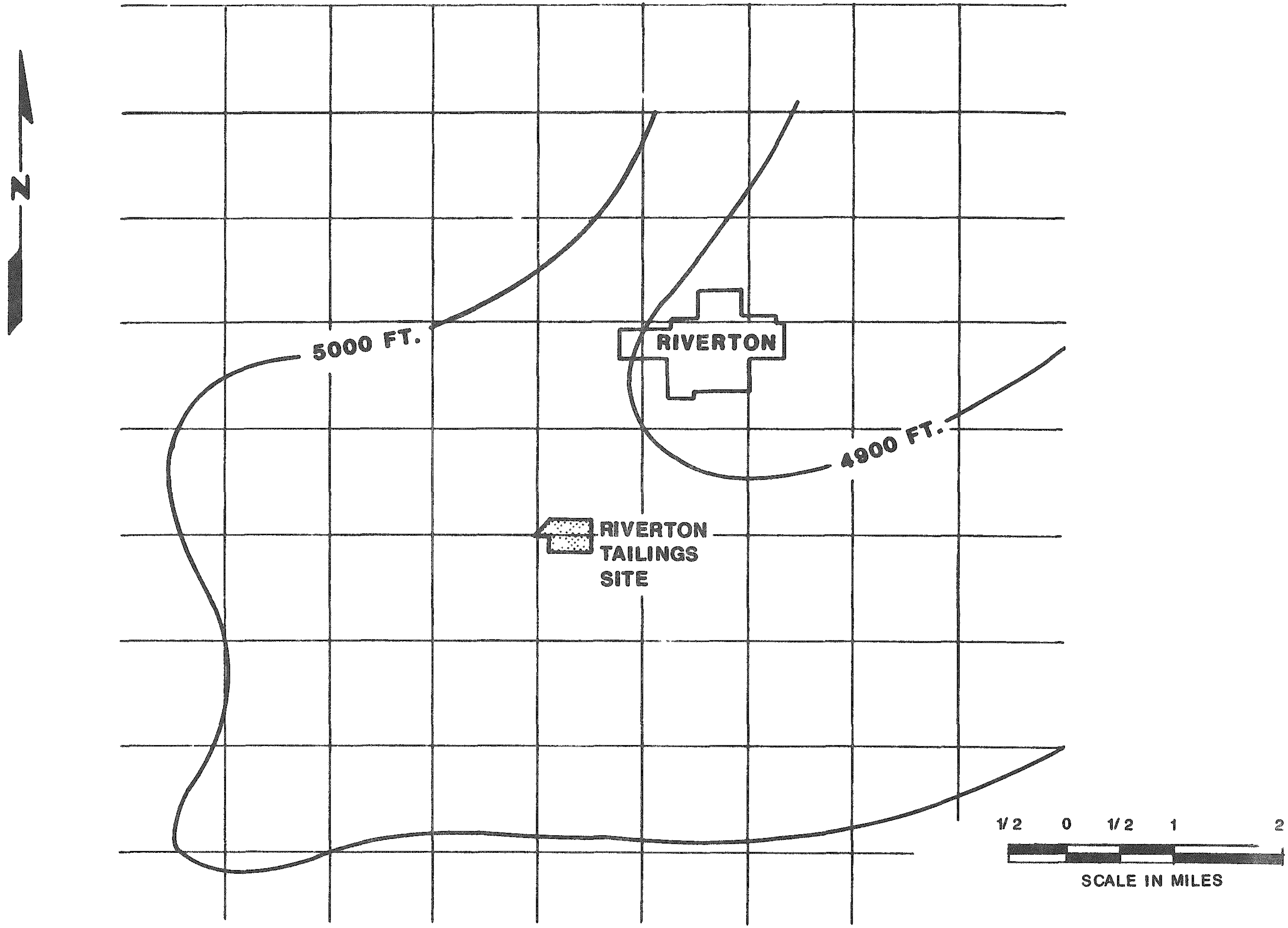
h = head in the confined unit in feet above mean sea level.

x = east coordinate with positive values measured in the eastern direction in feet.

y = north coordinate with positive values measured in the northern direction in feet.

The data used were:

	x	y	h
Well RVT-107	24131.4	24092.4	4936.4
Well RVT-702	27736.9	21012.9	4925.7
Well RVT-704	27033.8	22396.6	4928.5



REF. WHITCOMB AND LOWRY, 1968.

FIGURE C.2.20
REGIONAL POTENTIOMETRIC SURFACE IN DEEP CONFINED SANDSTONES

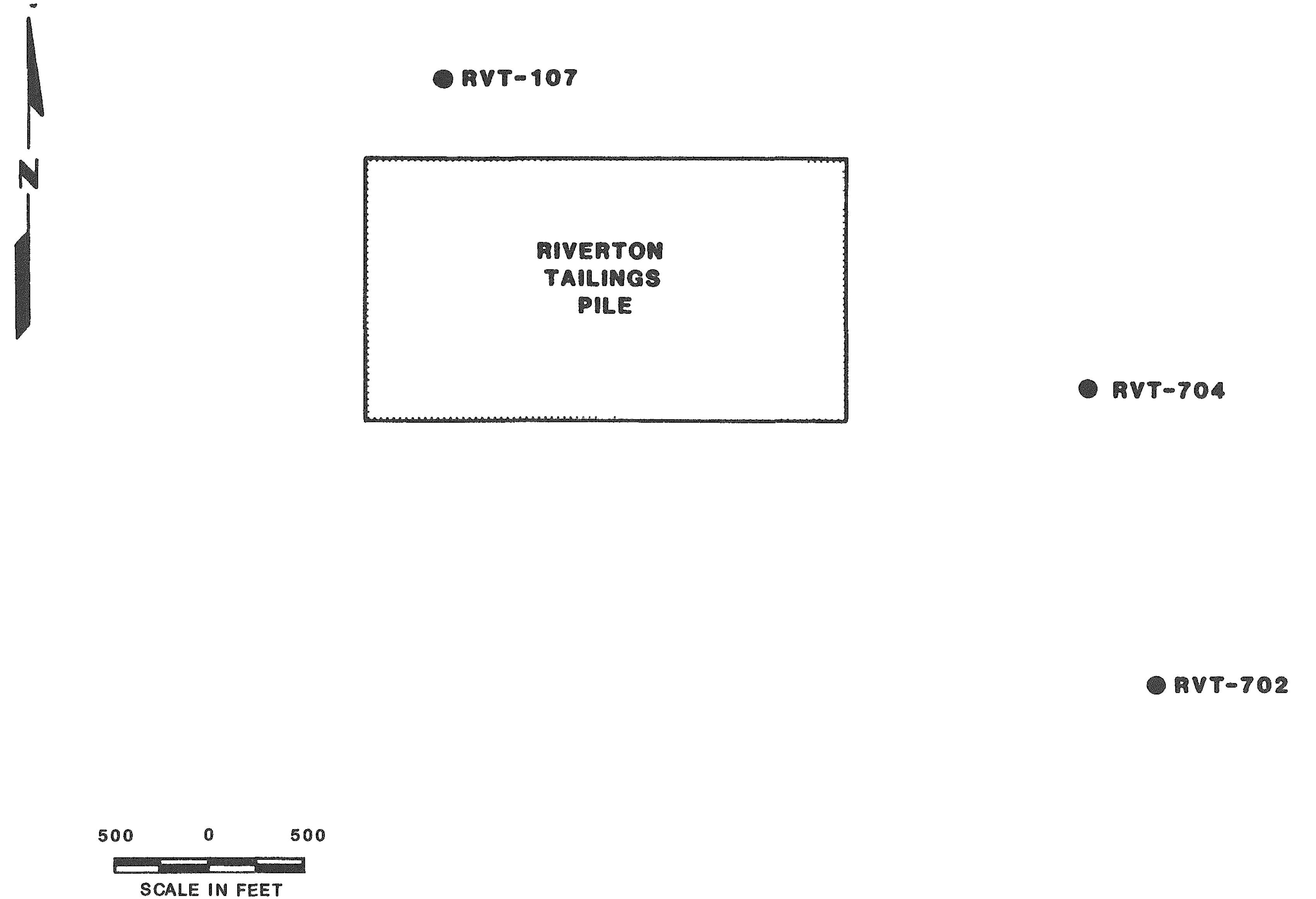


FIGURE C.2.21
LOCATIONS OF DOE WELLS USED TO ESTIMATE
LOCAL HYDRAULIC GRADIENT IN FIRST CONFINED SANDSTONE, RIVERTON SITE

The gradient vector associated with this plane is:

$$h = -0.0022i + 0.00091j$$

where:

i = the unit vector in the x direction.

j = the unit vector in the y direction.

Based on the gradient vector equation, the resultant vector for the hydraulic gradient is oriented in the S67E direction and is of magnitude:

$$\left|\nabla h . \nabla h\right| = \left[(-0.0022)^2 + (0.00091)^2\right]^{1/2}$$

$$= 0.0024$$

The local hydraulic gradient in the confined system therefore appears to correspond closely to the local hydraulic gradient in the unconfined system, which is of magnitude 0.0023 and of southeasterly orientation. This local gradient in the first confined sandstone cannot be reconciled with the regional gradient of the deeper confined sandstones shown in Figure C.2.20. A greater degree of communication between the unconfined aquifer and the first confined sandstone than between the first confined sandstone and sandstones deeper than 200 feet may be indicated.

Recharge to the confined aquifer occurs along outcrops of the Wind River Formation sandstones to the west and southwest where runoff from the Wind River mountain range infiltrates the outcrops under unconfined conditions. Recharge to the confined ground-water system also occurs by infiltration of stream water crossing outcrops, percolation through saturated overlying alluvium into subcrops, and irrigation return flow and canal seepage into outcrops. This recharge apparently does not satisfy the draft discharge from municipal and industrial wells. Municipal well water levels have dropped 60 to 70 feet in wells that are 500 to 800 feet deep during the last 50 years of pumping (FBDU, 1981).

Intercommunication between confined and unconfined systems

During the Riverton site assessment, attention was focused on the first confined sandstone layer at a depth of 40 to 55 feet beneath the site to assess the potential for downward movement of contaminated ground water from the unconfined to the confined aquifer. Geologic cores between the mill area and the tailings pile show 12 to 14 feet of siltstones and shales between the confined and unconfined systems. Communication between the two aquifers was assessed during two 24-hour pump tests. No significant water level changes were noted in the unstressed system while pumping from either the unconfined or confined system.

The issue of communication was further addressed by analyzing both unconfined and confined ground-water samples for tritium. The activity of radiogenic tritium was determined in samples from four on-site monitor wells completed in the unconfined aquifer and three on-site wells completed in the confined aquifer. Although some background tritium due to cosmic ray bombardment is present in all ground water, the dominant source of tritium in modern water is above-ground thermonuclear testing initiated in 1952. Measured tritium values are given in Table C.2.10:

Table C.2.10 Tritium levels in ground water, Riverton site

Well identification	Tritium units
Unconfined aquifer	
RC- 1	96
P - 8	69
P -10	72
RVT-100	70
RVT-113 (unconfined sandstone)	15
Confined aquifer	
RVT-106	24
RVT-110	26
Mill site well	38

Tritium data presented in Table C.2.10 indicate a maximum tritium concentration in the alluvial aquifer. However, the tritium concentration in the hydraulically connected unconfined sandstone was significantly lower than in the confined sandstone. Tritium levels in the confined sandstone were consistently lower than the 70 tritium units (TU) concentration measured in the alluvium, indicating the greater influence of modern recharge to the alluvial aquifer. These tritium concentrations from the confined system were all significantly larger than the generally accepted value of 5 to 10 TU for pre-bomb water and implied that some amount of water has recharged the shallow Wind River Formation since 1952.

Given the small likelihood that ground water sampled in the lower confined systems at a depth of 385 feet from the mill site well has been subject to contamination from the mill alluvial water and considering the anomalously high tritium concentration at that depth, it is possible that the high tritium concentrations observed in the first and second confined sandstone layers may be the result of sampling or analytical error. At this point, the tritium analysis should be considered inconclusive and should not be used to support any definite claims of vertical intercommunication or lack of intercommunication between the unconfined and confined systems.

Dry Cheyenne alternate disposal site

There are no wells in the Wind River Formation in the immediate vicinity of the Dry Cheyenne site. The water level is roughly 220 feet deep in an industrial well 2.5 miles to the southwest. The site is in an area that has a mean annual precipitation of only 5 to 10 inches. High evapotranspiration rates preclude the percolation of the limited precipitation into the deep water table (FBDU, 1981).

Borrow sites

No test pits or borings were completed at the Little Wind borrow site so the depth to ground water at the site is unknown. There is no other available ground-water information for this borrow site.

Borrow site 2 is immediately north of the tailings pile, and the ground-water conditions at this site would be the same as those described for the tailings site.

Test pits and borings at borrow site 10 reached a maximum depth of 31 feet. No ground water was encountered in these pits and borings, and there is no other available ground-water information for this site.

The Boulder Flats borrow site is just north of an active gravel pit operated by the Wyoming Highway Department. This pit is 15 to 18 feet deep, and no ground water has been encountered. The Wyoming Highway Department has conducted an exploratory drilling program at the Boulder Flats borrow site. The boreholes penetrated shale bedrock at a depth of 40 feet and indicated that ground water could be encountered at depths of 20 to 40 feet (Darr, 1985). There is no other ground-water information for this borrow site.

C.2.4.3 Ground-water and tailings pore water hydraulics

Riverton tailings site

The movement of tailings contaminants through the ground-water system at Riverton is controlled by the hydraulic properties of the tailings and the unconfined and confined aquifers. Aquifer and tailings parameters such as hydraulic conductivity and storativity, as well as variables related to vertical and horizontal hydraulic gradients, are required in order to predict future impacts of various remedial action measures using analytical or numerical modeling techniques. Hydraulic conductivity, storativity, and vertical communication relationships between hydrostratigraphic units have been assessed by pump tests, several slug and bailer tests, and water level measurements conducted by the DOE. Values of hydraulic conductivity from slug and bailer tests are indicative of the relative, site-specific variability between tested intervals. Tables

C.2.11 and C.2.12 report the final drawdown measurements in observation wells during two pump tests performed at the location shown in Figure C.2.8. Slight water level rises observed in the unstressed aquifer during both pump tests are believed to be related to factors other than the recharge of pumped ground water. Field measurements and data analyses obtained from the pump, slug, and bailer tests are on file at the UMTRA Project Office in Albuquerque, New Mexico.

The vertical movement of residual pore water and infiltrating rainfall through the pile is the principal driving force for migration of tailings contaminants into the ground-water system at the Riverton site. Dissolved contaminants in the tailings pore water move through the partially saturated pile in response to both the downward and upward hydraulic gradients shown in Figure C.2.22 for LBL locations RA, RB, and RC (Figure C.2.3).

It is particularly instructive to look at the profiles at locations RA and RB where the tailings are quite thick. At both the locations, the hydraulic heads decrease toward the bottom below a depth of 0.5 to 1 meter from the tailings surface. Between the tailings surface and about 1 meter in depth, the hydraulic head decreases upward. Thus, a "water divide" exists at a depth of approximately 1 meter below the tailings surface at both RA and RB. Above this divide, water moves predominantly upward due to evapotranspiration. Below the water divide, water moves downward toward the water table. Below the divide, the hydraulic head distributions as observed at location RB show little temporal variation. At location RA, the profiles show a greater temporal variation from each other down to a depth of 2.75 meters (LBL, 1984).

The similarity of the profiles measured at different times suggests that the presently observed profiles have been evolving over a long period of time, perhaps the 20 years since the time the pile was abandoned (1963). The difference in the profiles at shallow depths is indicative of the response of the system to daily and seasonal changes in precipitation and evaporation. The sharp change in the slope of the profile at location RB at a depth of 3 meters is due to the presence of a low permeability layer at that depth. The steady-state potential profile within the lower half of the tailings pile can be used to estimate the long-term rate of net infiltration of rainfall through the tailings, provided that the effective hydraulic conductivity is known (LBL, 1984).

Measured in-situ water contents obtained by CSU California tube sampling were extremely variable (Table C.2.13). The highest water contents were associated with the finest grained samples. However, water contents are not related generally to either gradation or depth. This points out the variability of drainage conditions within the pile which is probably a result of local layering.

Table C.2.11 Final drawdowns in Riverton observation wells during pump test on unconfined aquifer

Well number	Radial distance from pump well (feet)	Drawdown after 24 hours[a] (feet)	Completion stratum
RVT-100	5	0.55	Alluvium
RVT-101	12	0.40	Alluvium
RVT-102	17	0.07	Alluvium
RVT-103	46	0.16	Alluvium
RVT-104	187	-0.08	Alluvium
RVT-105	28	0.10	Alluvium
RVT-113	10	0.48	Underlying sandstone
RVT-112[b]	0	4.08	Alluvium and underlying sandstone
RVT-106	15	-0.08	First confined sandstone
RVT-107	73	-0.30	First confined sandstone
RVT-108	30	-0.08	First confined sandstone
RVT-109	115	0.00	First confined sandstone
RVT-110	27	-0.10	Second confined sandstone
P-14	195	0.10	Alluvium
P-23	3,330	-0.01	Alluvium
P-24	3,500	0.04	Alluvium

[a]Negative values indicate a rise in the water level rather than drawdown.

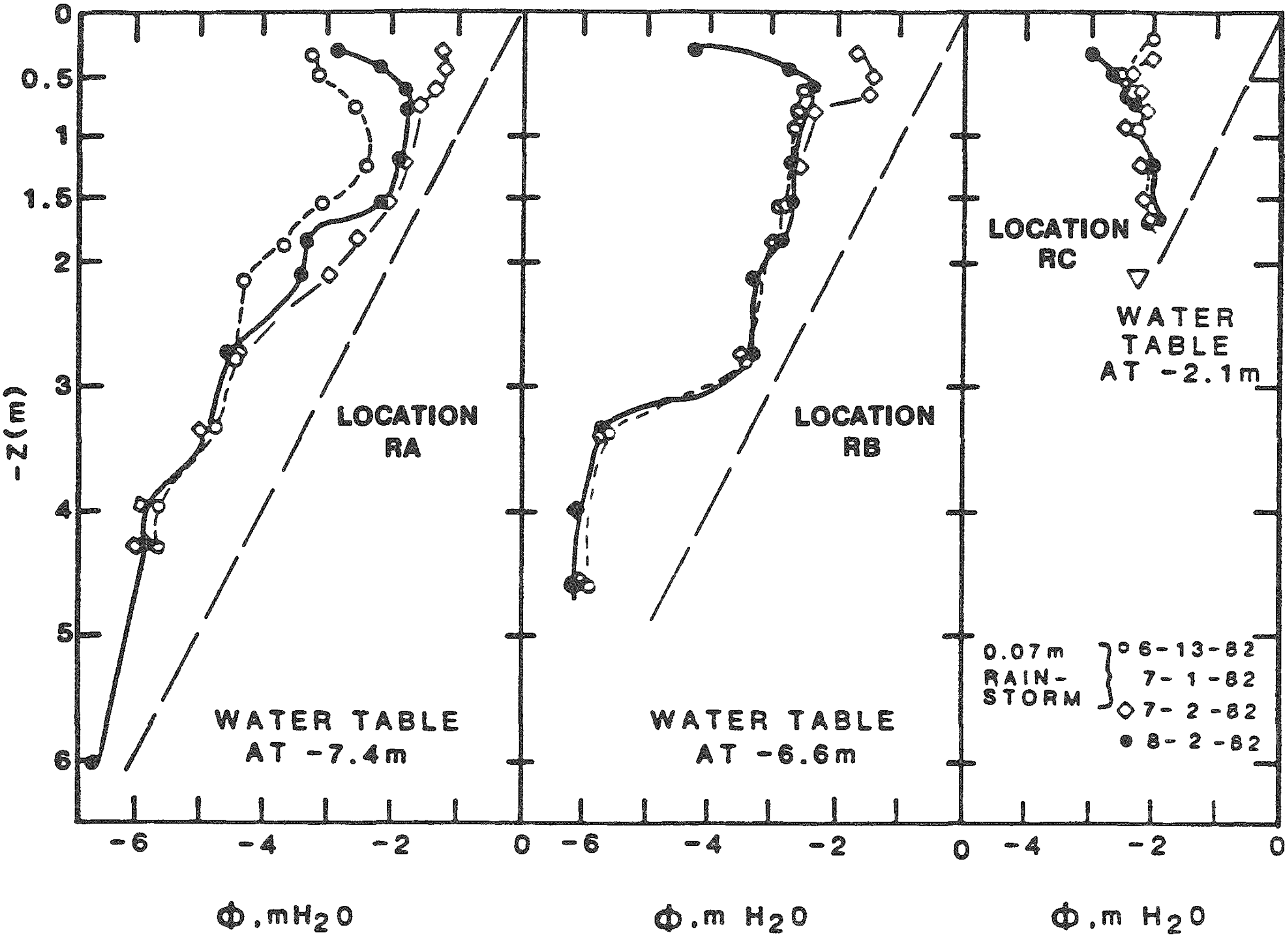
[b]Average discharge at pump well RVT-112 was 5 gpm.

Table C.2.12 Final drawdowns in Riverton observation wells during pump test on first confined sandstone

Well number	Radial distance from pump well (feet)	Drawdown after 24 hours[a] (feet)	Completion stratum
RVT-106	15	6.31	First confined sandstone
RVT-107	73	5.19	First confined sandstone
RVT-108	40	5.69	First confined sandstone
RVT-109	110	4.58	First confined sandstone
RVT-111[b]	0	25.85	First confined sandstone
RVT-110	24	2.70	Second confined sandstone
RVT-100	7	-0.01	Alluvium
RVT-101	10	-0.12	Alluvium
RVT-102	11	-0.03	Alluvium
RVT-103	40	-0.12	Alluvium
RVT-104	181	-0.10	Alluvium
RVT-105	23	-0.11	Alluvium
RVT-112	6	-0.03	Alluvium and underlying sandstone
RVT-113	16	0.00	Underlying sandstone
P-23	3,325	-0.02	Alluvium
P-24	3,500	0.02	Alluvium

[a]Negative values indicate a rise in the water level rather than drawdown.

[b]Average discharge at pump well RVT-111 was 18 gpm.



REF. LBL, 1984.

FIGURE C.2.22
PROFILES OF HYDRAULIC HEAD AT LBL LOCATIONS RA, RB, AND RC

Table C.2.13 Measured tailings pile water content in CSU California tube samples, Riverton site

Borehole number	Depth (feet)	Water content (percent)	Saturation (percent)
RIV-200	5.0	6.6	18.8
RIV-200	5.0	54.1	93.9
RIV-200	10.0	13.5	--
RIV-200	15.0	6.0	--
RIV-201	5.0	5.8	19.8
RIV-202	2.5	--	--
RIV-205	10.0	55.7	--
RIV-206	5.0	7.1	31.7
RIV-207	7.5	--	--
RIV-208	5.0	30.6	83.2
RIV-209	Surface	10.1	33.5
RIV-209	2.5	48.2	88.1
RIV-210	2.5	12.2	45.2
RIV-210	10.0	25.6	74.4
RIV-210	10.0	34.8	67.8
RIV-210	15.0	40.7	87.2
RIV-213	2.5	11.3	35.6
RIV-214	2.5	60.4	87.5

Ref. CSU, 1983a.

Local variability of adjacent materials was frequently observed through differences in gradation and plasticity between subsamples from the same tube sample. Those samples taken from the eastern side of the pile, where its surface and depth are lowest, showed fairly high water contents. These high water contents could be related to both surface drainage toward that side and close proximity to the water table (CSU, 1983a).

The samples obtained from the California tubes had saturations ranging from 19 to 94 percent with an average of 63 percent for the sandy samples and 54 percent for the sand-slime mixtures. Many of the samples were at or below their residual saturation. Based on these data, it appears that the pile is not now saturated. Some of the water falling on the pile will percolate through the pile under the partially saturated conditions. The amount of water flowing through the tailings depends a great deal on the potential for water to pond on the surface. Grading the reclaimed surface would minimize subsequent percolation through the system.

Critical information needed for long-term tailings management is the magnitude of vertical infiltration into the tailings resulting from natural precipitation. It is recognized that a major portion of the total annual precipitation is lost back to the atmosphere in the form of evapotranspiration. For the Riverton pile, neglecting overland flow, the annual infiltration is essentially equal to annual precipitation less evapotranspiration. The percolation rate through the pile is a function of the temporal distribution of precipitation and evapotranspiration over the site. The climate at Riverton is semi-arid to arid and is characterized by great deviations from normal precipitation. During the past 29 years, the annual precipitation measured at Riverton has ranged from 6.05 to 18.43 inches with an average of 9.62 inches (CSU, 1983a). A recent study showed in one particular case that approximately 15 percent of the average precipitation moved downward in uncovered tailings during a summer time period in a semi-arid environment (Lewis and Stephens, 1985). Fifteen percent of the annual average rainfall at Riverton is 1.4 inches (3.7 cm).

The mean monthly climatic data between 1972 and 1981 at Riverton are listed in Table C.2.14. The mean annual rainfall at Riverton for the 10-year duration of study is 21.2 cm, with the period of greatest rainfall being April to June. The data indicate that 52 percent of the average annual rainfall during this period fell during April, May, and June. Air temperature, relative humidity, wind speed, and solar radiation data were used to estimate potential evapotranspiration from the pile.

Table C.2.14 Mean montnly climatic data, Riverton, Wyoming, 1972-1981

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (centimeters)	0.43	0.53	1.25	2.97	4.32	4.17	1.55	0.91	1.91	1.96	1.17	0.53
Air temperature (°C)	-9.4	-4.9	-0.2	6.6	12.2	16.7	21.1	19.9	14.0	7.6	-1.5	-7.7
Relative humidity	0.68	0.63	0.57	0.53	0.52	0.42	0.39	0.40	0.42	0.52	0.63	0.65
Wind speed (kilometers per day)	220	224	282	297	309	328	301	286	270	228	212	232
$\frac{n}{N}$[a]	0.61	0.65	0.66	0.64	0.62	0.75	0.75	0.75	0.77	0.65	0.56	0.58
R_A[b]	280	430	660	790	940	990	960	830	640	510	320	250
Soil temperature[c]	3.6	1.9	2.5	5.6	8.9	12.5	16.1	18.3	16.8	13.9	10.0	6.3

[a] $\frac{n}{N}$ is the actual duration of bright sunshine per the maximum possible.

[b] R_A is the maximum upper atmosphere radiation at 43°N latitude in calories per square centimeter per day.

[c] °C at a depth of 1 meter.

Ref. LBL, 1984.

C.2.4.4 Ground-water quality

Water quality data should be reviewed in the context of water use and water quality standards because the implications of observed contaminant concentrations can be determined only when related to acceptable concentrations associated with a particular type of water use. Current Federal and Wyoming water quality standards are listed in Tables C.2.15 and C.2.16. An evaluation of local water use was presented in Section C.2.2.

Water quality samples, collected according to the procedures outlined in Section C.2.3, were obtained in all interstitial waters associated with the site. Pore waters from the partially saturated tailings pile, as well as from the unconfined and confined aquifers, were analyzed for a suite of constituents related to pile leachate. Detection limits for the constituents in all samples obtained by the DOE are listed in Table C.2.17. These detection limits are based on limits recommended by the EPA (EPA, 1983), modifications by the DOE for requirements of the UMTRA Project, and analytical laboratory capabilities.

Chemical profiles corresponding to the partially saturated tailings pore water at LBL location RB are presented in Figure C.2.23, and the contaminant concentrations used to define the profiles are listed in Table C.2.18. The profiles at location RB are representative of the vertical distribution of key constituents throughout the tailings pile. Figure C.2.23 illustrates the extreme variation in contaminant concentrations observed throughout the pile and suggests that the pH of tailings pore water may be influencing the behavior of some constituents.

Chemical analyses for all wells sampled by the DOE are presented in Tables C.2.19 through C.2.25. These tables list constituent concentrations in the unconfined and confined ground water and are sorted by sampled interval and level of contamination. Table C.2.19 lists samples for which the cation-anion balance error was greater than plus or minus 5 percent.

Radionuclide abundances have been determined by LBL for several vertical sections on the Riverton tailings pile in columns that extend from the surface of the present tailings cover, through the tailings, and into the underlying natural floodplain materials. The major results have been obtained by laboratory high-resolution, Ge-detector gamma-spectrometry on materials obtained either through continuous coring with Shelby tube samplers or carefully controlled, hand excavation. The profiles of various measured nuclides across the cover-tailings and tailings-soil interfaces are presented in Figures C.2.24 and C.2.25, respectively. The abundance of each nuclide is expressed on an absolute scale in terms of equivalent U ppm; plotted U concentrations are those which would be present if the uranium

Table C.2.15 Federal drinking water standards

Parameter	Drinking water standards[a]	
	Primary[b]	Secondary[c]
Arsenic	0.05	--
Barium	1.0	--
Cadmium	0.01	--
Chromium	0.05	--
Copper	--	1.0
Fluoride	4.0	--
Lead	0.05	--
Mercury	0.002	--
Nitrate	10.0	--
Selenium	0.01	--
Silver	0.05	--
Zinc	--	5.0
Chloride	--	250.0
Iron	--	0.3
Manganese	--	0.05
pH (standard units)	--	6.5-8.5
Sulfate	--	250
Total dissolved solids (TDS)	--	500
Uranium (health advisory level in picoCuries per liter)[d]	10.0	--
Radium-226 and -228 combined (in picoCuries per liter)	5.0	--

[a]All values are in milligrams per liter (mg/l) unless otherwise noted. Dashed lines indicate not applicable.
[b]Primary drinking water standards are contaminant concentrations that affect public health (40 CFR Part 141).
[c]Secondary drinking water standards are for contaminant concentrations that primarily affect the aesthetic qualities relating to the public acceptance of drinking water (40 CFR Part 143).
[d]Ref. Cothern et al., 1983.

Table C.2.16 State of Wyoming ground-water standards[a]

Constituent or parameter	Underground water class and use suitability I Domestic	II Agriculture	III Livestock
Aluminum (Al)	--	5.0	5.0
Ammonia (NH_3-N)	0.5	--	--
Arsenic (As)	0.05	0.1	0.2
Barium (Ba)	1.0	--	--
Beryllium (Be)	--	0.1	--
Boron (B)	0.75	0.75	5.0
Cadmium (Cd)	0.01	0.01	0.05
Chloride (Cl)	250.0	100.0	2,000.0
Chromium (Cr)	0.05	0.1	0.05
Cobalt (Co)	--	0.05	1.0
Copper (Cu)	1.0	0.2	0.5
Cyanide (CN)	0.2	--	--
Fluoride (F)	1.4-2.4	--	--
Hydrogen sulfide (H_2S)	0.05	--	--
Iron (Fe)	0.3	5.0	--
Lead (Pb)	0.05	5.0	0.1
Lithium (Li)	--	2.5	--
Manganese (Mn)	0.05	0.2	--
Mercury (Hg)	0.002	--	0.00005
Nickel (Ni)	--	0.2	--
Nitrate (NO_3-N)	10.0	--	--
Nitrite (NO_2-N)	1.0	--	10.0
(NO_3+NO_2)-N	--	--	100.0
Oil and grease	Virtually free	10.0	10.0
Phenol	0.001	--	--
Selenium (Se)	0.01	0.02	0.05
Silver (Ag)	0.05	--	--
Sulfate (SO_4)	250.0	200.0	3,000.0
Total dissolved solids (TDS)	500.0	2,000.0	5,000.0
Uranium (U)	5.0	5.0	5.0
Vanadium (V)	--	0.1	0.1
Zinc (Zn)	5.0	2.0	25.0
pH (standards units)	6.5-9.0	4.5-9.0	6.5-8.5
Sodium adsorption ratio (SAR)	--	8	--
Residual sodium carbonate (RSC in milli-equivalents per liter)	--	1.25 meq/l	--
Combined total radium-226 and radium-228 (in picoCuries per liter)	5	5	5
Total strontium-90 (in picoCuries per liter)	8	8	8
Gross alpha particle radioactivity (including radium-226 but excluding radon and uranium; in picoCuries per liter)	15	15	15

Table C.2.16 State of Wyoming ground-water standards[a] (Concluded)

Constituent or parameter	Underground water class and use suitability Special (A) Fish-Aquatic Life
Aluminum (Al)	0.1
Ammonia (NH_3)	0.02
Arsenic (As)	0.05
Barium (Ba)	5.0
Beryllium (Be)	0.011-1.1
Boron (B)	--
Cadmium (Cd)	0.0004-0.015
Chloride (Cl)	--
Chromium (Cr)	0.05
Cobalt (Co)	--
Copper (Cu)	0.01-0.04
Cyanide (CN)	0.005
Fluoride (F)	--
Hydrogen sulfide (H_2S)	0.002
Iron (Fe)	0.5
Lead (Pb)	0.004-0.15
Lithium (Li)	--
Manganese (Mn)	1.0
Mercury (Hg)	0.00005
Nickel (Ni)	0.05-0.4
Nitrate (NO_3-N)	--
Nitrite (NO_2-N)	--
(NO_3+NO_2)-N	--
Oil and grease	Virtually free
Phenol	0.001
Selenium (Se)	0.05
Silver (Ag)	0.0001-0.00025
Sulfate (SO_4)	--
Total dissolved solids (TDS)	500.0[b]-1,000.0[c]-2,000.0[d]
Uranium (U)	0.03-1.4
Vanadium (V)	--
Zinc (Zn)	0.05-0.6
pH (standard units)	6.5-9.0
Combined total radium-226 and radium-228 (in picoCuries per liter)	5
Total strontium-90 (in picoCuries per liter)	8
Gross alpha particle radioactivity (including radium-226 but excluding radon and uranium in picoCuries per liter)	15

[a]All values are in milligrams per liter (mg/l) unless otherwise indicated.
Dashed lines indicate not applicable.
[b]Egg hatching.
[c]Fish rearing.
[d]Fish and aquatic life.

Ref. WDEQ, 1980.

Table C.2.17 Detection limits for DOE water quality analyses

Constituent	Detection limit	Unit
Aluminum (Al)	0.003	mg/l
Arsenic (As)	0.001	mg/l
Barium (Ba)	0.002	mg/l
Cadmium (Cd)	0.0001	mg/l
Calcium (Ca)	0.01	mg/l
Chromium (Cr)	0.001	mg/l
Copper (Cu)	0.001	mg/l
Iron (Fe)	0.03	mg/l
Lead (Pb)	0.001	mg/l
Magnesium (Mg)	0.001	mg/l
Manganese (Mn)	0.01	mg/l
Mercury (Hg)	0.0002	mg/l
Molybdenum (Mo)	0.001	mg/l
Nickel (Ni)	0.04	mg/l
Potassium (K)	0.01	mg/l
Silver (Ag)	0.01	mg/l
Selenium (Se)	0.002	mg/l
Sodium (Na)	0.002	mg/l
Vanadium (V)	0.004	mg/l
Zinc (Zn)	0.005	mg/l
Ammonia (NH_3)	0.1	mg/l
Antimony (Sb)	0.003	mg/l
Chloride (Cl)	0.2	mg/l
Cyanide (CN)	0.001	mg/l
Fluoride (F)	0.1	mg/l
Nitrate (NO_3)	0.1	mg/l
Phosphorus (P)	0.01	mg/l
Sulfate (SO_4)	0.1	mg/l
Silica (SiO_2)	0.1	mg/l
Total dissolved solids (TDS)	10	mg/l
Radium-226 (Ra-226)	0.2	pCi/l
Thorium-230 (Th-230)	200	pCi/l
Lead-210 (Pb-210)	1.0	pCi/l
Uranium (U)	0.0003	mg/l

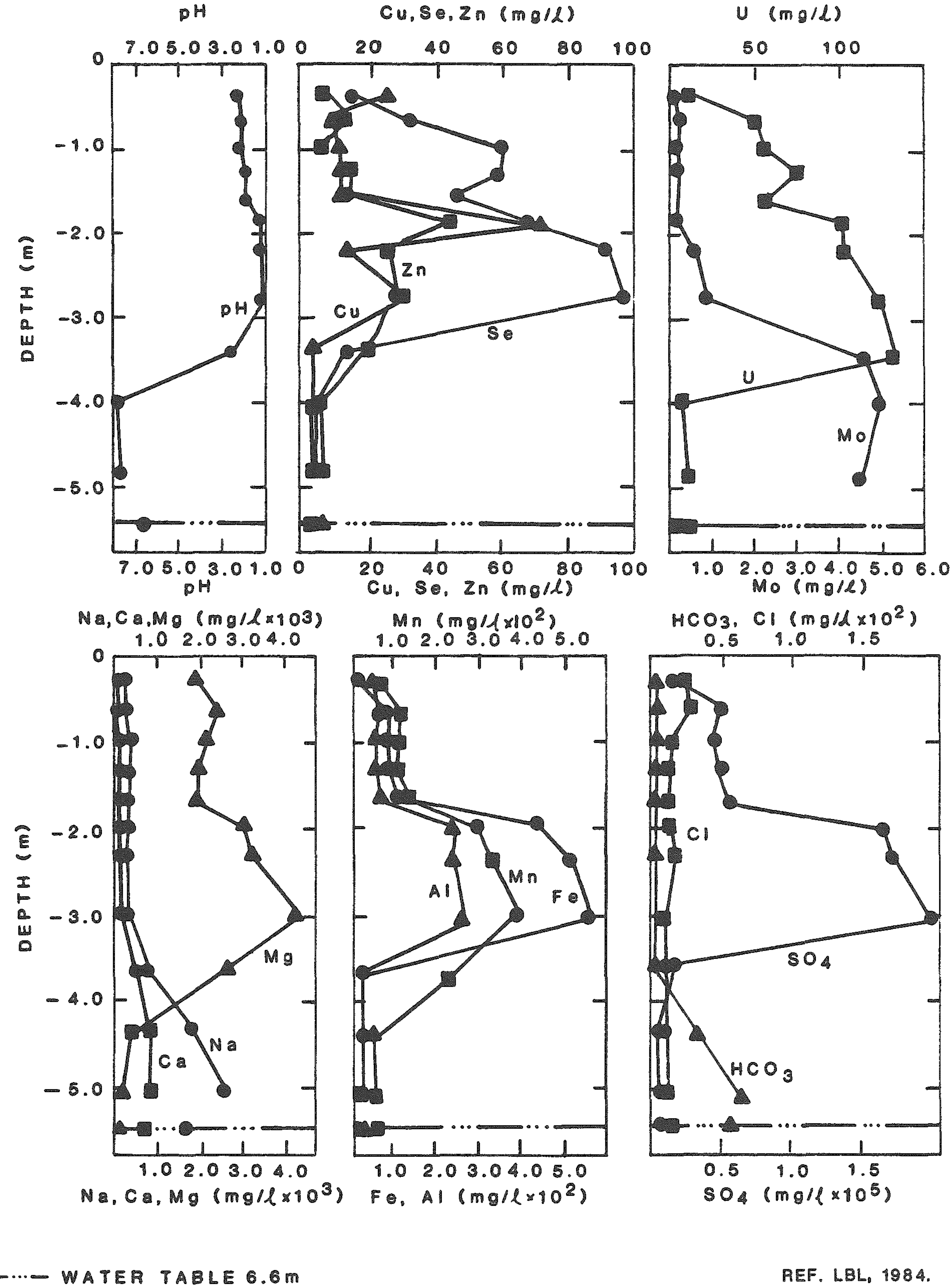


FIGURE C.2.23
CHEMICAL PROFILES OF TAILINGS PORE WATER AT LBL LOCATION RB

Table C.2.18 Chemical analyses of unsaturated tailings pore water, Riverton site

Sample number[b]	Concentration in milligrams per liter[a]								
	Na	K	Mg	Ca	Fe	Al	SO_4	Cl	Si
RA-1	259	0.78	430	300	15	76	8,850	76	53
RA-2	89	0.70	208	410	31	408	4,590	14	62
RA-3	60	0.78	320	309	27	1,326	11,800	26	85
RA-4	30	0.27	169	389	78	578	5,600	64	75
RA-5	20	2.51	80	480	32	250	2,957	21	75
RA-7	80	11.3	330	290	305	1,436	1.51×10^4	55	105
RA-11	319	5.8	1,280	220	306	8,285	2.68×10^5	78	57
RA-19	60	11.5	250	539	2.8	109	2,900	250	17
RB-1	268	0.27	1,110	300	1714	1,510	1.76×10^4	213	42
RB-2	209	0.55	1,450	212	1.58×10^4	3,490	4.74×10^4	241	38
RB-3	310	0.94	1,280	228	8,150	3,070	4.42×10^4	127	32
RB-4	239	0.25	1,100	228	8,150	3,250	4.49×10^4	127	36
RB-5	209	0.29	1,149	220	1.01×10^4	4,000	5.50×10^4	93	45
RB-6	20	0.22	1,900	140	4.32×10^4	1.15×10^4	1.69×10^5	115	43
RB-7	180	2.93	1,990	160	5.05×10^4	1.18×10^4	1.73×10^5	174	35
RB-9	30	0.22	2,620	160	5.65×10^4	1.25×10^4	1.99×10^5	87	35
RB-11	689	32	1,610	460	2.65×10^4	567	1.39×10^4	98	57
RB-13	1,760	41.0	279	609	<	0.54	4,950	104	17
RB-15	2,450	48.5	128	689	<	0.27	5,540	98	13
RC-1	2,550	68	1,180	559	<	32	1.31×10^{-1}	49	13
RC-2	2,370	19	799	509	<	9.1	8,420	73	13
RC-3	2,480	256	677	521	<	0.81	7,830	43	18
RC-4	2,760	37	690	562	<	1.0	7,540	158	13
RC-5	558	11	109	309	<	1.1	1,970	50	17

Table C.2.18 Chemical analyses of unsaturated tailings pore water, Riverton site (Concluded)

Sample number[b]	Concentration in milligrams per liter[a]						
	U	Mo	Cd	Cr	Se	Zn	Cu
RA-1	1,090	9	--	99	4.7	3.4	770
RA-2	618	31	--	99	3.8	1.8	18
RA-3	3,330	99	--	301	9.5	3.1	82
RA-4	1,166	36	--	98	3.8	1.7	20
RA-5	--	16	--	<	3.8	1.0	5.8
RA-7	476	9	--	301	5.7	6.0	20
RA-11	2.33×10^4	--	--	680	89	25	21
RA-19	880	3.5		<	3.8	1.0	0.3
RB-1	18	0.26×10^3	--	301	13	4	1.5
RB-2	18	1.7×10^3	--	620	33	14	8.2
RB-3	46	1.1×10^3	--	620	60	9	9.1
RB-4	58	1.1×10^3	--	680	58	16	10
RB-5	68	1.5×10^3	--	680	41	12	10
RB-6	54	5.0×10^3	--	780	70	45	80
RB-7	64	8.7×10^3	--	680	92	26	19
RB-9	108	4.5×10^4	--	1,100	98	30	31
RB-11	138	4.9×10^4	--	987	11	20	0.4
RB-13	20	4.4×10^4	--	<	<	1.0	0.1
RB-15	19	--	--	<	<	0.0	0.2
RC-1	1,730	13	--	0.01	<	1.0	<
RC-2	618	90	--	0.05	<	<	<
RC-3	31	72	--	0.39	<	<	<
RC-4	1,660	30	--	0.02	<	<	<
RC-5	218	13	--	0.01	<	<	<

[a]Concentrations below detection limits indicated by <; dashed lines indicate concentrations that were not determined.
[b]Sample numbers correspond to LBL locations RA, RB, and RC on Figure C.2.3.

Ref. LBL, 1984.

Table C.2.19 Unacceptable Riverton ground-water quality analyses[a]

Well	Date	T (°C)	Electrical conductivity (micromhos per centimeter)	TDS	pH (standard units)	F	Cl	NO_3	Alkalinity (as $CaCO_3$)	SO_4	Na	K
RVT-706	01/13/85	8.0	1,390	1,000	7.59	0.25	29	<1	221	490	103	2.95
RVT-710	01/13/85	5.0	1,116	560	7.04	0.35	14	2	506	190	70.0	2.60
RVT-714	01/10/85	5.0	643	510	7.10	0.43	4.1	<1	229	59	69.9	1.83
RVT-110	01/10/84	11.5	765	658	7.93	0.3	35	<1	100	260	136	2.60
RVT-101	12/08/83	--	--	1,410	--	<0.1	35	15	--	577	196	7.30
RVT-104	12/08/83	--	--	1,280	--	<0.1	71	15	--	544	222	7.18
RVT-110	12/08/83	--	--	719	--	<0.1	19	42.5	--	277	189	4.40
Bloomberg #1	12/08/83	--	--	592	--	1.6	5.9	12	--	263	214	0.94
Goggles #1	12/08/83	--	--	607	--	1.6	7.9	13	--	310	218	0.89
St. Stevens School	12/08/83	--	--	465	--	1.0	1.9	25.5	--	170	208	0.82
Moss #1	12/08/83	--	--	604	--	1.7	2.9	12	--	289	204	0.81
Kranz #1	12/08/83	--	--	633	--	<0.1	15	14.5	--	227	128	2.67
P-30	11/03/82	11.0	--	--	8.05	--	81	--	634	3,470	1,140	28.10
P-31	11/03/82	--	--	--	7.20	--	97	--	439	1,330	761	8.80
P-32	11/03/82	--	--	--	6.80	--	184	--	732	3,770	1,270	21.20
P-33	11/04/82	14.0	--	--	8.21	--	233	--	707	3,800	1,380	18.40
P-36	11/04/82	--	--	--	7.46	--	24	--	456	374	140	8.00
Schlotter	07/21/81	20.0	--	--	7.75	--	138	--	244	149	123	5.20
Harris	07/02/81	17.0	--	--	9.55	--	32	--	45	212	148	0.27
Raymond #1	06/12/81	21.0	--	--	8.90	--	8.3	--	197	205	154	0.39
P-5	06/11/81	25.0	--	--	7.24	--	35	--	329	384	77	9.50
P-8	06/15/81	21.0	--	--	7.61	--	12	--	301	185	71	7.90
P-12	07/14/81	18.0	--	--	7.61	--	49	--	360	517	214	8.70
P-14	07/14/81	19.0	--	--	7.50	--	108	--	421	460	158	36.10
P-15	07/14/81	18.0	--	--	7.50	--	92	--	392	624	155	8.60
P-17	07/28/81	22.0	--	--	6.97	--	103	--	677	2,420	570	36.40
P-20	07/28/81	--	--	--	6.60	--	61	--	762	2,380	708	16.60

Table C.2.19 Unacceptable Riverton ground-water quality analyses[a] (Continued)

Well	Date	Mg	Ca	Al	Fe	Mn	As	Ba	Cd	Cr	Hg	Pb	Sb	Se
RVT-706	01/13/85	46.1	111	<0.1	<0.03	1.37	<0.01	<0.1	<0.001	<0.01	<0.0002	<0.01	<0.003	<0.005
RVT-710	01/13/85	21.9	77.1	<0.1	0.07	2.32	<0.01	0.1	<0.001	<0.01	<0.0002	<0.01	<0.003	<0.005
RVT-714	01/10/85	15.5	61.5	<0.1	<0.03	1.46	<0.01	0.1	<0.001	<0.01	<0.0002	<0.01	<0.003	<0.005
RVT-110	01/10/84	7.8	61	<0.1	0.05	0.55	<0.005	<0.1	<0.005	<0.001	--	<0.001	<0.003	<0.005
RVT-710	12/08/83	50.4	177	<0.003	0.14	0.22	<0.001	--	--	<0.001	--	<0.001	0.017	<0.002
RVT-104	12/08/83	45.6	164	0.004	0.06	0.27	<0.001	--	--	<0.001	--	<0.001	0.013	<0.002
RVT-110	12/08/83	7.89	59.3	<0.003	0.58	0.64	<0.001	--	--	<0.001	--	<0.001	<0.003	<0.002
Bloomberg #1	12/08/83	0.08	6.06	<0.003	0.27	0.02	<0.001	0.008	--	<0.001	--	<0.001	<0.003	<0.002
Goggles #1	12/08/83	0.066	7.33	<0.003	0.14	0.03	<0.001	0.005	--	<0.001	--	<0.001	<0.003	<0.002
St. Stevens School	12/08/83	0.075	3.55	<0.003	0.13	0.02	<0.001	0.009	--	<0.001	--	<0.001	<0.003	<0.002
Moss #1	12/08/83	0.068	7.05	<0.003	<0.03	0.03	<0.001	0.004	<0.0001	<0.001	<0.0002	<0.001	<0.003	<0.002
Kranz #1	12/08/83	12.7	81	<0.03	0.14	0.07	<0.001	0.019	<0.0001	<0.001	<0.0002	<0.001	<0.003	<0.002
P-30	11/03/82	265	589	0.002	--	--	--	--	--	--	--	--	--	--
P-31	11/03/82	85	345	0.051	0.16	--	--	--	--	0.002	--	--	--	--
P-32	11/03/82	260	669	0.25	0.89	--	--	--	--	0.018	--	--	--	--
P-33	11/04/82	248	609	0.005	0.24	--	--	--	--	0.02	--	--	--	--
P-36	11/04/82	36	184	--	--	--	--	--	--	--	--	--	--	--
Schlotter	07/21/81	18	76.9	--	0.11	--	--	--	--	--	--	--	--	--
Harris	07/21/81	0.14	10.2	0.62	0.11	--	--	--	--	--	--	--	--	--
Raymond #1	06/12/81	--	5.29	0.027	0.11	--	--	--	--	--	--	--	--	--
P-5	06/11/81	34	128	--	0.011	--	--	--	--	--	--	--	--	--
P-8	06/15/81	19.8	87	0.25	0.012	--	--	--	--	--	--	--	--	--
P-12	07/14/81	27	101	--	0.5	--	--	--	--	--	--	--	--	--
P-14	07/14/81	110	373	--	0.34	--	0.01	--	--	--	--	--	--	--
P-15	07/14/81	53	182	0.26	0.11	--	--	--	--	--	--	--	--	--
P-17	07/28/81	163	829	--	0.5	--	--	--	--	--	--	--	--	--
P-20	07/28/81	137	1,040	--	21	--	--	--	--	--	--	--	--	--

Table C.2.19 Unacceptable Riverton ground-water quality analyses[a] (Concluded)

Well	Date	U	Mo	CN	PO_4	SiO_2	NH_4	Ag	Cu	Ni	V	Zn	Pb-210 (pCi/l)	Ra-226 (pCi/l)	Ra-228 (pCi/l)	Th-230 (pCi/l)
RVT-706	01/13/85	0.019	<0.01	--	<0.15	11.1	0.3	<0.01	<0.02	<0.04	<0.01	<0.005	<1.5	<1	--	<1
RVT-710	01/13/85	0.01	<0.01	--	<0.15	23.3	0.2	<0.01	<0.02	<0.04	0.02	0.007	<1.5	<1	--	<1
RVT-714	01/10/85	<0.003	<0.01	--	<0.15	29.5	0.1	<0.01	<0.02	<0.04	0.02	0.013	<1.5	<1	--	<1
RVT-110	01/10/84	0.005	0.04	--	--	--	--	<0.01	<0.1	<0.04	<0.004	<0.005	<1.5	--	<1.0	<1.0
RVT-710	12/08/83	0.22	0.03	<0.001	--	33.6	<0.1	0.001	<0.02	0.1	<0.004	0.017	--	--	--	--
RVT-104	12/08/83	0.159	0.034	<0.001	--	32.1	<0.1	0.001	<0.02	0.148	<0.004	0.05	--	--	--	0.001
RVT-110	12/08/83	0.003	0.072	<0.001	--	21.4	<0.1	--	<0.02	0.057	<0.004	0.023	--	0.6	--	--
Bloomberg #1	12/08/83	--	<0.001	<0.001	--	10.3	<0.1	--	<0.02	0.015	<0.004	0.039	--	--	--	--
Goggles #1	12/08/83	--	<0.001	<0.001	--	9.6	<0.1	--	<0.02	0.022	<0.004	0.006	--	--	0.1	1.0
St. Stevens School	12/08/83	--	<0.001	<0.001	--	10.3	<0.1	--	<0.02	0.024	<0.004	0.033	--	--	0.1	0.4
Moss #1	12/08/83	<0.003	<0.001	<0.001	0.04	9.8	<0.1	<0.0002	<0.02	0.024	<0.004	0.0192	0.0 ± 2.1	0.1 ± 0.2	--	0.0 ± 0.003
Kranz #1	12/08/83	--	<0.001	<0.001	--	23.1	<0.1	<0.0002	<0.02	0.022	<0.004	0.025	0.5 ± 2.4	0.1 ± 0.3	--	0.0004 ± 0.0005
P-30	11/03/82	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
P-31	11/03/82	0.072	0.029	--	--	--	--	--	--	--	--	--	--	--	--	--
P-32	11/03/82	2.4	0.038	--	--	--	--	--	--	--	--	--	--	--	--	--
P-33	11/04/82	0.3	0.028	--	--	--	--	--	--	--	--	--	--	--	--	--
P-36	11/04/82	0.052	0.031	--	--	--	--	--	--	--	--	--	--	--	--	--
Schlotter	07/21/81	--	--	--	--	--	--	--	--	--	0.009	--	--	--	--	--
Harris	07/21/81	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Raymond #1	06/12/81	--	0.004	--	--	--	--	--	--	--	--	--	--	--	--	--
P-5	06/11/81	0.32	0.12	--	--	--	--	--	--	--	--	--	--	--	--	--
P-8	06/15/81	0.11	--	--	--	--	--	--	--	--	--	--	--	--	--	--
P-12	07/14/81	0.016	0.038	--	--	--	--	--	--	--	--	--	--	--	--	--
P-14	07/14/81	1.4	0.13	--	--	--	--	--	--	--	0.001	--	--	--	--	--
P-15	07/14/81	0.18	0.39	--	--	--	--	--	--	--	--	--	--	--	--	--
P-17	07/28/81	0.64	0.9	--	--	--	--	--	--	--	--	--	--	--	--	--
P-20	07/28/81	0.4	3.7	--	--	--	--	--	--	--	--	--	--	--	--	--

[a] Samples with cation-anion balances in excess of plus or minus 5 percent. All values are in milligrams per liter (mg/l) unless otherwise noted. Dashed lines indicate no analyses.

Table C.2.20 Water quality analyses used to define background concentrations in the unconfined aquifer at Riverton, Wyoming[a]

Well	Date	T (°C)	Electrical conductivity (micromhos per centimeter)	TDS	pH (standard units)	F	Cl	NO_3	Alkalinity (as $CaCO_3$)	SO_4	Na	K	Mg
RVT-711	01/10/85	7	2,170	1,400	7.78	0.23	110	<1	287	550	152	4.48	50.1
RVT-715	01/10/85	6	459	290	6.97	0.25	3.6	<1	193	33	25.7	2.24	11.9
Raymond #2	04/14/84	8	--	707	7.26	<0.1	45	<0.1	255	244	95	14.6	266
Whiteman #2	06/05/84	8.2	--	1,270	7.07	<0.1	92	<0.1	280	582	190	6.6	35.5

Well	Date	Ca	Al	Fe	Mn	As	Ba	Cd	Cr	Hg	Pb	Sb	Se	U	Mo
RVT-711	01/10/85	173	<0.1	0.19	3.91	<0.01	0.2	<0.001	<0.01	<0.0002	<0.01	0.003	<0.005	0.01	<0.01
RVT-715	01/10/85	51.6	<0.1	0.14	1.91	<0.01	0.1	<0.001	<0.01	<0.0002	<0.01	0.003	<0.005	<0.003	<0.01
Raymond #2	04/14/84	95	<0.1	<0.03	0.59	<0.01	<0.1	<0.005	<0.01	<0.0002	<0.01	<0.003	<0.005	0.0077	<0.01
Whiteman #2	06/05/84	163	<0.1	0.46	0.15	<0.01	<0.1	<0.005	<0.01	<0.002	<0.01	<0.003	<0.005	0.0079	<0.01

Table C.2.20 Water quality analyses used to define background concentrations in the unconfined aquifer at Riverton, Wyoming[a] (Concluded)

Well	Date	CN	PO_4	SiO_2	NH_4	Ag	Cu	Ni	V	Zn	Pb-210 (pCi/l)	Ra-226 (pCi/l)	Ra-228 (pCi/l)	Th-230 (pCi/l)
RVT-711	01/10/85	--	<0.15	22.9	0.2	<0.01	<0.02	<0.04	<0.01	0.019	<1.5	<1	--	<1
RVT-715	01/10/85	--	<0.15	21.4	0.2	<0.01	<0.02	<0.04	<0.01	0.019	<1.5	<1	--	<1
Raymond #2	04/14/84	<0.01	<0.24	11.7	<0.1	<0.01	<0.02	<0.04	<0.01	0.121	0.2 ± 1.9	0.2 ± 0.2	--	0.0 ± 0.9
Whiteman #2	06/18/84	<0.01	<0.1	11.6	<0.1	<0.01	<0.02	<0.04	<0.01	<0.005	0.8 ± 1.3	0.1 ± 0.1	--	0.5 ± 0.6

[a]All wells located upgradient of tailings pile. All values in milligrams per liter (mg/l) unless otherwise noted. Dashed lines indicate no analyses.

Table C.2.21 Water quality analyses used to define background concentrations in the confined aquifer at Riverton, Wyoming[a]

Well	Date	T (°C)	Electrical conductivity (micromhos per centimeter)	TDS	pH (standard units)	F	Cl	NO_3	Alkalinity (as $CaCO_3$)	SO_4	Na	K	Mg
Kranz #1	01/10/84	0.5	568	582	6.99	0.4	18.0	<1.0	180	200	93	2.2	12.0
	04/04/84	--	--	635	--	<0.1	49.0	<0.1	--	305	165	1.5	11.5
	12/08/83	--	--	581	--	<0.1	1.0	15.5	--	222	114	2.75	12.9
	07/21/81	21	--	--	9.10	--	5.3	--	211	200	131	0.31	--
Clarke	07/21/82	21	--	--	8.91	--	12.0	--	150	229	164	0.39	0.09
Larson #1	04/04/84	--	--	814	--	<0.1	58.0	<0.1	--	366	197	0.80	10.3
Whitman #1	06/05/84	--	--	438	--	<0.1	23.0	<0.1	--	80.3	126	0.40	<0.001
Raphael Norse	03/30/84	--	--	701	--	<0.1	36.2	<0.1	--	341	176	0.87	5.23
Raymond #1	01/10/84	--	--	494	--	0.9	12.0	<1.0	180	180	160	0.47	0.062
	04/14/84	--	--	460	--	<0.1	38.0	<0.1	--	198	191	0.40	0.059
	12/08/83	--	--	493	--	1.3	4.9	12.5	--	189	180	0.83	0.062
St. Stevens School	01/10/84	--	--	536	--	0.8	11.0	15.0	180	150	160	0.48	0.065
	06/05/84	--	--	426	--	<0.1	25.0	<0.1	--	168	168	0.30	<0.001

Table C.2.21 Water quality analyses used to define background concentrations in the confined aquifer at Riverton, Wyoming[a] (Continued)

Well	Date	Ca	Al	Fe	Mn	As	Ba	Cd	Cr	Hg	Pb	Sb	Se	U	Mo
Kranz #1	01/10/84	81.0	<0.1	0.03	0.06	<0.005	<0.1	<0.005	<0.001	<0.0002	0.001	<0.003	<0.005	0.006	0.006
	04/04/84	52.1	<0.1	<0.03	<0.01	<0.01	<0.1	<0.005	<0.01	<0.0002	<0.01	<0.003	<0.005	0.0011	<0.01
	12/08/83	81.5	<0.003	0.45	0.07	<0.001	0.018	<0.0001	<0.001	<0.0003	<0.001	<0.003	<0.002	0.005	0.001
	07/21/81	3.6	0.18	0.17	--	--	--	--	--	--	--	--	--	--	--
Clarke	07/21/82	7.4	0.89	0.11	--	--	--	--	--	--	--	--	--	--	--
Larson #1	04/04/84	68.5	<0.1	0.16	0.13	<0.01	<0.1	<0.005	<0.01	<0.0002	<0.01	<0.003	<0.005	0.0013	<0.01
Whitman #1	06/05/84	4.21	<0.1	0.06	<0.01	<0.01	<0.1	<0.005	<0.01	<0.0002	<0.01	<0.003	<0.005	<0.0003	<0.01
Raphael Norse	03/30/84	51.2	<0.003	0.05	0.04	<0.001	<0.1	<0.0001	<0.001	<0.0002	<0.001	<0.003	<0.002	0.0008	0.001
Raymond #1	01/10/84	4.1	<0.1	0.05	<0.01	<0.005	<0.1	<0.005	<0.001	<0.0002	<0.001	<0.003	<0.005	<0.002	<0.005
	04/14/84	5.31	<0.1	0.04	<0.01	<0.01	<0.1	<0.005	<0.01	<0.0002	<0.01	<0.003	<0.005	<0.0012	<0.01
	12/08/83	6.55	<0.003	0.1	0.01	<0.001	0.007	<0.0001	<0.001	<0.0002	<0.001	<0.003	<0.002	<0.0003	<0.001
St. Stevens School	01/10/84	4.1	<0.1	0.08	<0.01	<0.005	<0.1	<0.005	<0.001	<0.0002	<0.001	0.003	<0.005	<0.002	<0.005
	06/05/84	3.52	<0.1	<0.03	<0.01	<0.01	<0.1	<0.005	<0.01	<0.0002	<0.01	<0.003	<0.005	<0.0003	<0.01

Table C.2.21 Water quality analyses used to define background concentrations in the confined aquifer at Riverton, Wyoming[a] (Concluded)

Well	Date	CN	PO_4	SiO_2	NH_4	Ag	Cu	Ni	V	Zn	Pb-210 (pCi/l)	Ra-226 (pCi/l)	Ra-228 (pCi/l)	Th-230 (pCi/l)
Krantz #1	01/10/84	--	<0.10	20.1	--	<0.01	<0.01	<0.04	<0.004	0.015	2.0	<1.0	<1	<1.0
	04/04/84	<0.01	<0.1	6.6	<0.1	<0.01	<0.02	<0.04	<0.01	<0.005	0.0 ± 1.6	0.1 ± 0.1	--	0.0 ± 0.4
	12/08/83	<0.001	<0.06	23.1	<0.1	--	<0.02	0.02	<0.004	0.029	0.2	0.0 ± 0.2	--	0.6 ± 0.7
	07/21/81	--	--	--	--	--	--	--	--	--	--	--	--	--
Clarke	07/21/82	--	--	--	--	--	--	--	--	--	--	--	--	--
Larson #1	04/04/84	<0.01	<0.1	6.6	<0.1	<0.01	<0.02	<0.04	<0.01	0.016	0.2 ± 2.0	0.0 ± 0.1	--	0.0 ± 0.0004
Whitman #1	06/05/84	<0.01	<0.1	<0.1	<0.1	<0.01	<0.02	<0.04	<0.01	<0.005	0.5 ± 1.2	0.5 ± 0.3	--	0.0 ± 0.0004
Raphael Norse	03/30/84	<0.001	<0.1	8.2	<0.1	<0.01	<0.001	<0.04	<0.004	<0.005	6.4	0.1 ± 0.2	--	--
Raymond #1	01/10/84	--	<0.10	8.3	--	<0.01	<0.01	<0.04	<0.004	<0.005	<1.5	<1.0	<1	<1.0
	04/14/84	<0.01	<0.1	<0.1	<0.1	<0.01	<0.02	<0.04	<0.01	<0.005	0.0 ± 1.3	0.5 ± 0.3	--	0.2 ± 0.6
	12/08/83	<0.001	<0.04	9.8	<0.1	--	<0.02	<0.018	<0.004	<0.014	0.0 ± 2.1	0.2 ± 0.3	--	--
St. Stevens School	01/10/84	--	<0.10	9.0	--	<0.01	<0.01	<0.04	<0.004	0.025	<1.5	<1.0	--	<1.0
	06/05/84	<0.01	<0.1	<0.1	<0.1	<0.01	<0.02	<0.04	<0.01	<0.005	0.0 ± 1.3	0.2 ± 0.2	--	0.0 ± 0.4

[a]All wells located upgradient of tailings pile. All values in milligrams per liter (mg/l) unless otherwise noted. Dashed lines indicate no analyses.

Table C.2.22 Water quality analyses of unconfined ground-water samples obtained downgradient of the Riverton tailings pile[a]

Well	Date	T (°C)	Electrical conductivity (micromhos per centimeter)	TDS	pH (standard units)	F	Cl	NO_3	Alkalinity (as $CaCO_3$)	SO_4	Na	K	Mg
DH-3	06/18/84	--	--	3,590	--	<0.1	390	<0.1	--	2,140	683	8.2	67.0
	01/10/84	--	--	3,414	6.40	0.4	100	<1.0	300	1,900	330	10.0	76.0
	12/08/83	--	--	3,470	--	--	95	11.5	--	2,000	421	12.3	85.6
RVT-707	11/14/84	5	8,000	7,590	6.89	0.89	220	<1.0	452	4,300	1,450	15.3	268
P-9	06/10/81	22	--	--	7.50	--	146	--	646	--	632	27.0	136
P-10	06/15/81	22	--	--	7.40	--	--	--	414	--	--	--	--
P-13	07/15/81	28	--	--	6.55	--	103	--	395	2,170	397	24.8	98.0
P-18	07/28/81	22	--	--	6.70	--	80	--	921	2,210	425	48.1	117
P-19	07/28/81	19	--	--	6.70	--	62	--	380	1,910	222	38.4	87.0
P-21	08/06/81	22	--	--	6.79	--	45	--	664	1,260	301	8.5	82.0
P-22	08/05/82	15	--	--	7.00	--	39	--	376	587	264	24.4	--
P-23	06/18/84	--	--	3,280	--	<0.1	300	<0.1	--	1,920	640	12.7	45.8
	11/04/82	15	--	--	6.70	--	50	--	464	1,810	328	1.5	77.0
P-24	06/18/84	--	--	4,010	--	<0.1	750	<0.1	--	2,360	1,030	13.8	90.3
	08/05/82	24	--	--	6.80	--	120	--	533	2,200	505	1.5	119
P-25	08/05/82	19	--	--	7.20	--	109	--	381	1,440	452	1.0	77.0
P-26	06/18/84	--	--	4,530	--	<0.1	480	<1.0	--	2,600	990	12.5	118
	08/06/82	19	--	--	7.05	--	169	--	518	2,280	629	1.2	140
P-27	11/02/82	11	--	--	6.80	--	134	--	567	2,590	653	14.8	172
P-28	11/04/82	10	--	--	8.00	--	46	--	213	470	161	6.4	22.0
P-29	11/04/82	12	--	--	7.69	--	57	--	359	826	294	7.2	39.0
P-31	06/05/84	--	--	4,220	--	<0.1	550	<0.1	--	2,410	822	7.8	88.3
P-32	06/07/84	--	--	9,700	--	<0.1	630	<0.1	--	6,000	2,190	19.1	293
	01/10/84	3.4	696	8,864	6.70	0.7	640	--	620	4,400	1,600	24.0	340
	12/08/83	--	--	8,960	--	1.1	220	10.5	--	5,510	1,610	33.3	348
P-34	11/04/82	--	--	--	7.60	--	32	--	402	643	223	7.6	46.0
P-35	11/04/82	12	--	--	7.55	--	88	--	352	268	142	6.0	22.0

Table C.2.22 Water quality analyses of unconfined ground-water samples obtained downgradient of the Riverton tailings pile[a] (Continued)

Well	Date	Ca	Al	Fe	Mn	As	Ba	Cd	Cr	Hg	Pb	Sb	Se	U	Mo
D-H3	06/18/84	505	<0.100	31.8	4.43	<0.010	<0.100	<0.0050	<0.010	<0.0002	<0.010	<0.003	<0.005	0.509	<0.010
	01/10/84	560	<0.100	21.0	4.60	0.019	<0.100	<0.0050	0.008	--	<0.001	<0.003	<0.005	0.690	0.070
	12/08/83	557	0.015	26.7	3.93	0.021	0.023	--	<0.001	--	0.015	0.030	0.023	--	0.062
RVT-707	11/14/84	405	<0.100	1.16	8.22	<0.010	<0.100	<0.0010	<0.010	<0.0002	<0.010	<0.003	<0.005	1.470	0.800
P-9	06/15/81	584	--	1.95	--	--	--	--	--	--	--	--	--	1.500	--
P-10	06/15/81	--	--	--	--	--	--	--	--	--	--	--	--	0.050	--
P-13	07/15/81	557	--	219	--	--	--	--	--	--	--	--	--	0.350	0.260
P-18	07/28/81	717	--	4.19	--	--	--	--	--	--	--	--	--	1.600	0.730
P-19	07/28/81	705	--	2.68	--	--	--	--	--	--	--	--	--	1.100	0.220
P-21	08/06/81	404	--	0.89	--	--	--	--	--	--	--	--	--	0.500	0.610
P-22	08/05/82	--	--	--	--	0.001	--	--	--	--	--	--	--	0.960	0.026
P-23	06/18/84	429	<0.100	2.14	3.47	<0.010	<0.100	<0.0050	<0.010	<0.0002	<0.010	<0.003	<0.005	1.360	<0.010
	11/04/82	565	--	--	--	--	--	--	--	--	--	--	--	1.200	0.460
P-24	06/18/84	462	<0.100	3.26	6.75	<0.100	<0.100	<0.0050	<0.010	<0.0002	<0.010	<0.003	<0.005	0.424	<0.010
	08/05/82	529	--	--	--	--	--	--	--	--	--	--	--	0.220	0.240
P-25	08/05/82	312	--	--	--	--	--	--	--	--	--	--	--	0.056	0.031
P-26	06/18/84	361	<0.100	0.12	3.95	<0.010	<0.100	<0.0050	<0.010	<0.0002	<0.010	<0.003	<0.005	<0.339	<0.010
	08/06/82	408	--	--	--	--	--	--	--	--	--	--	--	0.340	0.130
P-27	11/02/82	521	0.002	--	--	--	--	--	--	--	--	--	--	1.000	0.220
P-28	11/04/82	152	0.005	--	--	--	--	--	--	--	--	--	--	0.005	0.00013
P-29	11/04/82	157	0.008	--	--	--	--	--	0.002	--	--	--	--	0.004	0.012
P-31	06/05/84	584	<0.100	0.11	3.11	<0.010	<0.100	<0.0050	<0.010	<0.0002	<0.010	<0.003	<0.005	<0.0874	<0.010
P-32	06/07/84	582	<0.100	0.27	7.25	<0.010	<0.100	<0.0050	<0.010	<0.0002	<0.010	<0.003	<0.005	1.590	<0.010
	01/10/84	600	<0.100	0.39	11.0	0.005	<0.100	<0.0050	0.031	--	<0.001	0.003	<0.005	2.300	0.510
	12/08/83	600	0.029	0.57	11.3	0.020	0.026	0.0065	<0.001	--	0.064	0.098	0.127	1.760	0.118
P-34	11/04/82	220	0.003	0.014	--	--	--	--	--	--	--	--	--	0.060	0.019
P-35	11/04/82	116	0.008	0.04	--	--	--	--	--	--	--	--	--	0.016	0.009

Table C.2.22 Water quality analyses of unconfined ground-water samples obtained downgradient of the Riverton tailings pile[a] (Concluded)

Well	Date	CN	PO_4	SiO_2	NH_4	Ag	Cu	Ni	V	Zn	Pb-210 (pCi/l)	Ra-226 (pCi/l)	Ra-228 (pCi/l)	Th-230 (pCi/l)
D-H3	06/18/84	<0.010	<0.10	1.6	<0.10	<0.010	<0.02	0.060	<0.010	0.033	1.0 ± 1.2	6.3 ± 0.9	--	0.1 ± 0.5
	01/10/84	--	--	--	--	<0.010	<0.01	<0.040	<0.004	<0.005	3.0	6.9	--	<1.0
	12/08/83	<0.001	--	13.1	<0.10	0.003	<0.02	0.074	0.027	0.015	1.0	5.7	--	0.003
RVT-707	11/14/84	--	<0.15	31.0	0.50	<0.010	<0.02	0.130	<0.001	<0.005	<1.5	<1.0	--	<1.0
P-9	06/15/81	--	--	--	--	--	--	--	--	--	--	--	--	--
P-10	06/15/81	--	--	--	--	--	--	--	--	--	--	--	--	--
P-13	07/15/81	--	--	--	--	--	--	--	--	--	--	--	--	--
P-18	07/28/81	--	--	--	--	--	--	--	--	--	--	--	--	--
P-19	07/28/81	--	--	--	--	--	--	--	--	--	--	--	--	--
P-21	08/06/81	--	--	--	--	--	--	--	--	--	--	--	--	--
P-22	08/05/82	--	--	--	--	--	--	--	--	--	--	--	--	--
P-23	06/18/84	<0.010	<0.10	3.4	<0.10	<0.010	<0.02	0.050	<0.010	0.023	0.0 ± 1.5	2.0 ± 0.2	--	0.6 ± 0.6
	11/04/82	--	--	--	--	--	--	--	--	--	--	--	--	--
P-24	06/18/84	<0.010	<0.10	9.8	<0.10	<0.010	<0.02	0.080	<0.010	0.006	1.4 ± 1.2	0.1 ± 0.1	--	0.0 ± 0.4
	08/05/82	--	--	--	--	--	--	--	--	--	--	--	--	--
P-25	08/05/82	--	--	--	--	--	--	--	--	--	--	--	--	--
P-26	06/18/84	<0.010	<0.10	11.8	<0.10	<0.010	<0.02	<0.040	<0.010	0.130	0.0 ± 1.7	0.1 ± 0.1	--	0.0 ± 0.4
	08/06/82	--	--	--	--	--	--	--	--	--	--	--	--	--
P-27	11/02/82	--	--	--	--	--	--	--	--	--	--	--	--	--
P-28	11/04/82	--	--	--	--	--	--	--	--	--	--	--	--	--
P-29	11/04/82	--	--	--	--	--	--	--	--	--	--	--	--	--
P-31	06/05/84	<0.010	<0.10	12.6	<0.10	<0.010	<0.02	0.070	<0.010	0.010	1.1 ± 1.8	0.2 ± 0.2	--	0.0 ± 0.4
P-32	06/07/84	<0.010	<0.10	13.1	<0.10	<0.010	<0.02	0.130	<0.010	0.009	12.0 ± 2.0	0.3 ± 0.2	--	0.6 ± 1.2
	01/10/84	--	--	--	--	<0.010	<0.01	<0.040	<0.004	0.007	3.0	<1.0	--	<1.0
	12/08/83	<0.001	--	33.6	<0.10	0.0135	<0.02	0.054	0.010	0.038	5.0	--	--	13
P-34	11/04/82	--	--	--	--	--	--	--	--	--	--	--	--	--
P-35	11/04/82	--	--	--	--	--	--	--	--	--	--	--	--	--

[a] All values are in milligrams per liter (mg/l) unless otherwise noted. Dashed lines indicate no analyses.

Table C.2.23 Water quality analyses of unconfined ground-water samples obtained upgradient of the Riverton tailings pile[a]

Well	Date	T (°C)	Electrical conductivity (micromhos per centimeter)	TDS	pH (standard units)	F	Cl	NO_3	Alkalinity (as $CaCO_3$)	SO_4	Na	K	Mg
RVT-101	06/18/84	--	--	1,180	--	<0.1	77.0	<0.1	--	360	209	4.30	25.3
	01/10/84	13.8	1,438	1,314	7.31	0.4	78.0	<1.0	300	520	150	7.10	50.0
RVT-104	06/18/84	--	--	1,250	--	<0.1	92.0	<0.1	--	289	155	5.10	35.1
	11/10/84	9.8	1,272	1,332	7.30	0.4	78.0	2.0	300	520	150	7.30	50.0
RVT-105	06/18/84	--	--	1,180	--	<0.1	77.0	<0.1	--	284	162	4.10	27.3
	03/29/84	--	--	1,230	--	<0.1	68.1	<0.1	--	520	152	4.63	43.8
RVT-112	12/02/83	13.7	744	1,238	7.66	--	85.0	<10.0	220	600	170	6.10	50.0
RVT-113	06/18/84	--	--	1,190	--	<0.1	73.0	<0.1	--	535	178	2.60	23.4
	01/10/84	10.3	1,264	1,180	7.31	0.2	72.0	<1.0	220	550	109	5.00	22.0
	12/08/83	--	--	1,300	--	<0.1	70.2	15.0	--	583	182	5.23	24.9
P-11	07/14/81	28.0	--	--	7.40	--	165.0	--	370	1,380	393	9.10	82.0
P-16	07/21/81	18.0	-- 9	--	7.60	--	29.0	--	289	224	109	4.20	22.0

Table C.2.23 Water quality analyses of unconfined ground-water samples obtained upgradient of the Riverton tailings pile[a] (Continued)

Well	Date	Ca	Al	Fe	Mn	As	Ba	Cd	Cr	Hg	Pb	Sb	Se	U	Mo
RVT-101	06/18/84	82.5	<0.100	<0.03	0.22	<0.010	<0.10	<0.005	<0.010	<0.0002	<0.010	<0.003	<0.005	0.415	0.001
	01/10/84	180	<0.100	<0.03	0.23	0.005	<0.10	<0.005	0.001	--	<0.001	<0.003	0.009	0.190	0.080
RVT-104	06/18/84	105	<0.100	<0.03	0.06	<0.010	<0.10	<0.005	<0.010	<0.0002	<0.010	<0.003	<0.005	0.159	<0.010
	11/10/84	160	<0.100	<0.03	0.26	<0.005	<0.10	<0.005	0.001	--	<0.001	<0.003	0.010	0.140	0.080
RVT-105	06/18/84	95.0	<0.100	<0.03	0.08	<0.010	<0.10	<0.005	<0.010	<0.0002	<0.010	<0.003	<0.005	0.373	<0.010
	03/29/84	157	<0.003	<0.03	0.15	<0.001	<0.10	--	<0.001	--	<0.001	<0.003	<0.002	--	0.033
RVT-112	12/02/83	190	<0.010	0.02	0.52	<0.010	<0.05	<0.010	<0.020	--	0.020	--	0.010	--	0.090
RVT-113	06/18/84	148	<0.100	0.16	0.73	<0.010	<0.10	<0.005	<0.010	<0.0002	<0.010	<0.003	<0.005	0.305	<0.010
	01/10/84	220	<0.100	0.42	5.20	<0.005	0.20	<0.005	0.001	--	0.002	<0.003	<0.005	0.110	0.300
	12/08/83	212	<0.003	0.75	4.33	<0.001	0.58	--	<0.001	--	<0.001	0.007	<0.002	--	0.175
P-11	07/14/81	303	0.070	0.17	--	--	--	--	--	--	--	--	--	0.016	0.001
P-16	07/21/81	71.0	1.180	0.17	--	--	--	--	--	--	--	--	--	0.070	--

Table C.2.23 Water quality analyses of unconfined ground-water samples obtained upgradient of the Riverton tailings pile[a] (Concluded)

Well	Date	CN	PO_4	SiO_2	NH_4	Ag	Cu	Ni	V	Zn	Pb-210 (pCi/l)	Ra-226 (pCi/l)	Ra-228 (pCi/l)	Th-230 (pCi/l)
RVT-101	06/18/84	<0.010	<0.1	12.7	<0.1	<0.01	<0.020	<0.040	<0.010	0.007	0.2 ± 1.9	0.3 ± 0.2	--	0.2 ± 0.6
	01/10/84	--	--	--	--	<0.01	<0.010	<0.040	0.005	<0.005	<1.5	--	<1	<1.0
RVT-104	06/18/84	<0.010	<0.1	12.2	<0.1	<0.01	<0.020	<0.040	<0.010	<0.005	0.3 ± 1.2	0.1 ± 0.1	--	0.0 ± 0.4
	11/10/84	--	--	--	--	<0.01	<0.010	<0.040	0.005	0.013	<1.5	--	<1	<1.0
RVT-105	06/18/84	<0.010	<0.1	13.0	<0.1	<0.01	<0.020	<0.040	<0.010	0.012	0.6 ± 1.6	0.1 ± 0.1	--	1.7 ± 0.9
	03/29/84	<0.001	<0.1	11.0	<0.1	<0.01	0.002	<0.040	<0.004	0.007	4.1	0.1	--	--
RVT-112	12/02/83	--	--	--	--	--	<0.020	<0.500	<0.010	0.050	<2.0	--	<1	2.6
RVT-113	06/18/84	<0.010	<0.1	10.5	<0.1	<0.01	<0.020	<0.040	<0.010	<0.005	1.0 ± 1.1	0.2 ± 0.2	--	0.6 ± 0.6
	01/10/84	--	--	--	--	<0.01	0.070	<0.040	<0.004	0.007	<1.05	--	<1	<1.0
	12/08/83	<0.001	--	27.0	<0.1	--	<0.020	0.031	<0.004	0.021	--	0.2	--	0.001
P-11	07/14/81	--	--	--	--	--	--	--	--	--	--	--	--	--
P-16	07/21/81	--	--	--	--	--	--	--	--	--	--	--	--	--

[a]Wells located 400 feet north of tailings pile. All values are in milligrams per liter (mg/l) unless otherwise noted. Dashed lines indicate no analyses.

Table C.2.24 Water quality analyses of confined ground-water samples obtained downgradient of the Riverton tailings pile[a]

Well	Date	T (°C)	Electrical conductivity (micromhos per centimeter)	TDS	pH (standard units)	F	Cl	NO_3	Alkalinity (as $CaCO_3$)	SO_4	Na	K	Mg
Blomberg #1	06/07/84	--	--	535	--	<0.1	26.0	<0.1	--	117	124	0.400	0.038
	01/10/84	8.2	658	554	8.60	1.1	16.0	<1.0	140	250	180	0.500	0.074
	06/12/84	--	--	--	8.81	--	17.0	--	156	264	180	0.390	0.097
Goggles #1	06/07/84	--	--	602	--	<0.1	--	122.0	127	0.4	0.025		
	01/10/84	8.0	620	614	8.95	1.2	18.0	<1.0	100	290	200	0.510	0.069
	03/28/84	--	--	664	--	<0.1	22.4	<0.1	--	319	208	0.540	0.07
	11/03/82	11.0	--	--	8.81	--	--	--	134	--	--	--	--
Moss #1	06/07/84	--	--	554	--	<0.1	25.0	<0.1	--	127	126	0.400	0.031
	01/10/84	10.9	680	528	8.79	1.2	13.0	3.0	100	260	180	0.470	0.056
	03/28/84	--	--	622	--	<0.1	17.0	<0.1	--	292	189	0.530	0.01
	12/08/83	--	--	581	--	1.7	9.9	15.0	--	291	213	0.861	0.06
	07/21/81	--	--	--	7.85	--	22.0	22.0	140	264	178	0.390	0.09
Westlake #1	06/07/84	--	--	1,610	6.88	<0.1	36.0	<0.1	--	691	242	7.100	29.0

Table C.2.24 Water quality analyses of confined ground-water samples obtained downgradient of the Riverton tailings pile[a] (Continued)

Well	Date	Ca	Al	Fe	Mn	As	Ba	Cd	Cr	Hg	Pb	Sb	Se	U	Mo
Blomberg #1	06/07/84	6.91	<0.100	<0.03	<0.01	<0.010	<0.100	<0.0050	<0.010	<0.0002	<0.010	<0.003	<0.005	0.0008	<0.010
	01/10/84	6.00	<0.100	0.09	<0.01	<0.005	<0.100	<0.0050	<0.001	0.0005	<0.001	<0.003	<0.005	0.0020	<0.005
	06/12/84	8.40	0.400	11.00	--	--	--	--	--	--	--	--	--	--	--
Goggles #1	06/07/84	7.70	<0.100	0.06	<0.01	<0.010	<0.100	<0.0050	<0.010	<0.0002	<0.010	<0.003	<0.005	<0.0030	<0.010
	01/10/84	6.60	<0.100	0.08	<0.01	<0.005	<0.100	<0.0050	<0.001	<0.0002	<0.001	<0.003	<0.005	0.0020	<0.005
	03/28/84	6.96	<0.003	0.07	<0.01	<0.001	<0.100	<0.0001	<0.001	<0.0002	<0.001	<0.003	<0.002	<0.0003	<0.001
	11/03/82	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Moss #1	06/07/84	6.80	<0.100	<0.03	<0.01	<0.010	<0.100	<0.0050	<0.010	<0.0002	<0.010	<0.003	<0.005	<0.0030	<0.010
	01/10/84	5.70	<0.100	<0.03	<0.02	<0.005	<0.100	<0.0050	<0.001	0.0003	<0.001	<0.003	<0.005	<0.0050	<0.005
	03/28/84	6.81	<0.003	0.05	<0.01	<0.001	<0.100	<0.0001	<0.001	<0.0002	<0.001	<0.003	<0.002	<0.0003	<0.001
	12/08/83	5.50	<0.003	<0.03	0.02	<0.001	0.004	--	<0.001	--	<0.001	<0.003	<0.002	--	0.040
	07/21/81	15.40	0.220	0.11	--	--	--	--	--	--	--	--	--	--	--
Westlake #1	06/07/84	158.00	<0.100	0.08	1.32	<0.010	<0.100	<0.0050	<0.010	<0.0002	<0.010	<0.003	<0.005	0.2370	<0.010

Table C.2.24 Water quality analyses of confined ground-water samples obtained downgradient of the Riverton tailings pile[a] (Concluded)

Well	Date	CN	PO_4	SiO_2	NH_4	Ag	Cu	Ni	V	Zn	Pb-210 (pCi/l)	Ra-226 (pCi/l)	Ra-228 (pCi/l)	Th-230 (pCi/l)
Blomberg #1	06/07/84	<0.010	<0.10	3.60	<0.100	<0.01	<0.020	<0.040	<0.010	<0.005	0.0 ± 1.4	0.1 ± 0.1	--	0.2 ± 0.6
	01/10/84	--	<0.10	7.70	--	<0.01	<0.010	<0.040	<0.004	0.012	<1.5	<1.0	<1.0	<1.0
	06/12/84	--	--	--	--	--	--	--	--	--	--	--	--	--
Goggles #1	06/07/84	<0.010	<0.10	<0.10	<0.100	<0.01	<0.020	<0.040	<0.010	<0.005	--	--	--	--
	01/10/84	--	<0.10	7.70	--	<0.01	<0.010	<0.040	<0.004	<0.005	1.5	<1.0	<1.0	<1.0
	03/28/84	<0.001	<0.10	8.60	<0.003	<0.01	<0.001	<0.040	<0.004	<0.005	1.8	0.3 ± 0.3	<0.3	--
	11/03/82	--	--	--	--	--	--	--	--	--	--	--	--	0.0 ± 0.3
Moss #1	06/07/84	<0.010	<0.10	<0.10	<0.100	<0.01	<0.020	<0.040	<0.010	<0.005	0.0 ± 1.5	0.4 ± 0.2	--	0.0 ± 0.4
	01/10/84	--	0.19	7.06	--	<0.01	<0.010	<0.040	<0.004	<0.005	<1.5	<1.0	<1.0	<1.0
	03/28/84	<0.001	<0.10	9.60	<0.100	<0.01	<0.001	<0.040	<0.004	<0.005	1.4	0.7 ± 0.4	0.7	0.2
	12/08/83	<0.001	--	9.40	<0.100	--	<0.020	0.003	<0.004	0.012	--	--	0.3	0.4
	07/21/81	--	--	9.20	--	--	--	--	--	--	--	--	--	--
Westlake #1	06/07/84	<0.010	<0.10	9.40	<0.100	<0.01	<0.020	<0.040	<0.010	0.421	0.0 ± 1.6	0.2 ± 0.2	--	0.3 ± 0.9

[a]All values are in milligrams per liter (mg/l) unless otherwise noted. Dashed lines indicate no analyses.

Table C.2.25 Water quality analyses of confined ground-water samples obtained upgradient of the Riverton tailings pile[a]

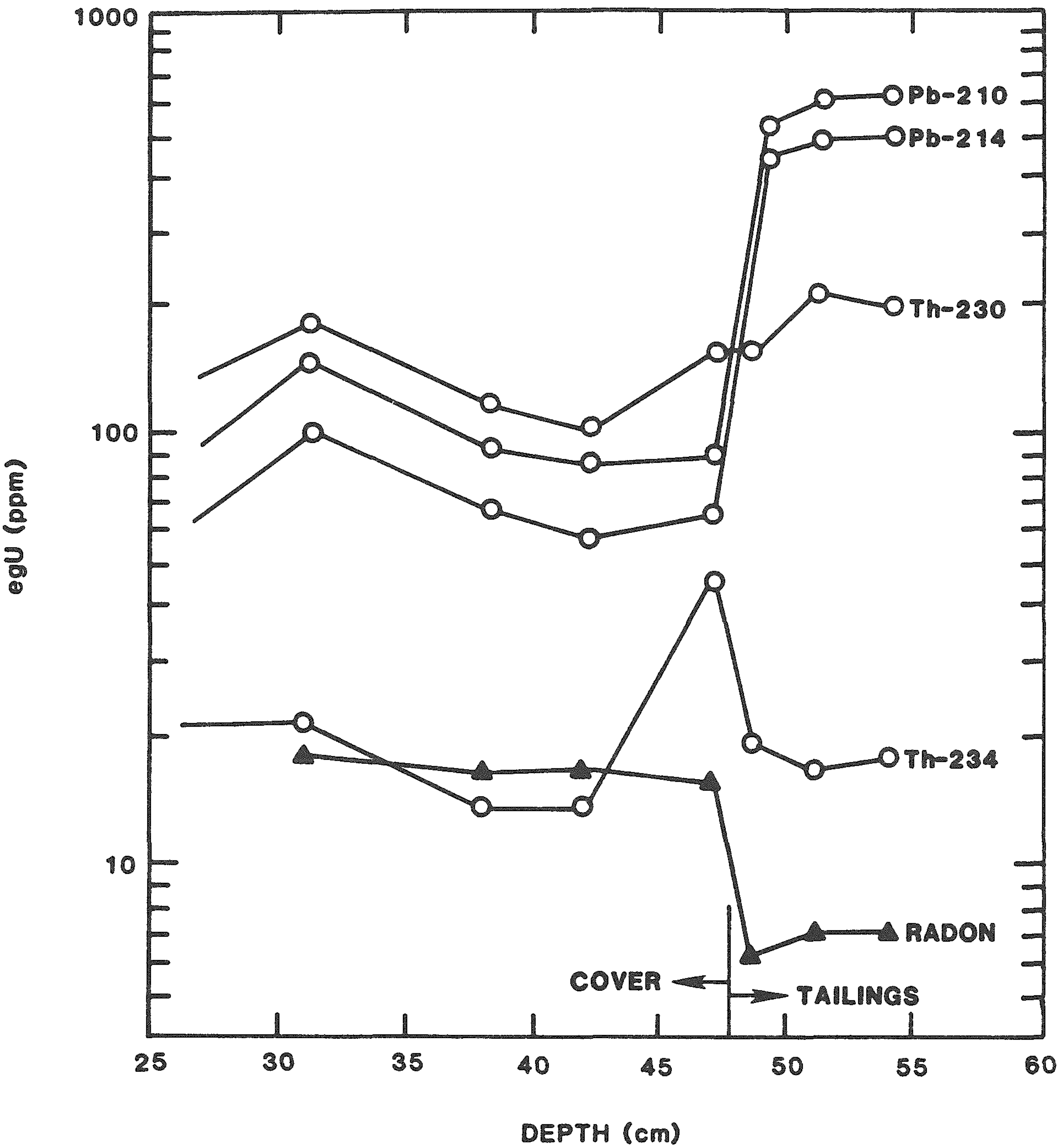
Well	Date	T (°C)	Electrical conductivity (micromhos per centimeter)	TDS	pH (standard units)	F	Cl	NO_3	Alkalinity (as $CaCO_3$)	SO_4	Na	K	Mg
RVT-106	06/18/84	--	--	1,350	--	<0.1	94	<0.1	--	583.0	248	2.40	19.8
	01/10/84	10.2	1,348	1,414	7.69	0.1	72	<1.0	72	<1.0	100	700	21.0
	12/08/83	--	--	1,450	--	<0.1	34	14.0	--	747.0	162	9.33	24.2
RVT-110	06/18/84	--	--	482	--	<0.1	39	<0.1	--	88.5	110	0.8	1.42
RVT-111	12/02/83	13.9	1,256	1,422	7.31	--	81	<10.0	220	580.0	160	6.0	49.0

Well	Date	Ca	Al	Fe	Mn	As	Ba	Cd	Cr	Hg	Pb	Sb	Se	U	Mo
RVT-106	06/18/84	142.0	<0.100	<0.04	0.39	<0.010	<0.100	<0.005	<0.010	<0.0002	<0.010	<0.003	<0.005	0.0111	<0.010
	01/10/84	250.0	<0.100	0.06	0.86	<0.005	<0.100	<0.005	0.001	--	0.001	<0.003	<0.005	0.012	1.100
	12/08/83	227.0	0.005	0.62	0.83	<0.001	0.038	--	<0.001	--	<0.001	0.010	<0.002	--	0.196
RVT-110	06/18/84	19.7	<0.100	<0.03	0.30	<0.010	<0.100	<0.005	<0.010	0.0002	<0.010	<0.003	<0.005	0.0007	<0.010
RVT-111	12/02/83	190.0	<0.010	0.03	0.55	<0.010	0.050	<0.010	<0.020	--	<0.020	--	0.010	--	0.070

Table C.2.25 Water quality analyses of confined ground-water samples obtained upgradient of the Riverton tailings pile[a] (Concluded)

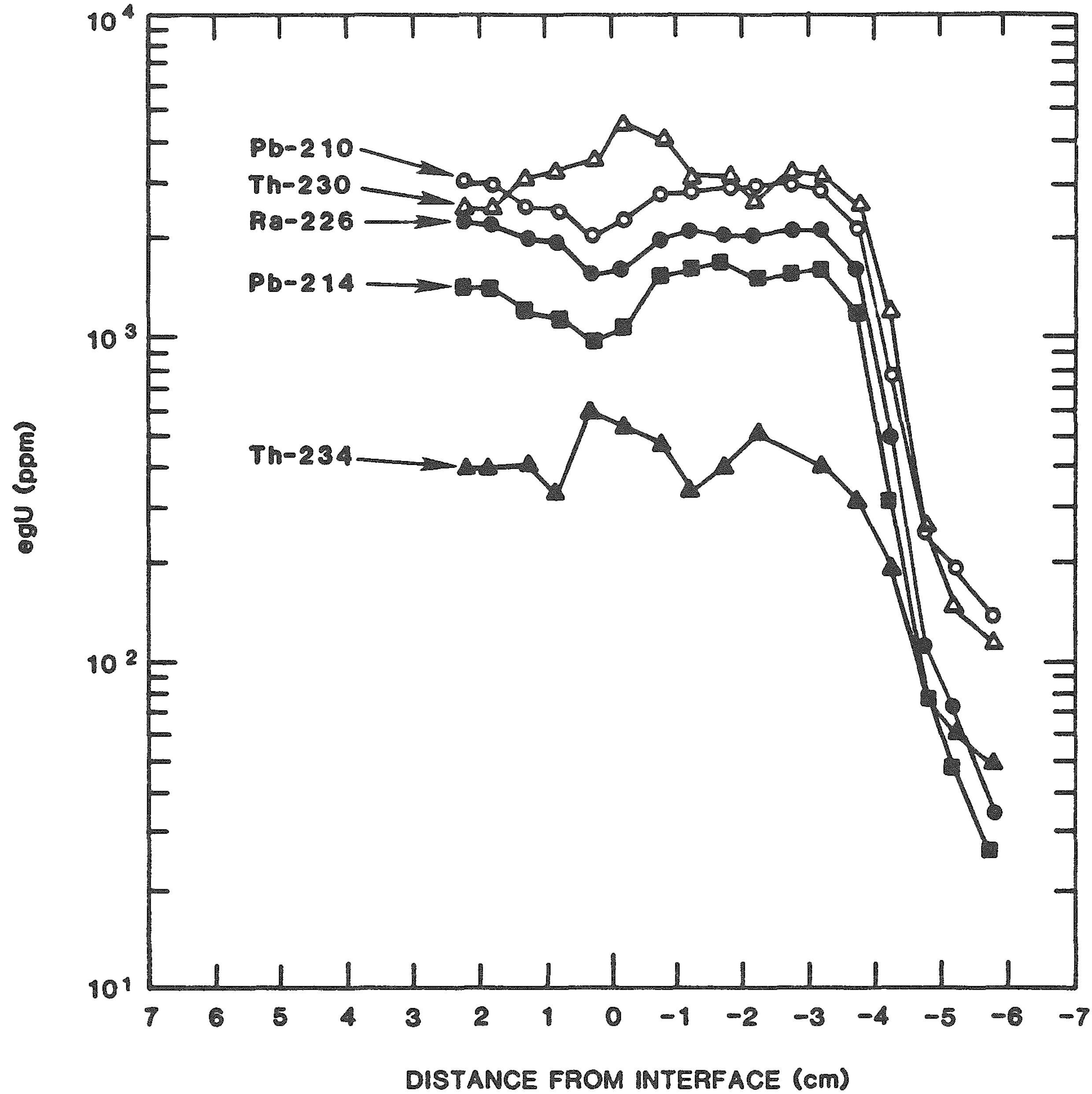
Well	Date	CN	PO_4	SiO_2	NH_4	Ag	Cu	Ni	V	Zn	Pb-210 (pCi/l)	Ra-226 (pCi/l)	Ra-228 (pCi/l)	Th-230 (pCi/l)
RVT-106	06/18/84	<0.010	<0.1	6.6	<1.0	<0.010	<0.02	<0.040	<0.010	0.0005	0.9 ± 1.3	0.1 ± 0.1	--	0.4 ± 0.6
	01/10/84	--	--	--	--	<0.010	<0.01	<0.040	<0.004	0.0050	<0.15	--	<1.0	<1.0
	12/08/83	<0.001	--	17.8	<0.1	0.001	<0.02	0.102	<0.004	0.0150	--	0.1	--	--
RVT-110	06/18/84	<0.010	<0.1	6.2	<0.1	<0.010	<0.02	<0.040	<0.010	0.0050	0.0 ± 1.6	0.4 ± 0.2	--	0.0 ± 0.4
RVT-111	12/02/83	--	--	--	--	--	<0.02	<0.500	<0.010	0.0800	<2.0	--	<1.0	<1.0

[a]Wells located 400 feet north of the tailings pile. All values are in milligrams per liter (mg/l) unless otherwise noted. Dashed lines indicate no analyses.



REF. LBL, 1984.

FIGURE C.2.24
RADIONUCLIDE DISTRIBUTION
ACROSS TAILINGS-COVER INTERFACE AT LBL LOCATION RA



REF. LBL, 1984.

FIGURE C.2.25
RADIONUCLIDE DISTRIBUTION
ACROSS TAILINGS-SOIL INTERFACE AT LBL LOCATION RB

series were in equilibrium, as determined by the quality of each measured nuclide. At equilibrium, all nuclide depth activities or equivalent U concentrations from a given sample would plot as a single point. Disequilibrium exists to the extent that the several nuclides plot as different values.

Dry Cheyenne alternate disposal site

Data from the four wells in the vicinity of the Dry Cheyenne site are summarized in Table C.2.4 (Section C.2.2.3). The water producing zones encountered are as shallow as 55 feet below the surface and as deep as 402 feet. Yields range from 1 to 50 gpm, and the two wells sampled for total dissolved solids (TDS) had concentrations of 4,130 and 5,500 mg/l (Kelly, 1984).

Borrow sites

No water quality data have been collected at the Little Wind borrow site, borrow sites 2 or 10, or the Boulder Flats borrow site.

C.2.5 DATA ANALYSES

C.2.5.1 Hydraulic data analysis

Pump test

Data obtained from the DOE pump tests were analyzed to estimate the hydraulic conductivity and storativity of both the unconfined system and the first confined sandstone of the Wind River Formation. Data obtained from the Hydro Geo-Chem pump test performed in the unconfined aquifer were not considered usable because the small average pumping rate of 0.88 gpm did not induce sufficient drawdown in the unconfined aquifer to permit reliable estimates of aquifer parameters. In effect, the small observed drawdowns were subject to excessive measurement error and resulted in wide variation of aquifer parameters between analyses of data for the various observation wells.

More consistent and responsive sets of drawdown data were obtained during two 24-hour pump tests performed by the DOE on wells RVT-111 and RVT-112 completed in the first confined sandstone and in the hydraulically connected alluvium and unconfined sandstone, respectively (Figure C.2.8). A complete record of the pump test data and analysis is on file at the UMTRA Project Office in Albuquerque, New Mexico.

Pump test analyses were based on various drawdown solutions to the radial ground-water flow equation which allowed determination of aquifer properties, given a known constant discharge rate and drawdown versus time relation as well as certain assumptions regarding physical properties of the aquifers. In all cases, transient flow was assumed throughout the duration of the pump test. Other assumptions included:

- o The aquifers are of infinite areal extent.
- o The aquifers are homogeneous, isotropic, and of uniform saturated thickness within the radius of influence.
- o The static potentiometric surface is horizontal within the radius of influence.
- o The aquifers are pumped at a constant discharge rate.
- o The pumped wells penetrate the entire thickness of the aquifers and, as a result, induce only horizontal flow components in the aquifers.
- o The well diameter is infinitesimally small relative to the areal extent of the aquifer, thereby permitting storage in the pump well to be neglected.

Analysis of pump test data obtained in the first confined sandstone was initially based on the Theis solution which describes drawdown in an aquifer for which transmissivity is constant in time and space, delayed yield is not occurring, and vertical leakage from overlying or underlying units is not significant. For large values of time and small radial distances from the well, the Jacob-Cooper approximation to the Theis solution was used (Davis and DeWiest, 1966). The Hantush-Jacob solution was used to refine the estimates of aquifer parameters when the drawdown became constant or plotted below the Theis type curve during later stages of the test which indicated that leakage from underlying or overlying units was significant (Kruseman and DeRidder, 1976).

Pump test data obtained for the unconfined alluvial and sandstone aquifer were analyzed using the same methods as those used to evaluate aquifer properties in the first confined sandstone. Also, recovery data obtained from the unconfined aquifer were analyzed using the Jacob-Cooper approximation. This method was used to validate hydraulic conductivity obtained from the other methods but could not be used to estimate storativity (Bouwer, 1978). Drawdown versus time plots for the unconfined aquifer reflected insignificant delayed yield effects except during early stages of the pump test. Because the maximum drawdown at the pumped well in the unconfined aquifer amounted to 20 percent of the initial saturated thickness, the maximum drawdown values for the observation wells were corrected using the relation (Walton, 1970):

$$s' = s - s^2/2b$$

where

s' = drawdown in an equivalent confined aquifer (feet).

s = measured drawdown in the unconfined aquifer (feet).

b = initial saturated thickness of the unconfined system (feet).

The maximum correction was 0.01 foot for a drawdown of 0.54 foot. Because the maximum correction was insignificant, actual drawdowns were used for the analyses.

Although the monitoring wells did not fully penetrate the pumped aquifer, both the RVT-111 and RVT-112 pump wells penetrated the entire thickness of respective pumped aquifers. Under conditions of horizontal flow induced by these wells, assuming negligible vertical leakage, the same drawdown would be observed at each monitoring well regardless of the depth of completion as long as the water level did not drop below the screened interval. Thus, there was no need to account for partial penetration effects.

The unconfined aquifer test was performed by applying an average pumping rate of 5.0 gpm at well RVT-112. This rate was the maximum rate possible that did not result in lowering of the water table below the screened interval. Because measurable drawdown was not observed in either the first or second confined sandstones and the curve for observation well RVT-100 fit the Theis type curve for later time data, upward leakage was not deemed to be significant and the Hantush-Jacob solution was not considered applicable. The saturated thickness was assumed to equal the distance between the initial water level elevation and the elevation at the bottom of the screened interval. Table C.2.26 lists results of the various pump test analyses for monitoring wells RVT-100, RVT-101, RVT-102, and RVT-113. Calculated values of hydraulic conductivity show a tight range of values indicating an isotropic condition in the cobbly alluvial deposits and connected sandstone. The reported values of hydraulic conductivity are within the range of values expected for alluvium in the area (McGreevy et al., 1969). An estimate for average, horizontal hydraulic conductivity of 56 feet per day (ft/day) for the entire unconfined system was calculated.

The estimated seepage velocity of the Riverton unconfined system can be calculated from the equation:

Table C.2.26 Results of pump test on unconfined aquifer, pump well RVT-112, Riverton site

Well number	Completed stratum	Radial distance from pump well (feet)	Method of analysis	Transmissivity (square feet per day)	Hydraulic conductivity[a] (feet per day)	Specific yield
RVT-100	Alluvium	5	Theis	901	44.2	0.070
RVT-100	Alluvium	5	Jacob-Cooper	1,188	58.2	0.014
RVT-100	Alluvium	5	Jacob-Cooper (recovery)	964	47.3	--
RVT-101	Alluvium	12	Jacob-Cooper	1,273	62.4	0.017
RVT-102	Alluvium	17	Jacob-Cooper	1,188	58.2	0.018
RVT-102	Alluvium	17	Jacob-Cooper (recovery)	1,273	62.4	--
RVT-113	Sandstone underlying alluvium	10	Jacob-Cooper	1,049	51.4	0.073

[a]Saturated thickness is 20.4 feet.

$$q_s = \frac{-K \nabla h}{n_e}$$

where

q_s = seepage velocity (feet per day).

K = hydraulic conductivity (56 ft/day from the DOE pump test).

h = hydraulic gradient (∇h = -0.0023 from LBL measured water levels).

n_e = effective porosity (0.30 for the alluvium and unconfined sandstone).

The seepage velocity was estimated to be 0.43 ft/day or 157 feet per year (ft/yr), requiring a time of 17.9 years for all contamination now present in the aquifer to reach the Little Wind River 2,800 feet downgradient of the pile, assuming no attenuation, dispersion, or diffusion which may increase the time of dissipation and reduce the contaminant concentration.

The second pump test was performed in the first confined sandstone at well RVT-111 by pumping at an average rate of 18 gpm. The drawdown data indicated that upward leakage was occurring at later times from the second confined sandstone in response to pumpage from the first confined sandstone. It was evident that water was being released from storage in the lower confining layer, and the data were analyzed by the Hantush method for semi-confined aquifers with vertical seepage (Lohman, 1972). Results of the analyses are presented in Table C.2.27. The average hydraulic conductivity of the first confined sandstone was estimated to be 30 ft/day.

The storage of water in each of the aquifers is characterized by the storage coefficient which is equal to the volume of water an aquifer releases from storage per unit area per unit change in head. For an unconfined system, the storage coefficient is almost equal to specific yield (S_y) because most of the water is released by gravity drainage. For unconfined systems, this value is on the order of 10^{-1} to 10^{-2}. An arithmetic average of the specific yield values presented in Table C.2.26 indicate an estimated specific yield of 3.0 x 10^{-2} for the unconfined aquifer. The first confined sandstone was characterized by a geometric average storage coefficient of 1.3 x 10^{-5} and 3.9 x 10^{-5} when storativity obtained for well RVT-106 using the Hantush modified method was not included. In a

Table C.2.27 Results of pump test on first confined sandstone, pump well RVT-111, Riverton site

Observation well number	Radial distance[a] from pump well (feet)	Method of analysis	Transmissivity (square feet per day)	Hydraulic[b] conductivity (feet per day)	Storativity	K'[c] (ft/day)
RVT-106	15	Hantush Modified	212	16.3	5.7×10^{-3}	4.9×10^{-1}
RVT-106	15	Jacob-Cooper	633	43.3	1.1×10^{-6}	--
RVT-107	>3	Jacob-Cooper	423	32.5	3.7×10^{-5}	--
RVT-108	40	Jacob-Cooper	488	37.5	1.1×10^{-5}	--
RVT-109	110	Hantush Modified	230	17.7	7.1×10^{-5}	4.0×10^{-2}
RVT-109	110	Jacob-Cooper	334	25.7	7.8×10^{-5}	--

[a] All observation wells completed in first confined sandstone.
[b] Saturated thickness is 13.0 feet.
[c] Vertical hydraulic conductivity assuming that the specific storage of the aquifer is equal to the specific storage of the aquitard and that leakage is through either overlying or underlying aquitard. Pump test results, i.e., drawdown in underlying sandstone but not in overlying unconfined aquifer, support leakage primarily from below.

confined system, most of the water is released by compression of the aquifer and expansion of the water, and the storage coefficient is on the order of 10^{-4} to 10^{-7} (Freeze and Cherry, 1979).

Packer tests

Double packer hydraulic conductivity tests conducted by FBDU in the confined sandstone and overlying confining shale and siltstone units beneath the tailings revealed horizontal conductivity values of between 0 and 0.2 ft/day in the units (Table C.2.28). This indicates a potential for leakage between the unconfined and confined aquifer systems. Horizontal hydraulic conductivity in the first and second confined sandstones ranged from 4.6 to 40,600 ft/day, but the latter value was believed to have been caused by fracturing in the second confined sandstone induced by the packer testing. An intermediate value of 14.7 ft/day was considered more representative of horizontal conductivity in the confined sandstones. This value was the same order of magnitude as the hydraulic conductivity of 30 ft/day estimated for the first confined sandstone on the basis of pump test results and thus substantiated previous calculations.

Slug and bailer tests

Estimates of hydraulic conductivity also were made on the basis of slug and bailer tests. The DOE slug tests results from the unconfined aquifer were analyzed using the Bouwer-Rice method for partially penetrating wells in unconfined aquifers (Bouwer, 1978). The geometric mean of hydraulic conductivity values obtained from the tests in the unconfined aquifer was 1.8 ft/day. This low hydraulic conductivity value reflects only a very small portion of the aquifer and is sensitive to configuration of the developed zone around the screened interval. Because the length of the sand pack or developed zone is typically twice the length of the screened interval in the DOE wells, it is likely that the low values reflect some percentage of a vertical component of flow.

A bailer test was also performed at well RVT-708 which was completed in the siltstone-shale-siltstone sequence underlying the unconfined system. Within 7 days after completion, the 2-inch well accumulated 0.420 cubic foot of ground water. Analysis of the bailer test data is shown in Table C.2.29. A hydraulic conductivity of 10^{-7} centimeter per second (cm/s) was estimated for large times after bailing (Ferris et al., 1962). Although the last measured hydraulic head was 7.09 feet below the initial head in the well, the conductivity appeared to be approaching a value on the order of 10^{-7} cm/sec. Thus, the shale confining

Table C.2.28 Results of double packer hydraulic conductivity tests, Riverton site

Borehole number	Stratigraphic unit	Interval tested[a] (feet)	Hydraulic conductivity (ft/day)	Remarks
2	Shale	23.0 - 28.0	0.2	
2	Sandstone	30.5 - 45.0	14.7	Water rose to top of casing after test.
3	Sandstone	27.0 - 45.0	4.6	Fractured at 24.0 feet; lost circulation during drilling.
4	Siltstone, sandstone	28.0 - 33.0	0.2	
4	Sandstone	42.0 - 47.2	40,600[b]	Fractured at 44.0 feet; lost circulation during drilling.
4	Sandstone	46.0 - 47.2	0.0	Took no water during test.

[a]Depths measured from surface.

[b]High value probably due to fracturing during test.

Table C.2.29 Bailer test results for shale aquitard, Riverton site

Drawdown (feet)	Time (seconds)	Transmissivity[a] (square feet per day)
15.95	600	3.49×10^{-6}
15.93	900	2.33×10^{-6}
15.92	1,200	1.75×10^{-6}
15.92	1,500	1.40×10^{-6}
15.88	1,800	1.17×10^{-7}
15.93	2,700	1.77×10^{-6}
15.82	3,600	5.87×10^{-7}
15.76	6,600	3.21×10^{-7}
15.52	12,600	1.71×10^{-7}
13.21	73,920	3.42×10^{-8}
11.12	161,580	1.86×10^{-8}
10.08	188,580	1.76×10^{-8}
8.32	250,080	1.61×10^{-8}
7.09	278,880	1.70×10^{-8}

[a]Transmissivity was determined with the equation (Ferris et al., 1962):

$$T = q/ts'$$

where

T = transmissivity (square feet per day).
q = volume of well (0.420 cubic foot).
t = time (seconds).
s' = drawdown (feet).

layer will tend to restrict contaminant migration, even though the downward vertical hydraulic gradient indicates there is a potential for downward ground-water flow.

The potential for vertical movement of ground water was further assessed by determination of hydraulic head levels in the unconfined and confined aquifers. Table C.2.30 lists static water levels at some DOE wells and one LBL well. The data suggest that a downward vertical hydraulic gradient exists with a difference in head, i.e., the head in the unconfined aquifer minus the head in the first confined sandstone ranged from 0.06 to 2.43 feet. Together with the measurable hydraulic conductivity associated with the shale confining layer, the downward gradient suggests that unconfined water may be moving into the underlying confined system.

The time for ground water to move to the first confined sandstone and to the more prolific and used deeper sandstones can be estimated with Darcy's Law. The assumptions made are:

- The average vertical hydraulic conductivity of the shale, claystone, and siltstone layers is 0.1 ft/yr. This value was from the bailer test results for horizontal hydraulic conductivity which is usually greater than vertical hydraulic conductivity. The value is reasonable for these types of sediment (Davis and DeWeist, 1966).

- The magnitude of the vertical gradient between the unconfined aquifer and first confined sandstone is 2.5 ft/10 ft = 0.25. This is the maximum measured value.

- The magnitude of the vertical hydraulic gradient between the first confined aquifer and the deeper confined aquifer is 5.0 ft/180 ft = 0.028. This value is conservative in areas away from a well pumping from the deeper sandstones because a comparison of Figure C.2.20 and measured water levels reported on Table C.2.31 (see page C-163) indicate that the vertical hydraulic gradient may be upward rather than downward.

- The total thickness of shale, siltstone, and claystone between the unconfined aquifer and the first confined sandstone is 10 feet (see Figure C.2.15).

- The total thickness of shale, siltstone, and claystone between the first confined aquifer and deeper confined aquifer is 100 feet (see Figure C.2.15).

- The effective porosity of the shale, claystone, and siltstone is 0.05, a conservatively low value (Davis and DeWiest, 1966).

Table C.2.30 Water levels at Riverton drilling sites, January, 1985

Well	Completion stratum	Top of casing (feet)	Depth to water (feet)	Water level (feet)
RVT-100	Alluvium	4,946.21	7.40	4,938.81
RVT-101	Alluvium	4,946.58	7.88	4,938.70
RVT-102	Alluvium	4,946.73	8.00	4,938.73
RVT-103	Alluvium	4,946.43	7.93	4,938.50
RVT-104	Alluvium	4,945.90	7.93	4,937.97
RVT-105	Alluvium	4,946.79	7.98	4,938.81
P-14	Alluvium	4,946.85	9.56	4,937.29
RVT-112	Alluvium and unconfined sandstone	4,947.27	8.50	4,938.77
RVT-113	Unconfined sandstone	4,946.40	7.61	4,938.79
RVT-106	1st confined sandstone	4,945.88	9.26	4,936.62
RVT-107	1st confined sandstone	4,945.98	9.60	4,936.38
RVT-108	1st confined sandstone	4,946.02	9.40	4,936.62
RVT-109	1st confined sandstone	4,946.08	8.92	4,937.16
RVT-110	2nd confined sandstone	4,946.44	9.55	4,936.99
RVT-708	Shale aquitard	4,930.60	8.66[a]	4,921.94[b]
RVT-707	Alluvium	4,930.60	3.89	4,926.11
RVT-702	1st confined sandstone	4,930.70	5.00	4,925.70
RVT-705	1st confined sandstone	4,930.70	4.65	4,926.05

[a]Measured 1 week following well completion.
[b]Unrecovered hydraulic head 1 week following well completion.

The estimated seepage velocity between the unconfined aquifer and first confined sandstone is:

$$\frac{(0.1 \text{ ft/yr})(0.25)}{0.05} = 0.5 \text{ ft/yr}$$

The estimated time needed to travel the 10 feet between the systems is 10 ft/0.5 ft/yr = 20 years.

The estimated seepage velocity between the first confined aquifer and deeper confined aquifers is:

$$\frac{(0.1 \text{ ft/yr})\ (0.028)}{0.05} = 0.056 \text{ ft/yr}$$

The estimated time needed to travel through the 100 feet of shale, claystone, and siltstone is:

100 ft/0.056 ft/yr = 1786 years

C.2.5.2 Geochemical data analysis

Analysis of ground water and tailings pore water quality data indicate that:

- o Sulfate, molybdenum, uranium, and other contaminants have been transported into the unconfined aquifer.
- o There is some geochemical evidence suggesting that the confined aquifer may have been contaminated by the unconfined ground water.
- o The source of the contamination is the uranium mill tailings pile.

Figures C.2.26, C.2.27, and C.2.28 show the sulfate (SO_4), uranium (U), and molybdenum (Mo) plumes that are presently observed in the unconfined ground water downgradient of the site. Elevated concentrations of other major dissolved species, including Na and Ca, also occur in the unconfined aquifer downgradient from the pile. As shown by the contaminant plumes for sulfate, uranium, and molybdenum, the contaminant migration parallels the hydraulic gradient. The plumes of sulfate and uranium appear to be mobile with the highest concentrations closest to the Little Wind River. The molybdenum plume appears to be attenuated or generated at a later time than the other two plumes. The highest concentrations of molybdenum are directly beneath the tailings pile.

An interesting feature of the sulfate and uranium plumes is that maximum concentrations occur downgradient

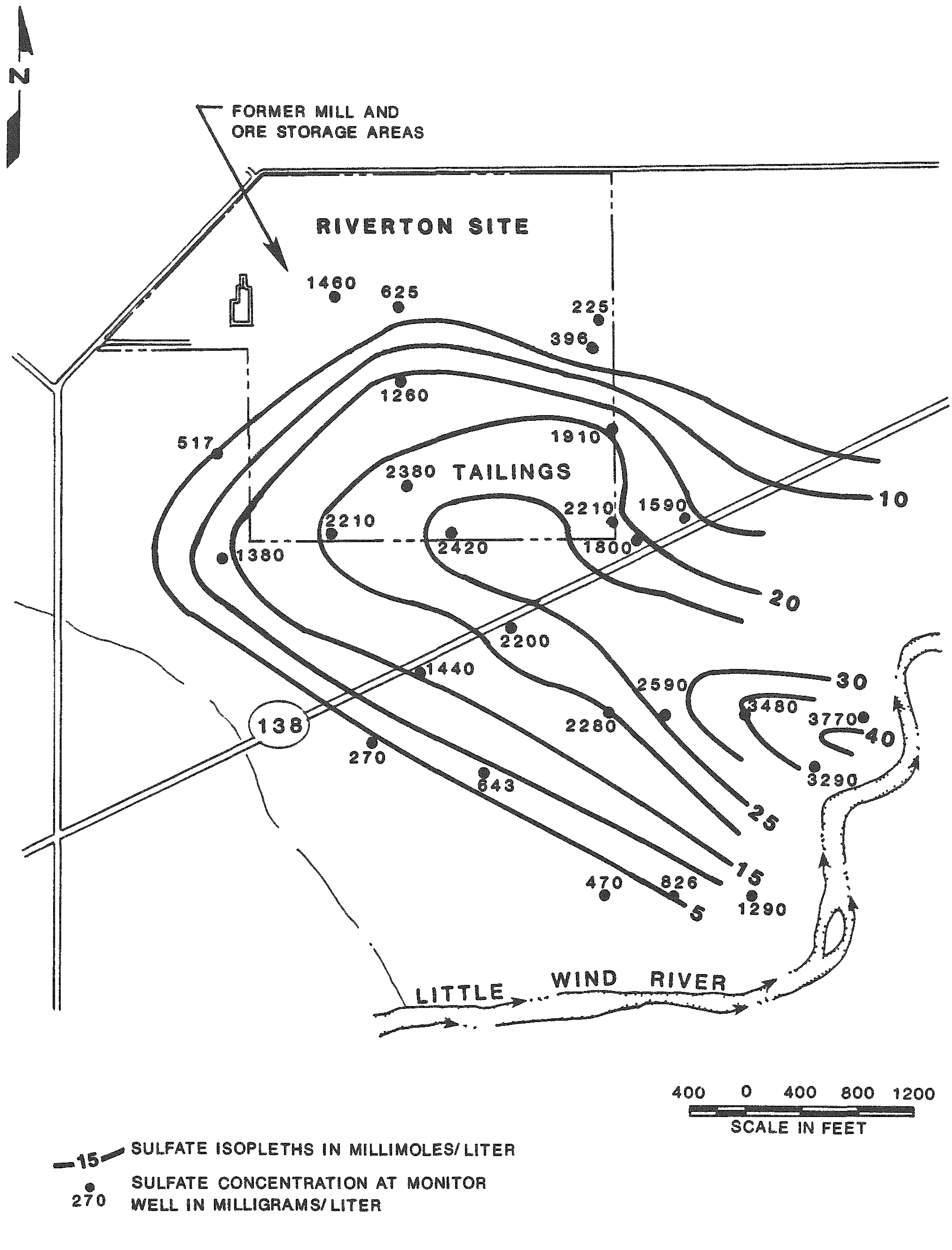


FIGURE C.2.26
SULFATE PLUME AT THE RIVERTON SITE

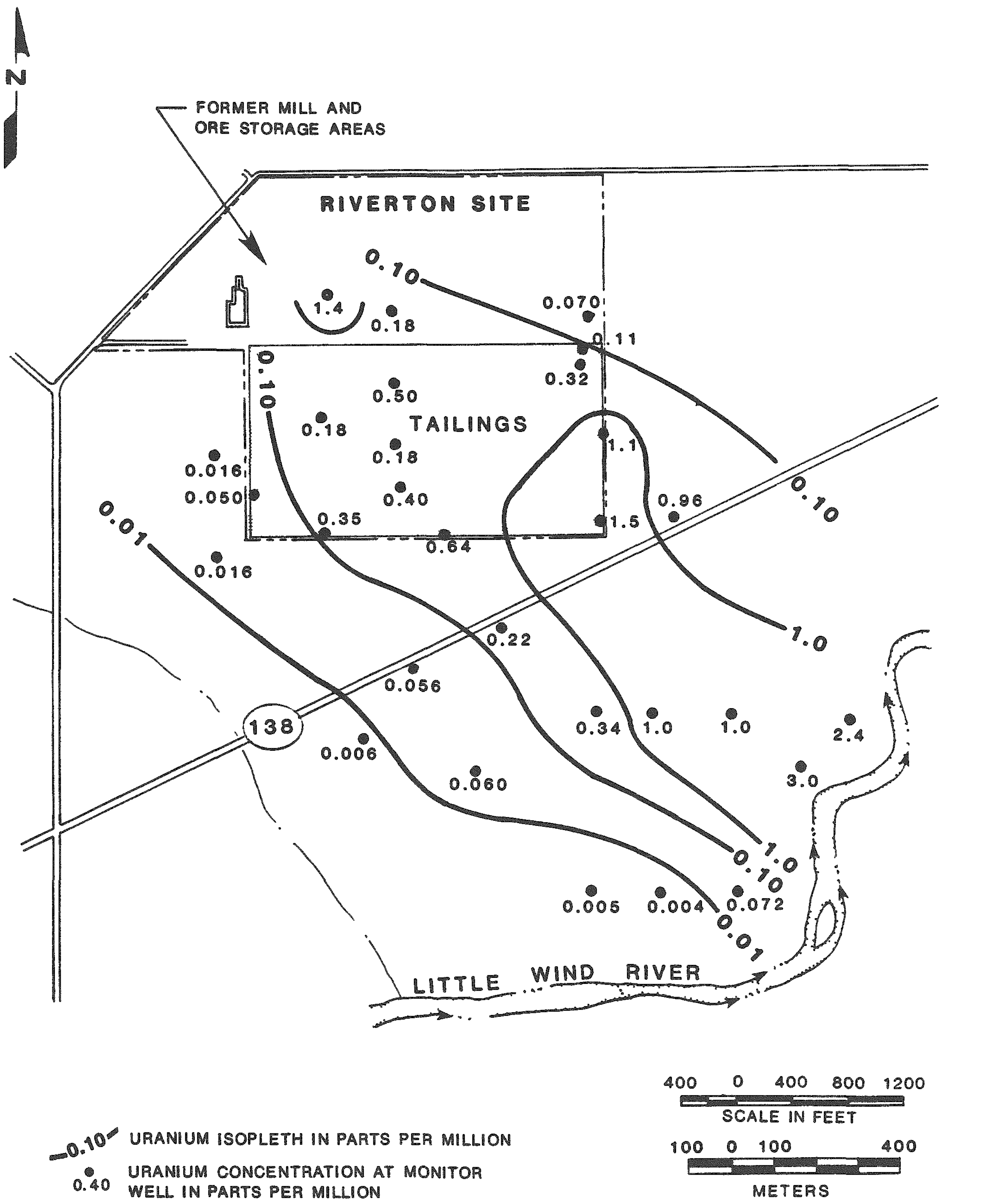


FIGURE C.2.27
URANIUM PLUME AT THE RIVERTON SITE

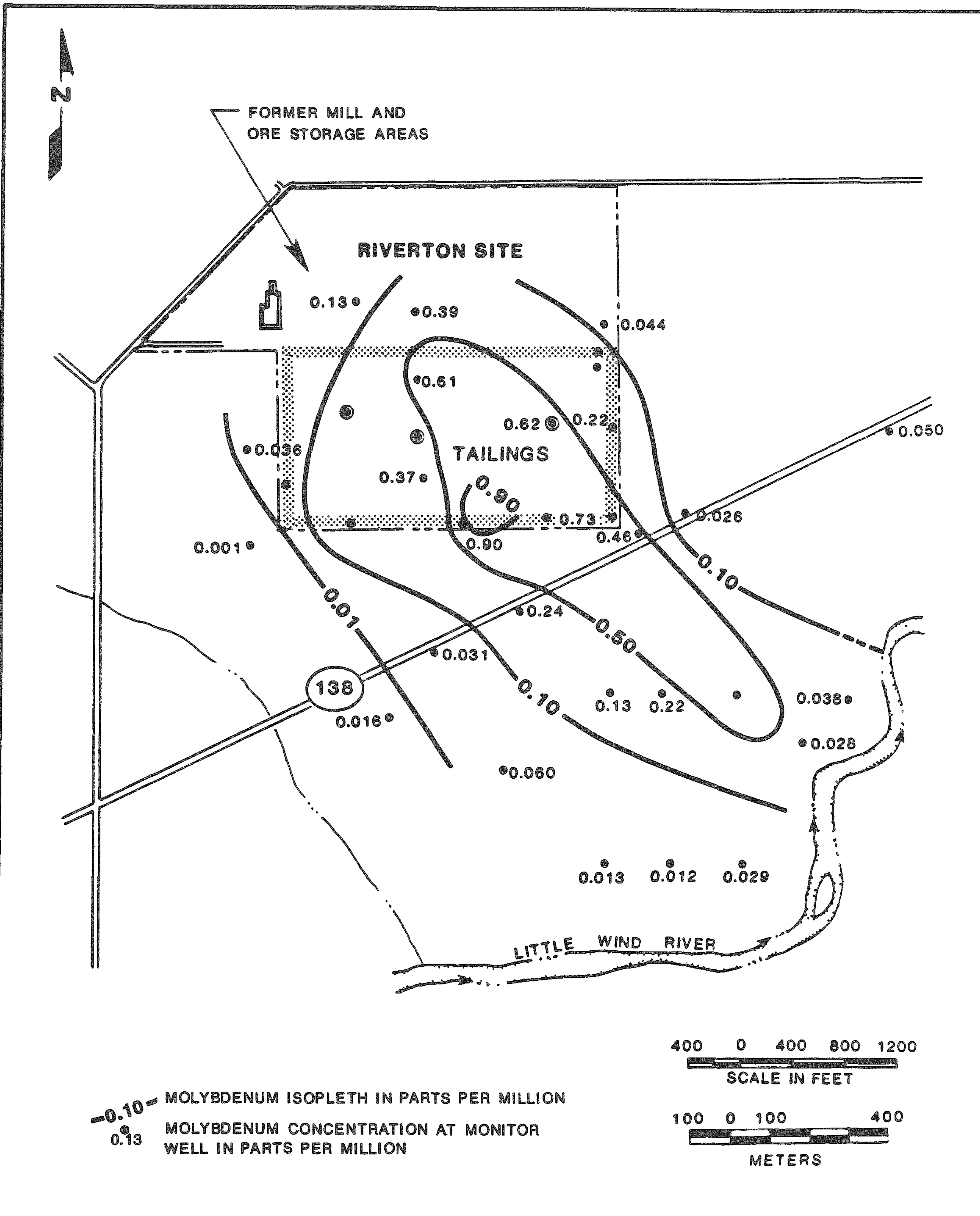


FIGURE C.2.28
MOLYBDENUM PLUME AT THE RIVERTON SITE

near the Little Wind River. This concentration offset from directly beneath the tailings pile indicates that accelerated past dewatering of the pile probably occurred during deposition of a tailings slurry. The current lower sulfate and uranium concentrations beneath the pile indicate continued mixing with tailings pore water but at reduced rates. It is possible that some of the sulfate contamination is due to sulfuric acid spills at the acid plant within the designated tailings site. However, it was conservatively assumed that all sulfate contamination resulted from the tailings.

Uranium concentrations in the shallow ground water beneath and downgradient from the pile are more than two orders of magnitude elevated above background concentrations. Aside from uranium, no appreciable elevated radionuclide activities were detected in the ground water of the unconfined aquifer.

The contaminant plume for molybdenum shows a different configuration relative to sulfate and uranium with maximum concentrations of 0.9 mg/l directly beneath the pile and decreasing concentrations downgradient. These elevated concentrations correlate with high molybdenum values in the base of the tailings. The observation that the highest concentrations of molybdenum are not found downgradient, as is the case for uranium and sulfate, could suggest that it is retarded by sorption. However, the anionic speciation of molybdenum at neutral ground-water pH, which was observed beneath the pile, would tend to minimize such effects. A lack of downgradient molybdenum may be related to more recent mobilization by intrusion of ground water into the base of the pile, neutralization of the pore water by the intruding ground water, and by the presence of carbonate tailings.

The neutralization mechanism has been documented in both LBL and GECR geochemical studies (GECR, 1983; Narasimhan et al., 1982; LBL, 1984). These studies have shown that, despite significant mixing with acidic tailings water, the pH of contaminated ground water beneath the pile varies from 6.35 to 6.99. This range of pH values is only slightly lower than uncontaminated ground water upgradient from the pile, which is characterized by a pH range of 7.50 to 7.60. This is indicative of significant buffering capacity resulting from dissolution of carbonate minerals in the sediments and from dissolved bicarbonate in the uncontaminated ground water. In addition, LBL researchers have calculated that these aquifers are supersaturated with respect to calcite, suggesting that the calcite buffering capacity has not been exceeded by reaction with acid.

The pH buffering due to acid neutralization by carbonate minerals in the soil and alluvium and by dissolved bicarbonate in the uncontaminated ground water under low pH conditions is governed by the reactions:

$$CaCO_3 + 2H^+ \rightleftharpoons Ca^{+2} + CO_2 + H_2O$$

(soil) (tailings)

and

$$HCO_3 + H^+ \leftrightarrows CO_2 + H_2O$$

(ground water) (tailings)

Production of CO_2 gas by these reactions is confirmed by high partial pressures of CO_2 measured in pore gases within the pile shown in Table C.2.31. The high concentrations of CO_2 relative to atmospheric concentrations indicate that CO_2 is being generated within the pile from dissolved bicarbonate at the low pH interface.

Table C.2.31 LBL gas component analysis from the Riverton tailings pile

Sample location	$O_2 - N_2$	CO_2	H_2O
RB	76.8	13.4	9.8
RA	75.7	18.2	6.2
P-2	92.9	0.45	6.6
P-7	59.5	31.4	9.1

Ref. LBL, 1984.

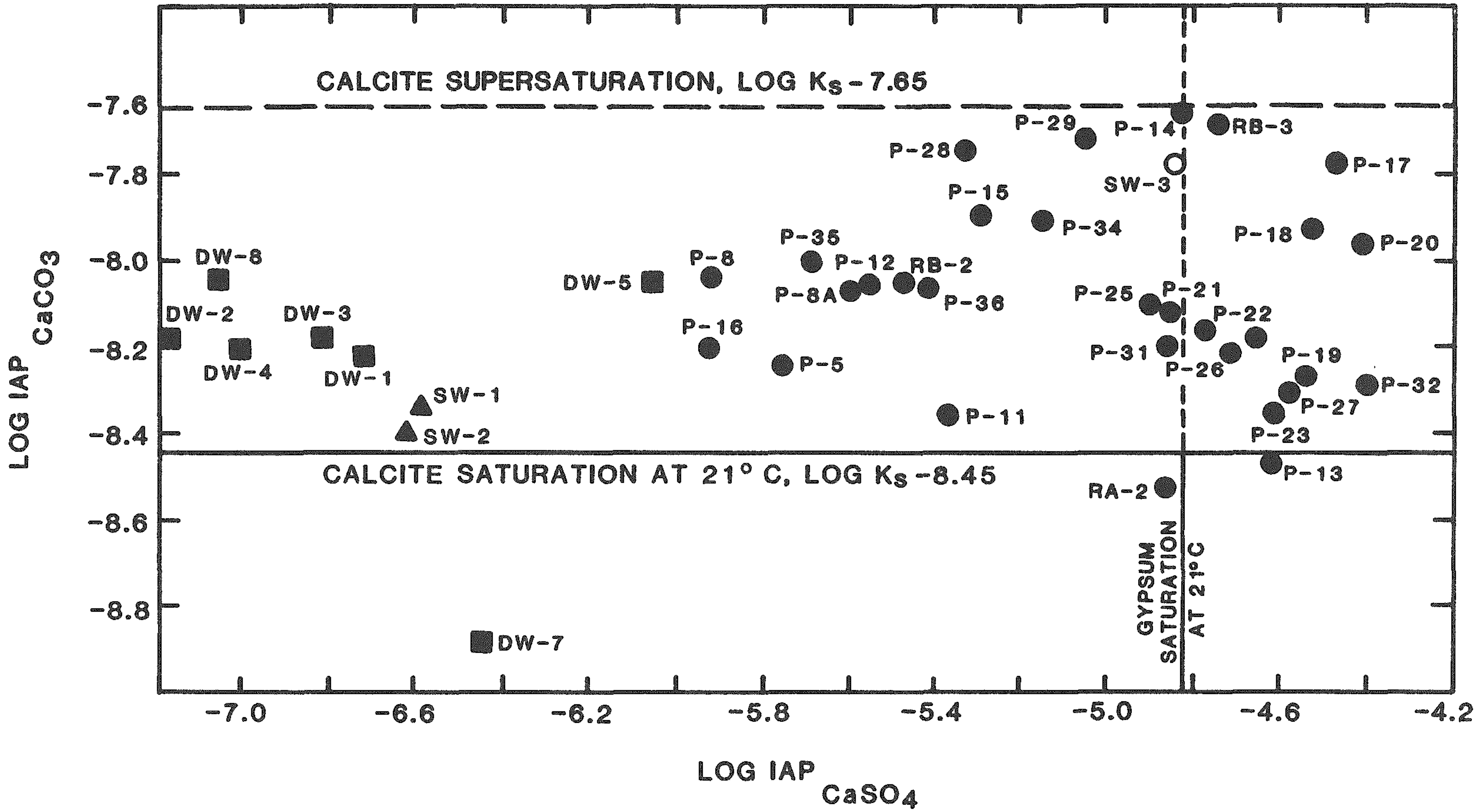
At the present time, insufficient data exist to actually predict the long-term buffering capacity of the ground water beneath the pile. Given the large amount of acidic tailings pore water that has already migrated from the pile into the underlying ground water and the subsequent reduction of acid sulfate concentrations in the remaining pore water, depletion of the carbonate buffer in the future appears to be unlikely (White et al., 1984).

The LBL geochemical studies have also suggested that unconfined ground water upgradient from the pile is subsequently undersaturated with respect to gypsum, whereas water beneath and downgradient of the pile is saturated or supersaturated (Figure C.2.29). The areal extent of gypsum saturation overlies the sulfate contaminant plume, indicating that the increase in tailings derived sulfate is a major cause of gypsum precipitation. An additional contribution is the aqueous calcium produced from dissolution of calcite. The overall chemical reaction leading to gypsum precipitation is:

$$CaCO_3 + H_2SO_4 + H_2O \longrightarrow CaSO_4 2H_2O + CO_2$$

(soil) (tailings) (gypsum) (gas)

Precipitated gypsum has been observed at the base of the tailings due to the above reaction of H_2SO_4 with



REF. LBL, 1984.

FIGURE C.2.29
LOGARITHMS OF SATURATION INDICES FOR CALCITE AND GYPSUM IN RIVERTON GROUNDWATER SAMPLES

carbonate minerals. Such gypsum deposits will remain stable or undissolved as long as pH conditions at the base of the pile do not become strongly acid. Proposed construction activities are expected to promote continued dissolution of carbonate minerals from the natural sediments, thereby preventing the basal pore waters from becoming acid. In fact, column tests performed by Pyrih (1982; 1983) using natural sediments and acid raffinate solutions suggest that additional sulfate minerals such as gypsum, bassanite, jarosite, and possibly anhydrite are likely to be precipitated at the base of the pile. These precipitation mechanisms may occlude pore space in the strata and thus act as natural barriers to further downward movement of contaminated percolating water in the future.

Profiles of major and selected trace elements are shown for location RB in Figure C.2.23. As indicated, maximum chemical concentrations occur at intermediate depths within the pile. Clearly these high concentrations, particularly iron and aluminum sulfate, are associated with very low pH. This chemistry is indicative of residual process water containing concentrated H_2SO_4 used to leach uranium during milling. Low pH water is effective in dissolving large amounts of iron and aluminum as well as trace metals such as selenium, copper, and zinc from silicate and oxide minerals (LBL, 1984).

In the upper 1.5 meters of the tailings pile, pore water pH is higher. This pH increase corresponds to a sharp drop in dissolved chemical concentrations, particularly in iron and aluminum. The normally occurring upward hydraulic gradients in the top meter of the tailings (Tokunaga and Narasimhan, 1982) indicate that the bulk of the annual precipitation is lost by evapotranspiration. However, the chemical data in Figure C.2.23 show consistent decreases in dissolved concentrations in the upper 1 meter and not increases as would be expected for simple evaporation. Relatively rapid infiltration measured in artificial recharge tests, coupled with heavy precipitation events such as summer thunderstorms, suggest periodic recharge events. Dilution and vertical displacement of the low pH pore water by recharge would result in the loss of acid soluble iron and aluminum salts (LBL, 1984).

The lower third of the tailings pile contains even more dilute neutral pore water than the upper 1.5 meters. Although the water table is normally 1 to 2 meters below the land surface, major and sustained flood events during spring runoff in the Wind River Mountains may raise the water levels in the alluvium close to land surface. This rise could result in intrusion of the shallow ground water into the base of the tailings, which appear to be below grade relative to the natural land surface. Dilution can also occur by upward movement of ground water into the partially saturated zone in the tailings by capillary action. Dilution by ground water is indicated by similar concentrations of major ions of pore water at the base of the tailings and ground water in the underlying alluvium. Such dilution also results in near background concentrations of iron, aluminum, and trace metals other than molybdenum and uranium in the pore water at the base of the tailings. As indicated in Figure C.2.23, however, molybdenum exhibits significant increases with depth. The dominant molybdenum species at neutral pH is the soluble MoO_4^{-2} anion (Baes and Messmer, 1976) which may be mobilized by ground-water intrusion. Decreased but still significantly elevated concentrations of uranium also are present in the base of the tailings, indicating aqueous complexation at neutral pH (LBL, 1984).

In the case of the Riverton site, it appears that the sharp increase in the pH of tailings pore waters between 2.8 and 4.0 meters in depth is related to the presence of alkaline carbonate tailings at this depth rather than to the dilution effects of ground-water inundation of the pile base. Under certain conditions, a number of toxic elements associated with the tailings could become desorbed from pile materials with an increase in pH. This is particularly true for oxidizing ground water in which adsorption processes tend to influence trace elements concentrations far more than solubility mechanisms (Henry et al., 1982). Both the ground water and the tailings pore water at Riverton are characterized by oxidizing conditions. These oxidizing conditions, along with the high pH levels that may be due to some combination of a ground-water dilution-neutralization mechanism and a carbonate tailings neutralization mechanism, may be responsible for the observed depletion of trace elements in the lower third of the pile. The pH measurements of samples from the four cores through the pile indicate that carbonate tailings occur near the base of the central part of the pile where the representative chemical profile was located (GECR, 1983). The acid tailings are characterized by a pH of less than 4.0, while the carbonate tailings have a pH of between 5.0 and 7.0 and contain a significant amount of sulfate derived from the acid leaching process indicating a mixture of carbonate and acid tailings.

Although it is possible that trace elements such as uranium, molybdenum, arsenic, and selenium may form soluble and potentially mobile species in oxidizing water at Riverton under both high and low pH conditions, the mobility of these constituents is controlled more by adsorption processes than by solubility. These elements appear to be adsorbed by amorphous ferric hydroxides, as well as by other oxides, clay minerals, and carbonaceous minerals present in the tailings. According to laboratory studies, adsorption of these elements is at a maximum under low or intermediate pH conditions and decreases with increasing pH levels (Henry et al., 1982).

Another geochemical mechanism that contributes to the low observed aqueous concentrations of trace elements in the pile base is co-precipitation and occlusion of these elements with precipitating ferric oxyhydroxides at the pH interface. The potential for precipitation of oxides and hydroxides is significant because these compounds have high surface energies and are effective in co-precipitation, occlusion, and adsorption of trace metals. Thermodynamically, the aqueous iron species in the tailings water would precipitate as tailings water mixes with the buffered ground water underlying the tailings. The precipitation of iron and manganese oxides and hydroxides, along with neutralization, forms an interface zone within 1 meter of the tailings base and generally serves as a mechanism to prevent the migration of trace metals into the environment.

Precipitation of contaminants at the lower interface or within a short distance below the tailings is well documented for the Riverton site. The mechanism of neutralization and dilution of the sulfate complexes from the acid tailings near the carbonate tailings, followed by precipitation of carbonate and hydroxide salts in the soils, may explain the observed profiles of the chemical elements across the interface (GECR, 1983).

Thus, it appears that the presence of carbonate tailings and calcium-carbonate oversaturation of the ground water may actually buffer the free acidity of the acidic tailings pore water, causing the precipitation of iron hydroxides together with adsorbed trace constituents. Only if the pH at the base of the pile were to increase to 8.0 or 10.0 and if oxidizing infiltration were not reduced, would potential increased migration of constituents such as U, Mo, Se, and As become a concern. No significant changes in either pH or Eh are expected as a result of any of the proposed remedial action measures.

Interestingly, the neutralization zone at roughly a 3-meter depth corresponds to a zone having low permeability (see Figure C.2.22). It appears that precipitated species have clogged some of the pore spaces. Such a zone could effectively inhibit movement of many otherwise mobile constituents.

Given the high calcite buffering capacity of the ground water and the similarity of the major chemistry between pore water in the pile base and in the underlying aquifer, the possibility that the chemical interface in the lower part of the pile was developed solely in response to dilution caused by inundation events was investigated. Historical records from the Little Wind River indicate a maximum flood discharge after pile disposal of 14,700 cfs on June 17, 1963 (SHB, 1984). The maximum discharge of the Wind River north of the site after the 1958 water year was 9,550 cfs on June 24, 1967 (USGS, 1984c). Neither of these flood flows could alone have caused ground-water inundation of the pile. However, coupled with the large irrigation return flows characteristic of spring and summer months, a flood event could have caused inundation of the tailings base.

For purposes of accurately defining the extent of ground-water contamination in the unconfined and confined ground-water systems, only those samples which had a cation-anion balance error of plus or minus 5 percent or less were given consideration. All other samples were assumed to have been subject to sampling or measurement error and would not have been reliable indicators of contamination from the pile. Table C.2.19 lists all samples judged to be invalid on the basis of this criterion.

A review of the ground-water quality for a number of wells completed in the unconfined and confined aquifers reveals some evidence of contamination in the confined ground water. The review included confined ground water sampled from the domestic wells shown in Figure C.2.30. In particular, three wells completed in the confined system appear to have been contaminated by constituents originating in the tailings pile. Elevated concentrations of alkali and alkali-earth metals, chloride, sulfate, and uranium, which are present in high concentrations within the tailings pile, have been found in wells RVT-106 and RVT-111 and in the Westlake domestic well.

Four samples taken upgradient of the tailings pile were used to characterize the chemistry of the native, or background, unconfined waters (see Table C.2.20). These samples were fresh to slightly brackish with total dissolved solids (TDS) values ranging from 290 mg/l to 1,400 mg/l and were dominated by HCO_3 or SO_4 and Na or Ca. Their pH values were near neutral, ranging from 6.97 to 7.78. None of these samples contained an inorganic constituent in excess of the EPA primary drinking water standards, but all of them contain at least one constituent in excess of the EPA secondary drinking water standards. Above standards concentrations of TDS, Cl, SO_4, Fe, or Mn are present in some of these samples. The primary standards are based on health considerations, and the secondary standards on aesthetic considerations. State of Wyoming Class I standards for TDS, Cl, SO_4, Fe, Mn, Se, or Ra were exceeded in some samples.

Thirteen samples taken upgradient of the tailings pile were used to characterize the chemistry of the background confined ground water. Water quality analyses for these samples are presented in Table C.2.21. The samples had TDS values ranging from 426 to 814 mg/l, and most of the samples were dominated by Na and SO_4. The water tends to become less sodic with depth. The Ca content of deeper samples was much lower than that of the shallower samples. Most of the samples indicated alkaline conditions with pH values between 8.0 and 9.0. None of these samples contained any inorganic constituents in excess of the EPA primary

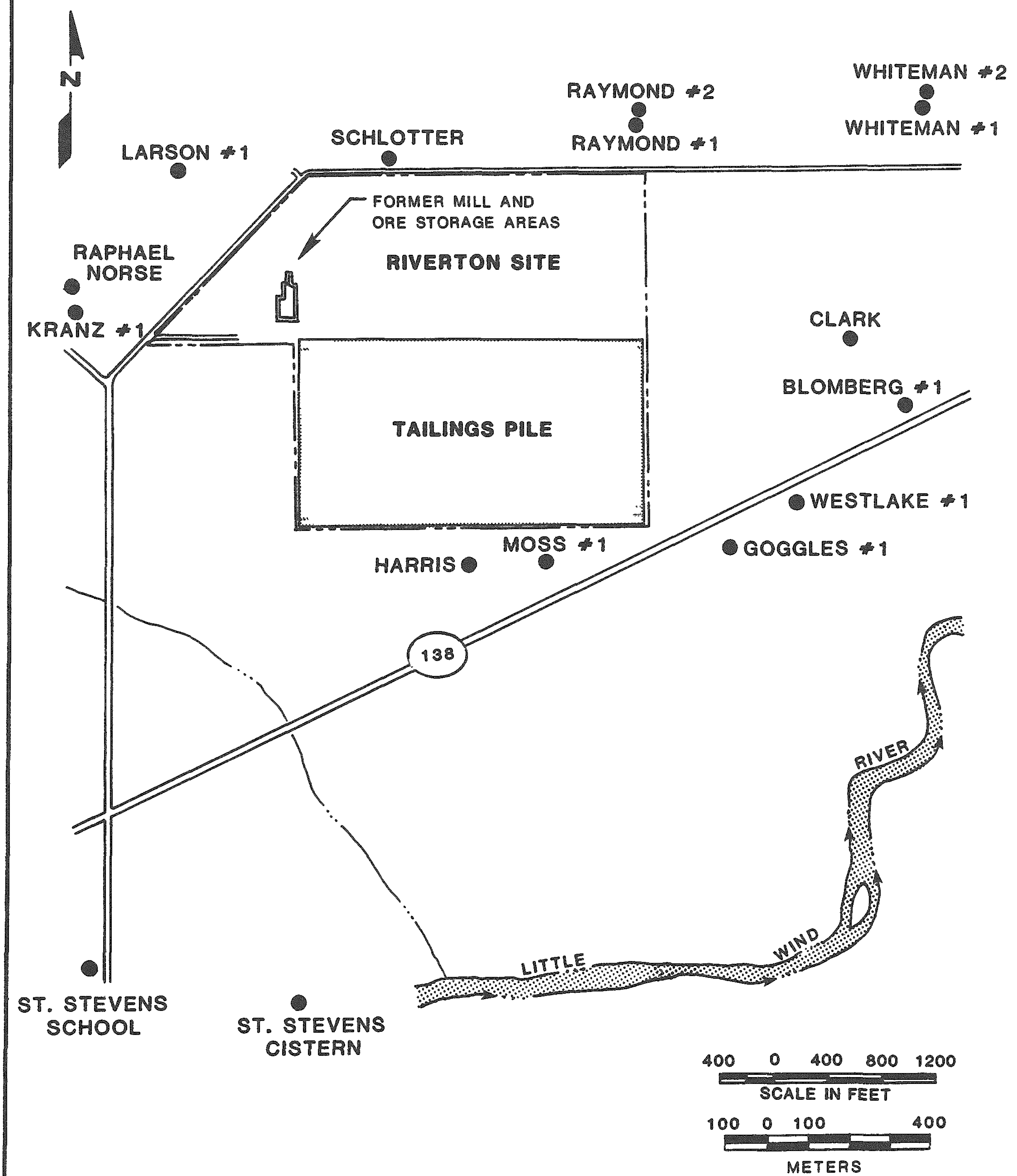


FIGURE C.2.30
RIVERTON DOMESTIC WELLS SAMPLED BY DOE FOR GROUNDWATER QUALITY

drinking water standards, but several of them exceeded the EPA secondary standards for TDS, SO_4, Mn, or pH.

With one exception, the background waters of the confined aquifer are alkaline, with pH values ranging from 7.80 to 8.91. The pH values of confined ground water downgradient of the pile, again with one exception, range from 6.88 to 8.95, about the same as the background waters (see Table C.2.24); therefore, a high pH does not appear to be an indication of contamination. Confined ground water containing indications of contamination has relatively low values of pH; pH in the Westlake well sample was 6.88 while pH values in wells RVT-106 and RVT-111 ranged from 7.7 to 7.9. Low values of pH are also a reliable indicator of contamination in the unconfined aquifer.

Information regarding contamination of unconfined and confined ground water can be obtained by measurement of the concentrations of certain conservative species in the confined water. Some sample properties are relatively conservative and are unaffected by processes which alter solution composition. Chloride is a conservative species whose concentration in solution is usually altered only through mixing with other solutions. The same can be said of SO_4 as long as it is not supersaturated with respect to gypsum or other sulfate minerals. Uranium in the form of UO_2 is not as conservative as Cl or SO_4 but will often remain in solution by forming complexes with CO_3 or SO_4. Finally, although Na, K, Mg, and Ca commonly participate in cation exchange reactions, the sum of their equivalencies will often remain nearly constant because they tend to exchange with one another on an iso-equivalent basis.

On the basis of these properties, a definition of contamination was established using the conservative tracers. A ground-water sample is defined as being contaminated by the uranium tailings pile if any of the following observations can be made:

- The sample contains more than 92 mg/l of chloride or more than 582 mg/l of sulfate and more than 19.47 milliequivalents per liter (meq/l) of total sodium, potassium, magnesium, and calcium. These are the maximum concentrations found in any unconfined background sample.

- The sample contains more than 0.01 mg/l of uranium. This is the highest concentration found in any background sample.

- The sample contains a detectable amount of molybdenum. The tailings pore water contains high concentrations of molybdenum while none has been found in any unconfined background sample.

According to the above definition of contamination in the unconfined ground water, a number of contaminated wells in the unconfined aquifer were identified and listed in Table C.2.32.

Comparison of background unconfined samples with unconfined samples taken near to and downgradient of the pile shows that the latter samples may contain elevated concentrations of Na, K, Mg, Ca, Cl, SO_4, Al, Fe, Mn, As, Cr, Mo, Se, U, Pb-210, Ra-226, Ra-228, and Th-230. There are no EPA drinking water standards for Na, K, Mg, Ca, Al, Mo, or U. Although concentrations of Th-230, As, and Cr are elevated in some wells, they do not exceed the EPA primary drinking water standards. Above-standards concentrations of Ra-226 plus Ra-228 have been found only in one well, DH-3, which is completed directly beneath the pile. Above-standards concentrations of Se have been found in two wells, DH-3 and P-32. Well P-32 is 0.5 mile southwest of the pile. It should be noted that above-standards concentrations of Se have been reported in only two of six samples taken from these wells. Selenium was not detected in the other four samples. Concentrations of Fe, Mn, and SO_4 exceeding the EPA secondary drinking water standards are found in most of the alluvial wells installed south and southwest of the pile as well as those in the ore storage area north of the pile. Table C.2.32 shows which wells contain elevated or above-standards concentrations of As, Cr, Mo, U, Th-230, Ra-226 plus Ra-228, Se, Fe, Mn, or SO_4. Most of these constituents are known to exist in high concentrations within the tailings pore solution (see Table C.2.18). Therefore, it is reasonable to assume that they originated in the pile or the ore storage area and not in some as yet undetermined source.

Contaminated samples from the unconfined aquifer will not necessarily contain elevated concentrations of all the constituents listed above for the following reasons:

- o The chemical composition of the pile is spatially variable.
- o The chemical environment may change as constituents are transported away from the pile. This could cause many species to leave solution.
- o Some constituents may be retarded and would be transported more slowly than others.
- o Many species are subject to cation exchange.

Figure C.2.31 is a bivariate plot of sulfate and chloride for analyses from the contaminated unconfined system and the confined system. Sulfate and chloride act conservatively and are not subject to significant chemical precipitation or dissolution after participating in reactions immediately beneath the pile. Contaminated confined water

Table C.2.32 Riverton wells indicating contamination of unconfined ground water

	Elevated concentrations but not above Federal or state standards					Concentrations above Federal or state standards					
Well	As	Cr	Mo	U	Th-230	Fe	Mn	SO_4	Ra-226 + Ra-228	Se	Cl
DH-3	X		X	X		X	X	X	X	X	X
RVT-707			X	X		X	X	X			
P-9				X		X					
P-10				X				X			
P-13			X	X		X		X			
P-18			X	X		X		X			
P-19			X	X		X		X			
P-21			X	X		X		X			
P-22			X	X		X		X			
P-23			X	X		X	X	X			X
P-24			X	X		X	X	X			X
P-25			X	X				X			X
P-26			X	X			X	X			
P-27			X	X				X			
P-28								X			X
P-29			X					X			
P-31			X	X			X	X			X
P-32	X	X	X	X	X	X	X	X		X	
P-34			X	X				X			
P-35				X				X			
RVT-101			X	X			X	X			
RVT-104			X	X			X	X			
RVT-105			X	X	X		X	X			
RVT-112		X	X		X		X	X			
RVT-113			X	X		X	X	X			
P-11				X				X			
P-16				X							

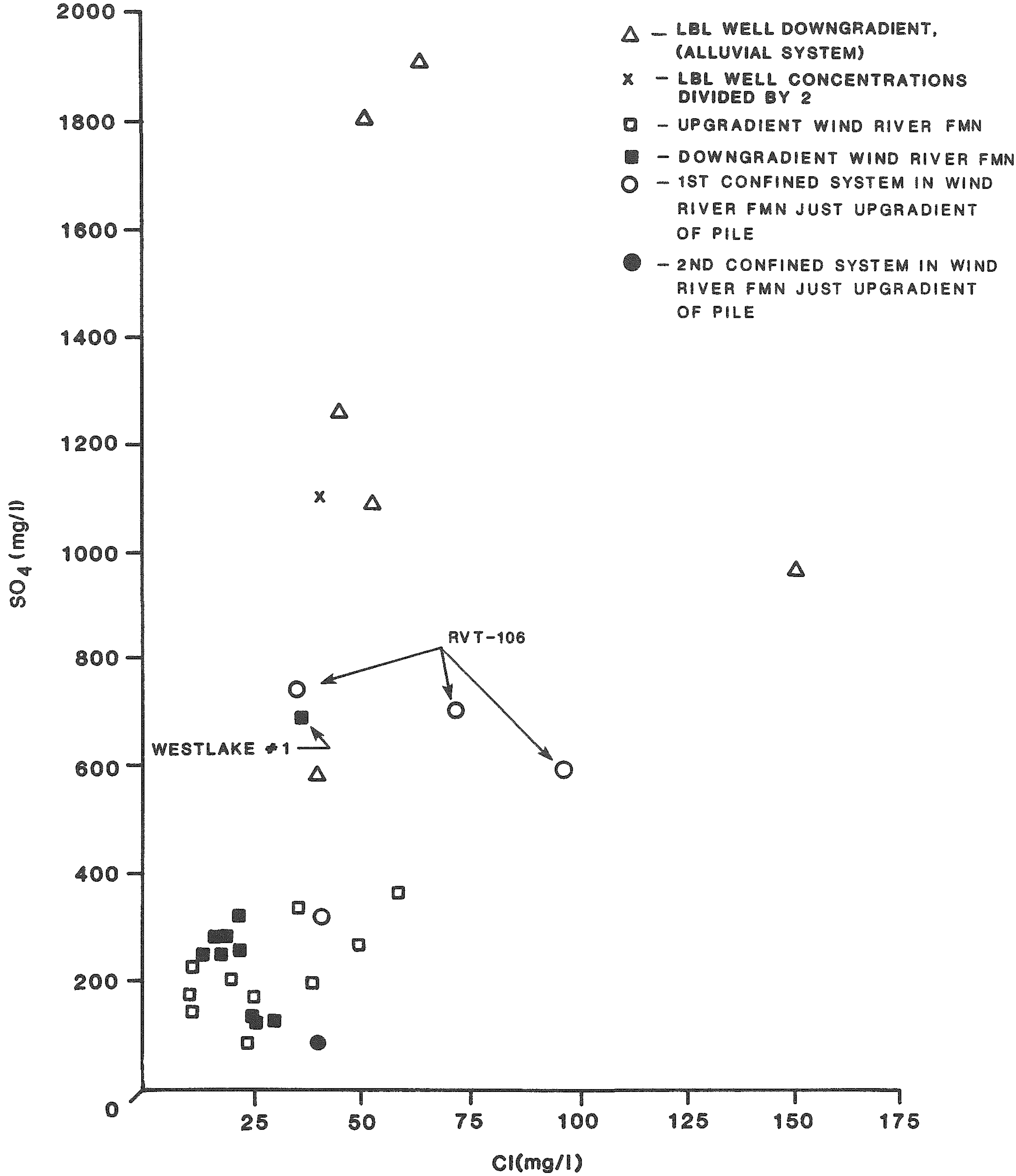


FIGURE C.2.31

BIVARIATE PLOT OF SULFATE AND CHLORIDE IN RIVERTON GROUNDWATER

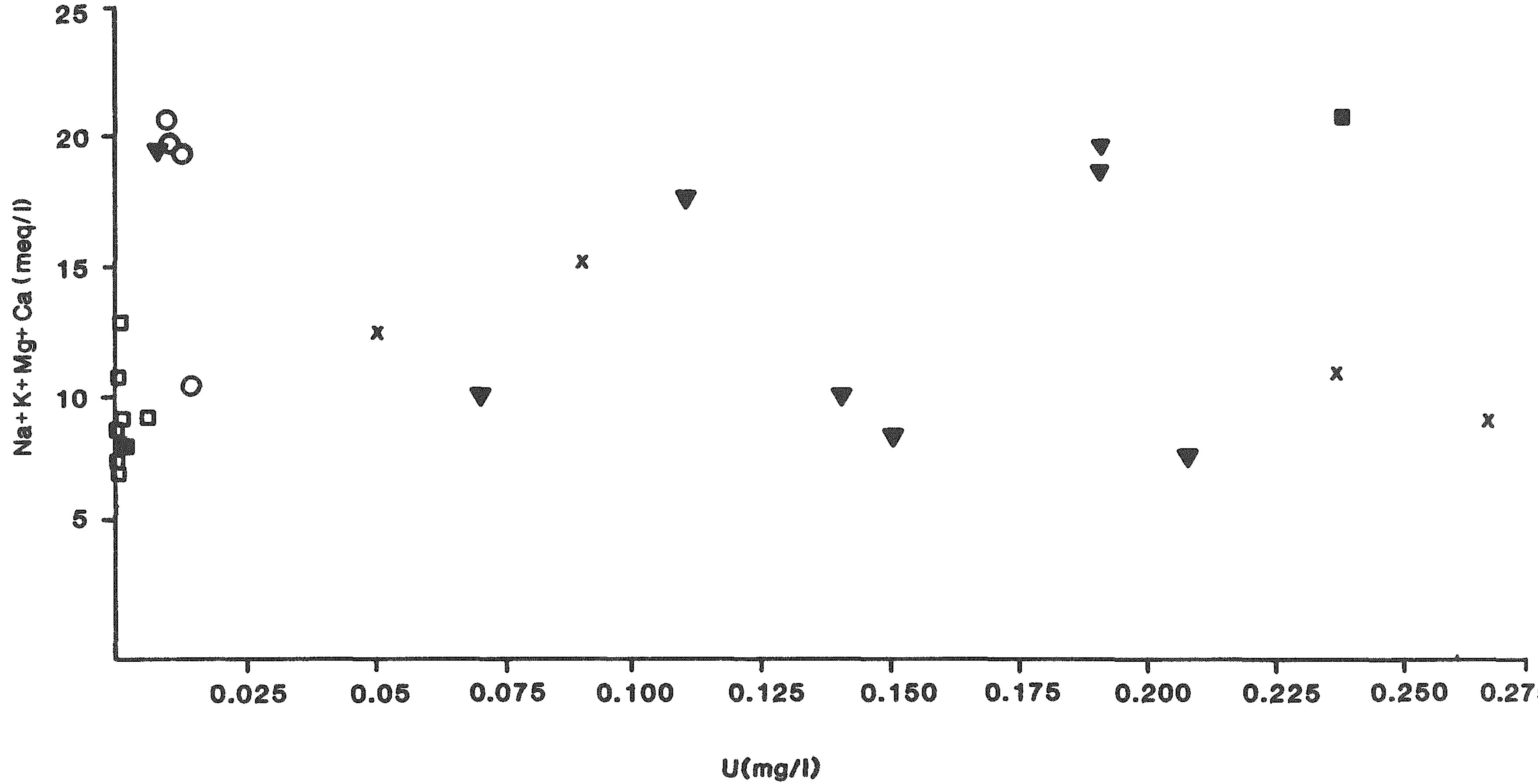
would plot on a line intermediate to contaminated unconfined water and uncontaminated water from the confined system. Figure C.2.31 indicates that Cl and SO_4 concentrations of ground-water samples from well RVT-106 and the Westlake domestic well have been shifted from those associated with uncontaminated confined ground water toward those associated with contaminated unconfined ground water. The bivariate plots for samples from these wells therefore imply that a certain amount of mixing of contaminated unconfined water and uncontaminated confined water may have occurred.

Contamination is also indicated by Figure C.2.32 which is a bivariate plot of uranium concentrations and the sum of major cation equivalences. Again, these elements represent conservative indicators of solute movement. According to this figure, the sum of Na^+, K^+, Mg^{+2}, and Ca^{+2} concentrations and uranium concentrations indicate a shift toward the composition of contaminated unconfined ground water in samples obtained from wells RVT-106, RVT-111, and the domestic Westlake well.

The contamination in the sample from the Westlake well may be due to perforated or screened casing through the unconfined aquifer in addition to the confined aquifer. Logging of the Westlake well to determine the contributing interval and additional sampling of the Westlake, RVT-106, and RVT-111 wells may be needed to identify the sources of the observed, elevated contaminant concentrations.

Elevated sulfate and uranium concentrations observed north of the pile and east of the mill area appeared to be related to contamination from the ore storage area situated in the northern portion of the site. These concentrations are not likely to be associated with northward radial flow of residual tailings pore water due to initial pile drainage because these constituents are mobile and would probably have been transported downgradient of the pile by this time. Moreover, concentrations to the west of the pile are not similarly elevated.

Contamination of unconfined ground water north of the pile by the ore storge area implied that the direction of flow in the northern part of the site was toward the southeast, consistent with the flow direction observed downgradient of the site. The possibility of northward movement of contaminated ground water toward the Wind River was investigated by installing a series of piezometers between the pile and the Wind River (Figure C.2.33). Together with measurements obtained from other piezometers north of the pile, the water levels in the piezometers indicated that the shallow ground-water divide between the Wind and Little Wind Rivers is near the ore storage area (Figure C.2.34). Thus, any ground-water contamination originating from the pile would not migrate toward the Wind River in advecting ground water.



x — DOWNGRADIENT ALLUVIAL SYSTEM CONCENTRATIONS DIVIDED BY 5

□ — UPGRADIENT WIND RIVER FMN

■ — DOWNGRADIENT WIND RIVER FMN

○ — 1ST CONFINED SYSTEM IN WIND RIVER FMN JUST UPGRADIENT OF PILE

▼ — UPGRADIENT ALLUVIUM NEAR PILE

FIGURE C.2.32

BIVARIATE PLOT OF URANIUM AND TOTAL MAJOR CATION EQUIVALENCES FOR RIVERTON GROUNDWATER

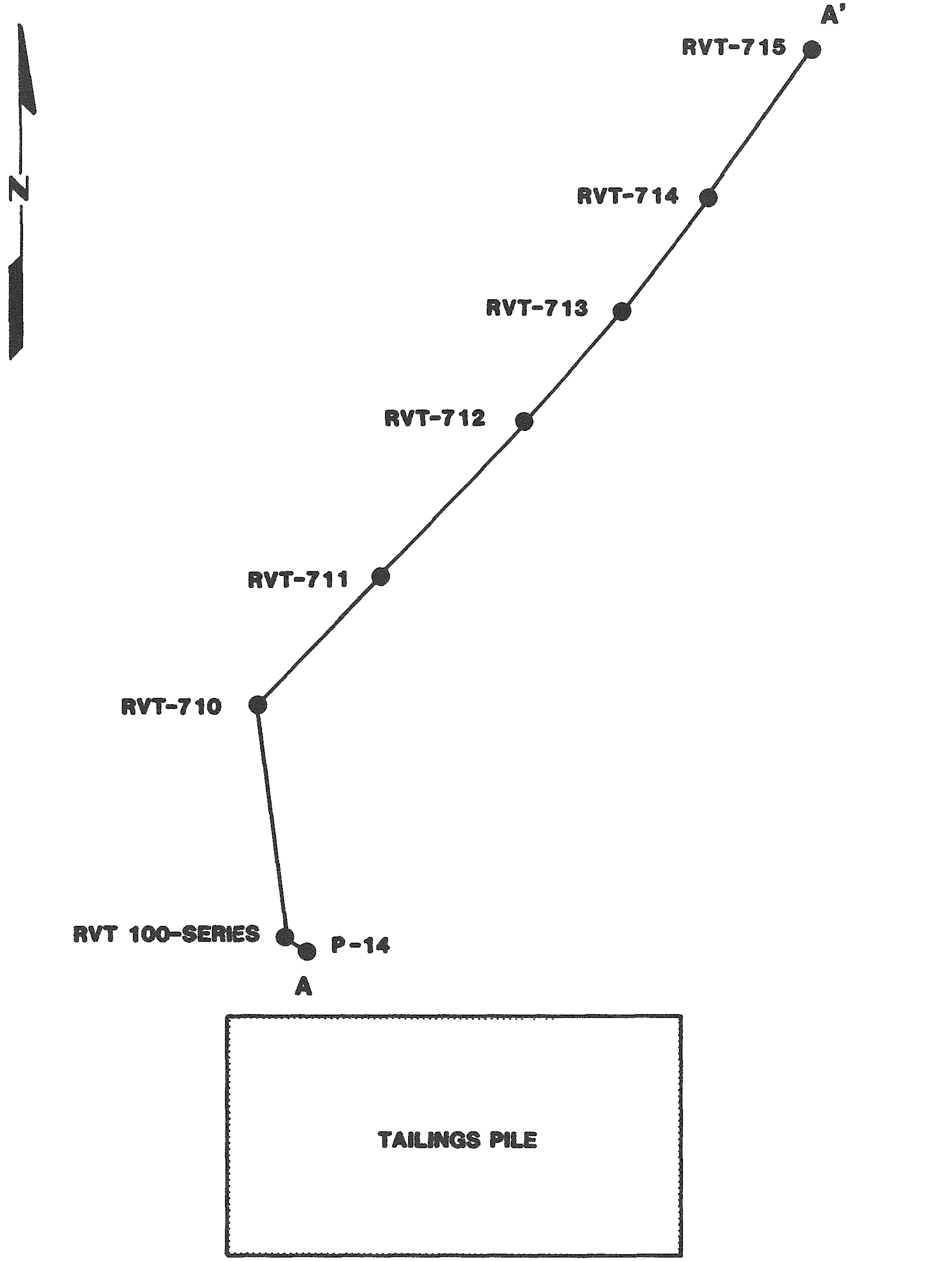


FIGURE C.2.33
TRAVERSE FOR WATER LEVEL MEASUREMENTS NORTH OF RIVERTON SITE

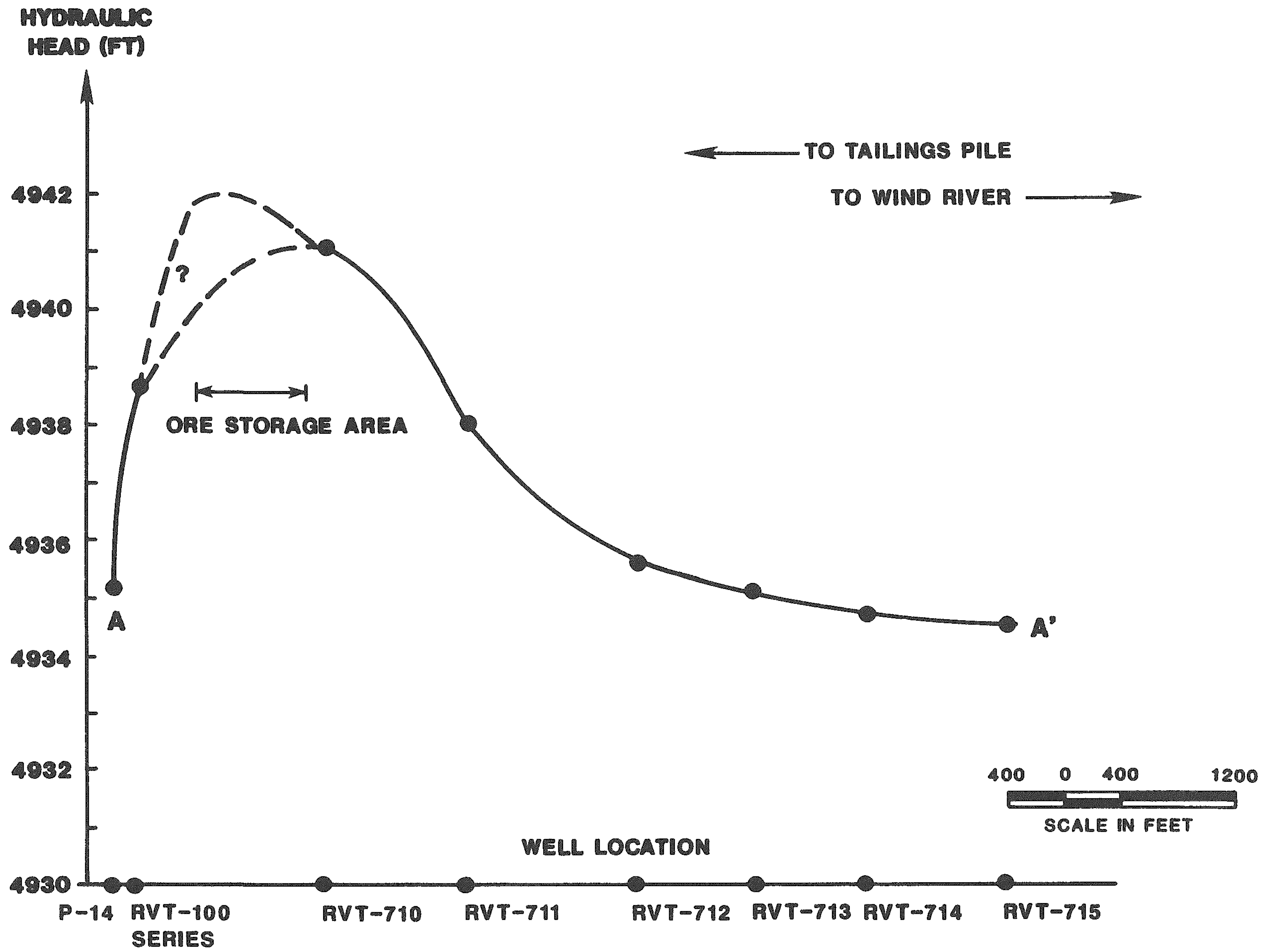


FIGURE C.2.34 GROUNDWATER DIVIDE NORTH OF RIVERTON SITE

Water-quality measurements obtained from well RVT-706 indicated no contamination, thereby indicating that the plumes shown in Figures C.2.26, C.2.27, and C.2.28 do not extend south of the Little Wind River (see Table C.2.22). Moreover, the static water level measured in this well was significantly higher than the stage measured at the Little Wind River directly north of the well, indicating shallow ground-water movement from the south to the Little Wind River.

C.2.5.3 Hydrologic modeling

Purpose

Computer codes that can be used to characterize the ground-water flow regime and the geochemical environment in an aquifer system have become increasingly available over the past several decades. These codes are based on generally accepted physical principles which govern the behavior of ground water and the solubility of chemical constituents in hydrologic systems affected by tailings disposal. They are useful particularly for prediction of short- and long-term impacts of various remedial action plans because they account for complex interactions of mass and energy within the physical system before and after implementation of the proposed remedial action, subject to certain assumptions.

Several computer codes have been identified as reliable algorithms for both calibration and predictive modeling. These codes have been used to describe the observed vertical distribution of water in the Riverton tailings pile, the predominantly downward migration of contaminants through the pile, the chemical precipitation of key constituents in the pile, and the movement of remaining mobilized contaminants through the unconfined ground-water system. Calibration and coupling of these models has permitted quantitative characterization of the Riverton site, both with respect to the movement of ground water and the transport of chemical constituents.

Given the complexities of natural physical systems, especially those which are in physical or chemical disequilibrium, the use of computer models to rigorously describe observed or predicted processes can greatly facilitate site characterization efforts and remedial action impact analyses. Although the models do not explicitly account for disequilibrium conditions that prevail at the site with respect to geochemical behavior, they do supply a basis for defining approximate impacts of various remedial action strategies. Five codes have been calibrated and used to reproduce past behavior of both the ground-water flow regime and the geochemical environment. The calibrated models were subsequently used to predict geohydrologic and geochemical impacts of proposed remedial action measures.

TRUST code

The TRUST code can be used to describe unsaturated ground-water flow within the tailings due to vertical infiltration and is well suited to the characterization of mill tailings sites. TRUST is an integrated finite-difference code that can be used to solve the nonlinear Richards' equation over a one-, two-, or three-dimensional space domain in a deformable medium. The TRUST code is particularly useful for application to the semi-arid Riverton site where steep moisture gradients across the infiltration front may cause numerical instability because the code incorporates a variety of numerical stability controls.

The TRUST algorithm has been used successfully to match the observed and simulated fluid potential distributions within the unsaturated tailings pile. The vertical distribution of fluid potential provides the driving force for contaminant movement from the pile into the underlying unconfined aquifer and is used as input to a coupled solute transport and chemical speciation code that describes migration of contaminants through the tailings-soil interface (Reisenauer et al., 1982; Narasimhan and Witherspoon, 1978).

PHREEQE code

The PHREEQE code, developed by the USGS, is an ion association, aqueous speciation code that defines the geochemical environment in terms of user-defined chemical species that are assumed to dominate the environment (Parkhurst et al., 1980). Its precursors include the WATEQ, SOLMNEQ, WATEQF, and WATEQ2 aqueous speciation models. The PHREEQE model can predict the speciation in a solution which either mixes with another solution or reacts with solid phase mineral constituents. It does so by simultaneously solving a set of independent, nonlinear equations describing chemical mass balance, mass action, electroneutrality, and electron balance under conditions of chemical equilibrium for a set of independent concentration variables. The model also can account for multiple phase boundaries.

The user first identifies the species which influence geochemical conditions in the tailings and aquifer. After all species are identified, a mass balance equation is written for each species whereby the total concentration of all species associated within a given element is defined as a sum of aqueous concentrations. The mass balance equations serve to uniquely define the activities of free ions in solution.

Additional equations for electrical neutrality and conservation of electrons are required because mass balance equations for oxygen and hydrogen cannot be completely defined. The pH of the solution is automatically adjusted until electroneutrality is attained within a specified error tolerance. Given aqueous species molalities, electrical neutrality, and identification of geochemical processes, pH can be calculated theoretically by PHREEQE. Alternatively, the pH can be defined analytically, in which case the electrical neutrality constraints are no longer needed. Electron balance equations are used to state that electrons cannot be created or destroyed. Electron molalities are not included explicitly in other equations because free electrons never actually occur in solution. Conservation of electrons uniquely defines prevailing Eh conditions.

In addition to mass balance, electroneutrality, and electron balance equations, mass action equations must be written in order to define changes in the geochemical system due to pairing of anions and cations. Mass action equations for mineral phases must also be considered. The mass action equations involve use of equilibrium constants which are defined internally with the thermodynamic data base. These constants are allowed to vary according to specified temperature inputs.

Other equations used to characterize the geochemical system include the mass action equation for the dissociation of water and equations which relate molalities to thermodynamic activities. PHREEQE computes activity coefficients using calculations based on ionic strength of the solution (Parkhurst et al., 1980).

<u>TRUMP code</u>

The TRUMP integrated, finite difference algorithm utilizes a discrete form of the advection-dispersion equation to simulate reactive and non-reactive chemical transport in up to three dimensions. External sources or sinks, linear adsorption, and first order reactions can be specified (Edwards, 1972). For this particular investigation, it was assumed that the contaminated, unconfined aquifer is governed by steady state conditions within the area affected by the tailings. Therefore, a single execution of the TRUST flow model and specification of a constant lateral groundwater velocity were sufficient to define the behavior of the flow regime for the TRUMP solute transport simulation.

<u>DYNAMIX code</u>

Advective and dispersive transport of contaminants through the Riverton pile and simultaneous chemical speciation of key contaminants have been simulated using a coupled, chemical transport code called DYNAMIX. This newly developed, multiple species, chemical transport code can be used to simulate, in one, two, or three dimensions, the simultaneous transport of multiple chemical species and their aqueous interactions in the presence of a buffer such as calcite. It has been used to simulate advective movement of dissolved sulfate, as well as the chemical precipitation of sulfate that appears to be occurring at the base of the pile (LBL, 1984; Narasimhan et al., 1984).

DYNAMIX is an explicit linkage of TRUMP, a numerical analog of the advection-dispersion equation, and PHREEQE, a chemical speciation code that simulates chemical reactions such as precipitation and ion association under assumed equilibrium conditions. Fluid potential distributions in the pile obtained from TRUST were used to define the advective driving force of contaminant migration across the tailings-soil interface. The PHREEQE component of DYNAMIX performed mixing of tailings water and unconfined ground water in the presence of a calcite buffered neutralization zone at the interface. Precipitated sulfate obtained from the vertical mixing procedure acted as a sink term for simulating the observed sulfate plume in the unconfined aquifer using the TRUMP algorithm.

Although the DYNAMIX algorithm has not yet been validated by the DOE, it does appear to realistically duplicate the observed geochemical conditions beneath the pile. The DYNAMIX code is based solely on the validated TRUST and PHREEQE algorithms (LBL, 1984).

USGS code

The USGS finite difference code can be used to describe saturated flow in three dimensions and was applied to simulate the effects of slurry wall emplacement and aquifer restoration on shallow ground-water flow at and around the Riverton processing site. With the code, heterogeneous and anisotropic material properties and flow fields with irregular hydraulic boundaries can be modeled. Stress on the system can be from precipitation or discharging or recharging wells. A variable spaced grid can be used, and one or more layers of nodes can be used to represent each hydraulic unit. A strongly implicit procedure is used to solve the simultaneous difference equations (Trescott, 1976).

Modeling procedures

The method used to characterize the hydrologic and geochemical system at the Riverton site first involved calibration of the three models, TRUST, DYNAMIX, and TRUMP, by LBL researchers. Calibration, or history matching, was performed by adjusting parameters and input variables of each model until the simulated physical or chemical response adequately corresponded to the observed response. Sulfate was chosen as an indication of chemical response because of its conservative behavior in ground water. The sulfate plume was therefore a representative measure of the extent of contamination caused by advective, dispersive, and diffusive solute transport. The sequence of procedures for the calibration was as follows:

- o Approximate reproduction of the measured fluid potentials within the partially saturated tailings using the TRUST algorithm.
- o Determination of precipitation-dissolution reactions controlling the water quality resulting from the mixing of tailings fluid and ambient shallow ground water using the PHREEQE algorithm.
- o Simulation of chemical mixing of the tailings fluid and the shallow ground water using the DYNAMIX algorithm resulting in the definition of the rate of sulfate precipitation.
- o Duplication of the observed sulfate plume in the unconfined aquifer using the TRUMP algorithm by removing precipitated sulfate from incoming tailings pore fluid.

Table C.2.33 summarizes various parameter values used in the hydrodynamic and solute transport modeling.

Simulation of fluid potentials in unsaturated tailings

Fluid potentials were simulated with the TRUST code using a one-dimensional, 6.75-meter column representation of the tailings and subsoils. The 6.75-meter height was chosen because it was equal to the average distance between the tailings surface and the water table. The tailings column was subdivided into finite difference elements based on assumed material properties and observed hydraulic potential gradients. Mean monthly climatic data presented in Table C.2.14 were used to define the surface boundary conditions.

Fluid potential profile data from LBL location RB were used to represent the entire pile. In order to duplicate the ground-water divide observed at 1 meter of depth shown in Figure C.2.22, the Complimentary Relationship Areal Evaporation (CRAE) model (Morton, 1978) was used to estimate potential evapotranspiration. It was assumed that average evapotranspiration losses at the site would represent roughly 55 percent of net losses. Figure C.2.35 shows the results of a 20-year simulation when 22 centimeters of rainfall, along with evapotranspiration calculated from the CRAE model, were lumped into quarterly averaged sources and sinks. The calculated quarterly fluxes, along with temperature dependent viscosity values, are listed in Table C.2.34. Agreement between simulated and currently observed

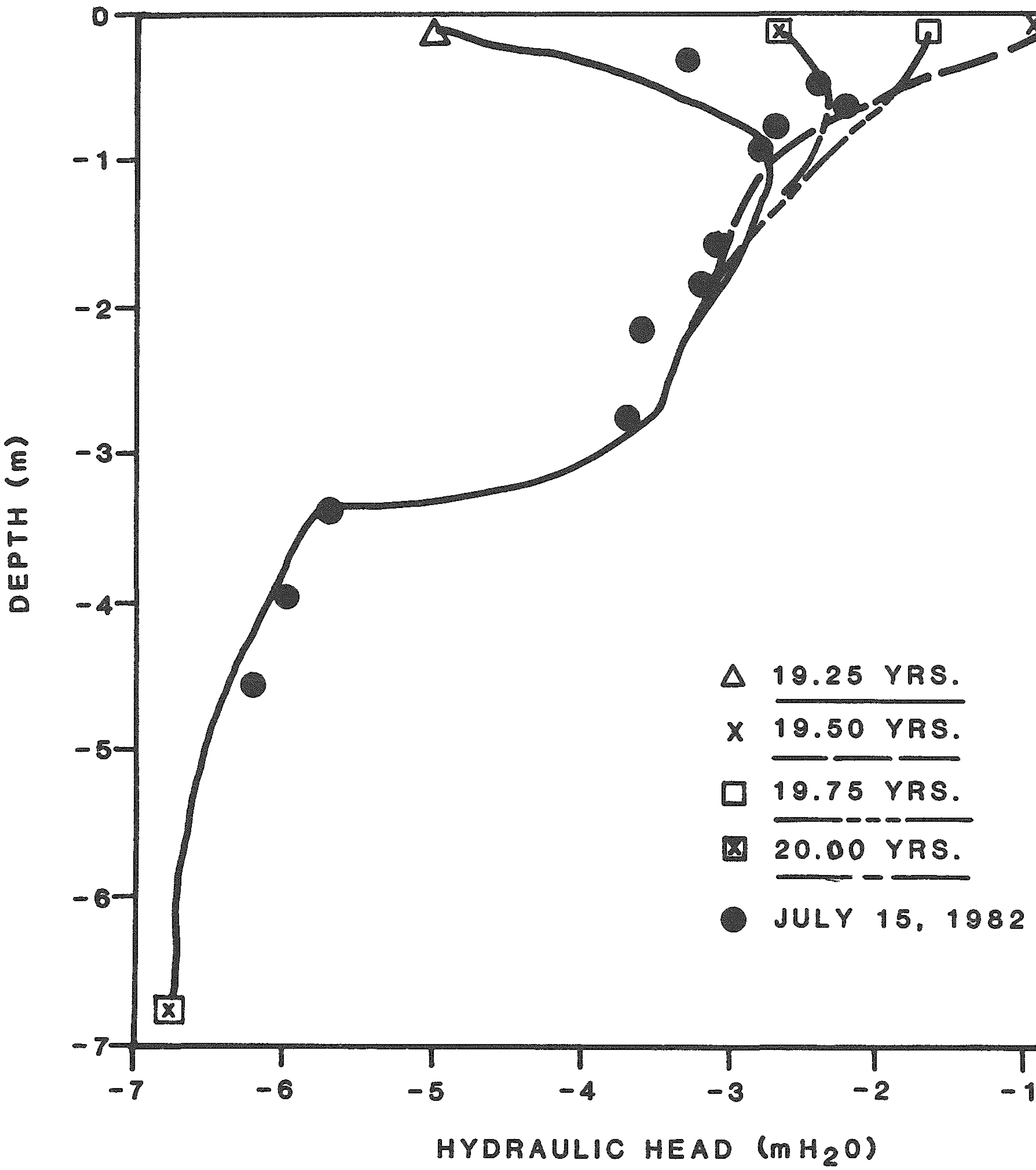
Table C.2.33 Hydrologic, solute transport, and physical modeling parameters, Riverton site

Parameter	Value
Ground-water Darcy velocity	6.34×10^{-7} m/s (20 m/yr)
Aquifer porosity	0.30
Aquifer hydraulic conductivity	2.82×10^{-4} m/s (80 ft/day)[a]
Slurry wall hydraulic conductivity	10^{-9} m/s
Aquifer transmissivity	2.822×10^{-4} to 2.822×10^{-3} m^2/s
Slurry wall transmissivity	9.09×10^{-9} m^2/s
Aquifer storage coefficient	0.0[b]
Steady state infiltration flux	6.98×10^{-10} m/s (2.2 cm/yr)
Aquifer saturated thickness	10.0 m
Pile length	800.0 m
Pile width	350.0 m
Pile height	2.9 m (9.5 ft)
Pile saturated moisture content	0.45[c]
Dilution front velocity	1.90×10^{-9} m/s (0.197 ft/yr)
Pile surface concentration	1,757 moles/m^3
Aquifer background sulfate concentration	2.34 moles/m^3
Aquifer longitudinal dispersivity	1.0 m
Pile longitudinal dispersivity	0.30 m[c]
Aquifer transverse dispersivity	0.1 m
Pile transverse dispersivity	0.03 m[c]
Aquifer diffusion coefficient	1.6×10^{-9} m^2/s

Table C.2.33 Hydrologic, solute transport, and physical modeling parameters, Riverton site (Concluded)

Parameter	Value
Pile diffusion coefficient	2.6×10^{-9} to 3.0×10^{-9} m^2/s
Distance from pile surface to water table	6.75 m
Distance from stabilized pile surface to water table	6.60 m
Slurry wall depth	9.00 m
Hydraulic head at Little Wind River	1,501.0 m

[a]Based on the 20-m/yr Darcy velocity from sulfate plume movement and 30 percent porosity.
[b]Steady state conditions.
[c]Assumes an aquifer porosity of 30 percent.



REF. LBL, 1984.

FIGURE C.2.35
SIMULATED AND OBSERVED HYDRAULIC HEAD PROFILES AT LBL LOCATION RB

fluid potential profiles at location RB indicates that the mechanism of water redistribution within the tailings was estimated accurately using the specified rainfall and evapotranspiration rates over the 20-year period. Thus, the effects of potential remedial actions can be estimated using the specified rainfall and evapotranspiration rates with appropriate changes in material properties.

Table C.2.34 Quarterly surface boundary fluxes and viscosity values, Riverton site

Quarter	Flux (m^3/s)	Viscosity (kg/m-s)
1	-2.551×10^{-9}	1.6×10^{-3}
2	6.219×10^{-9}	1.3×10^{-3}
3	2.319×50^{-10}	1.1×10^{-3}
4	-1.208×10^{-9}	1.3×10^{-3}

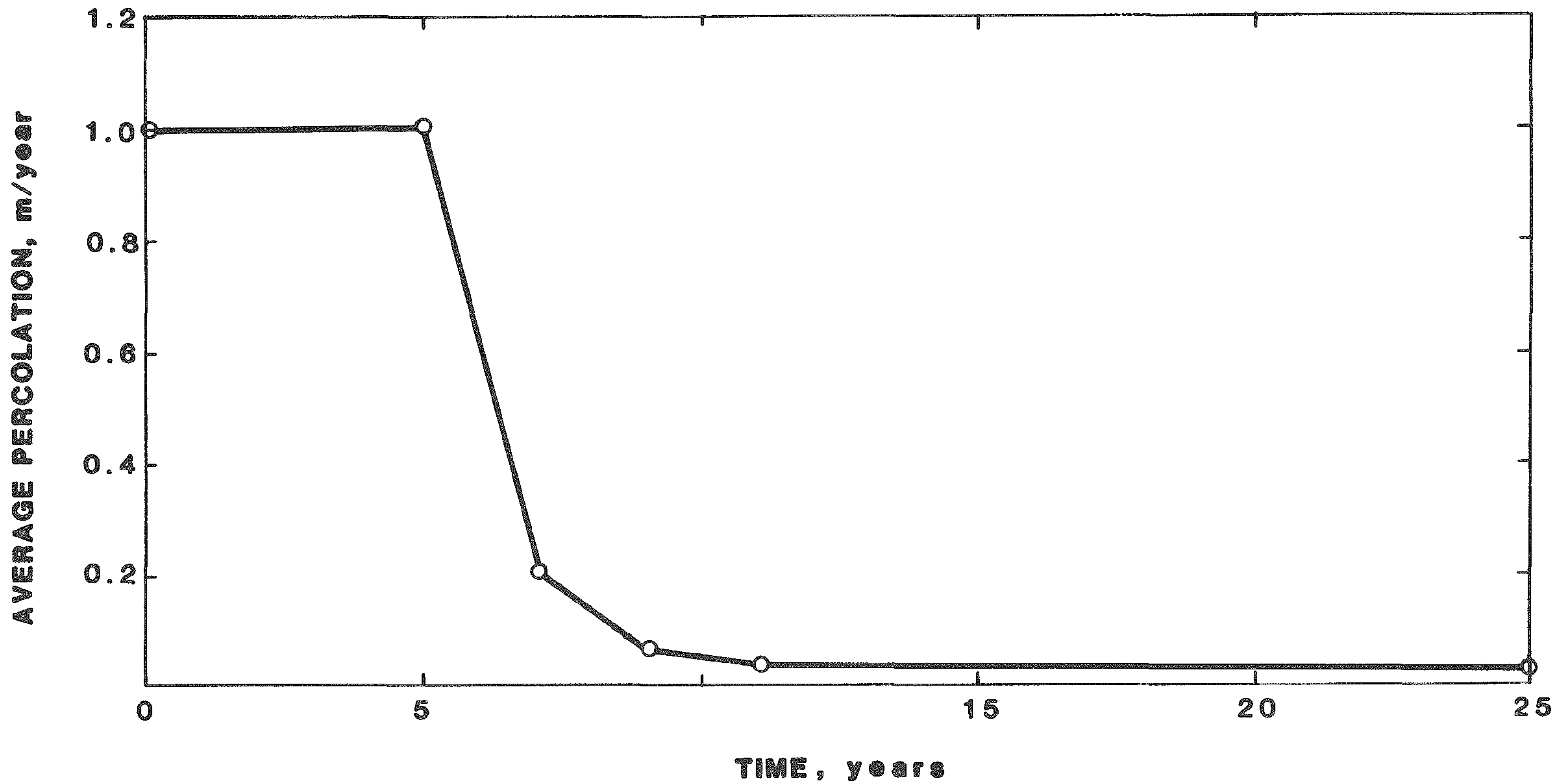
Figure C.2.36 illustrates the change in the rate of simulated percolation through the base of the tailings as a function of time. To describe rapid dewatering of the pile throughout the 5 years of active disposal, the pile was maintained at close to 100 percent saturation. Subsequent rates during pile drainage were calculated through time on the basis of the 20-year TRUST estimate of the hydraulic potential gradient. The estimate of unsaturated hydraulic conductivity was obtained from the intrinsic permeability versus hydraulic potential relation given in Figure C.2.37. Percolation rates were estimated from the gradient and hydraulic conductivity using Darcy's Law.

Mixing at tailings-soil interface

The pH is the prime variable in controlling contaminant speciation and concentration both in the tailings pore water and in the ground water. The pH of contaminated unconfined ground water beneath the pile is slightly lower than the pH of uncontaminated ground water upgradient of the pile. The slight pH depression occurs in spite of significant mixing with low pH tailings water, as evidenced by corresponding high sulfate concentrations. This pH buffering is indicative of acid neutralization by carbonate minerals in the soil and alluvium and, to a lesser extent, by dissolved bicarbonate in the uncontaminated ground water. At low pH, these reactions can be written:

$$\underset{\text{(soil)}}{CaCO_3} + \underset{\text{(tailings)}}{2H^+} \rightleftarrows Ca^{+2} + CO_2 + H_2O \qquad (1)$$

and



REF. LBL, 1984.

FIGURE C.2.36
AVERAGED VERTICAL PERCOLATION RATES
THROUGH RIVERTON TAILINGS AS A FUNCTION OF TIME

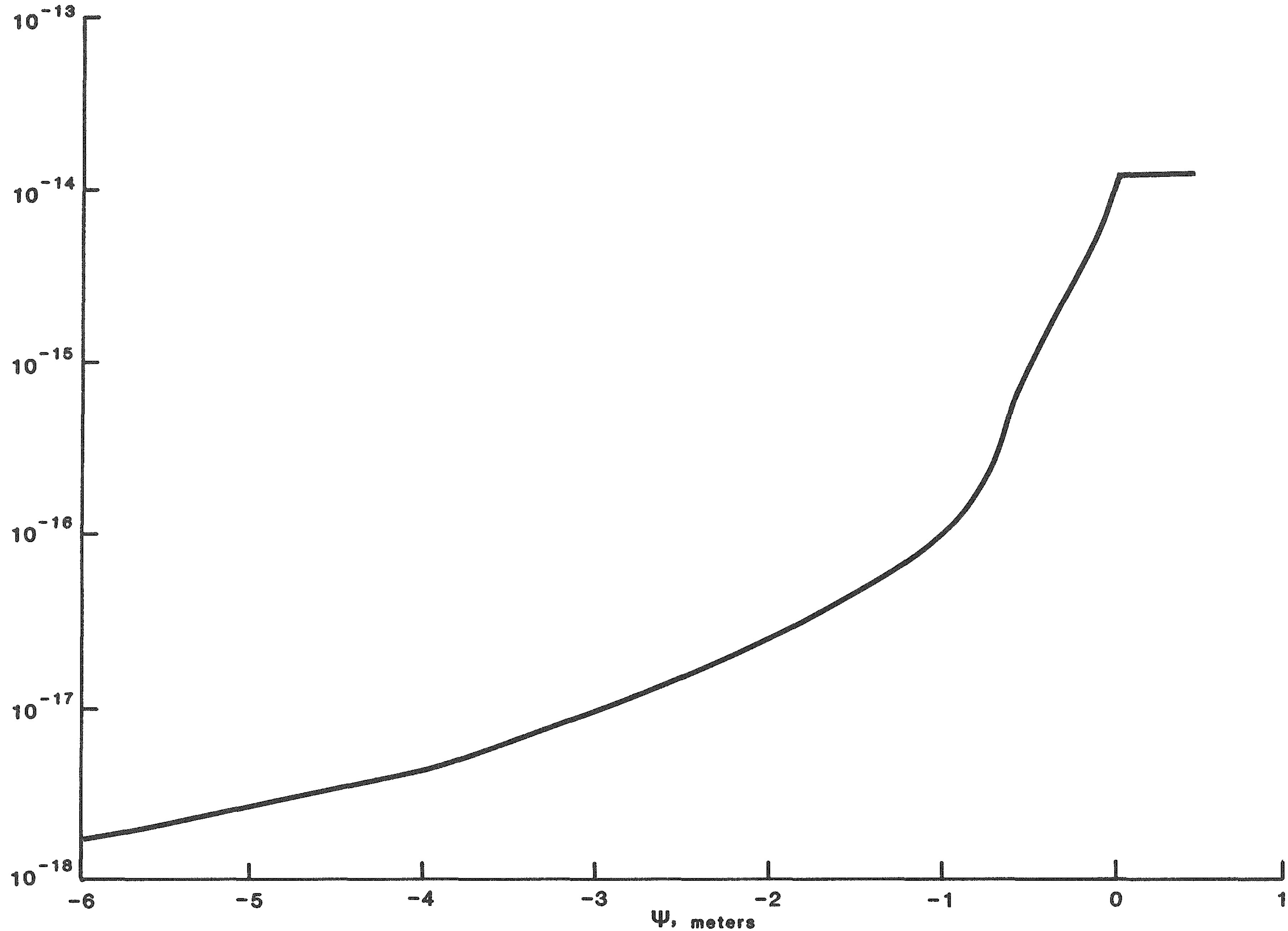


FIGURE C.2.37 INTRINSIC PERMEABILITY VERSUS SUCTION FOR RIVERTON SOIL MATERIAL

$$HCO_3^- + H^+ \rightleftarrows CO_2 + H_2O \quad (2)$$

(ground water) (tailings)

Production of CO_2 gas by reactions (1) and (2) above is confirmed by high partial pressures of CO_2 measured in pore gases within the pile (see Table C.2.31).

The saturated state of the ground water relative to calcite, which is governed by reaction (1), was calculated by the PHREEQE code. A plot of the ionic activity products (IAP) for Ca and CO_2 versus Ca and SO_4 in ground waters are shown in Figure C.2.29. The horizontal and vertical lines are the respective values for the solubility products (K_s) for calcite and gypsum at comparable temperatures. Ground-water compositions with IAP's greater than these K_s values are supersaturated with respect to the solid phase, and samples with IAP's less than K_s are undersaturated.

The IAP data in Figure C.2.29 indicate that almost all of the ground water in both the unconfined aquifer and the confined aquifer is supersaturated with respect to the thermodynamic solubility constant for calcite. Supersaturation with respect to calcite of the unconfined ground water beneath and downgradient of the tailings pile indicates that the calcite buffering capacity has not been exceeded by the acid neutralization reaction, given by reaction (1). This explains why the pH of the contaminated ground water remains near neutral.

Unconfined ground water upgradient from the pile is substantially undersaturated with respect to gypsum whereas water beneath and downgradient of the pile is saturated or supersaturated. An important contribution of gypsum is the aqueous calcium produced from dissolution of calcite, given by reaction (1). The overall chemical reaction leading to gypsum precipitation is:

$$CaCO_3 + H_2SO_4 + H_2O \text{ -- } CaSO_4 2H_2O + CO_2 \quad (3)$$

(soil) (tailings) (gypsum) (gas)

Other precipitation reactions during contaminant mixing involve high concentrations of dissolved metals in the tailings pore waters, principally iron and aluminum. Assuming oxidizing conditions within the tailings based on measurable O_2 partial pressures, precipitation can be represented as:

$$Fe^{+3} + 3H_2O \text{ -- } Fe(OH)_3 + 3H^+ \quad (4)$$

and

$$Al^{+3} + 3H_2O \text{ -- } Al(OH)_3 + 3H^+ \quad (5)$$

While the specific iron and aluminum hydroxides represented in reactions (4) and (5) may not be the exact phases formed by mixing, the stoichiometry involving the production of hydrogen ions is correct. Based on high dissolved iron and aluminum concentrations, precipitation of hydroxides at near neutral pH accounts for a greater total hydrogen ion input during mixing than do hydrogen ions initially present in the low pH tailings water.

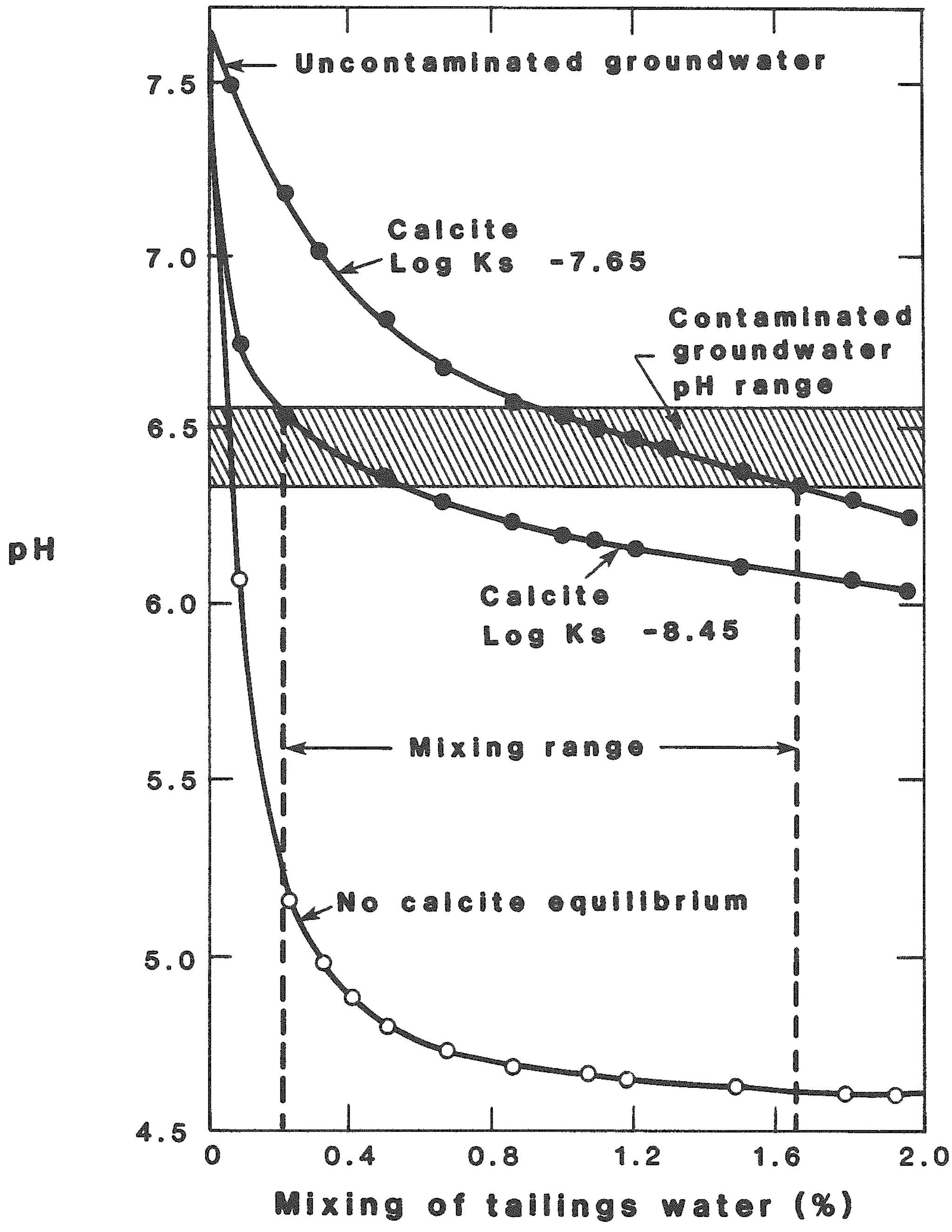
Using the PHREEQE code, reactions (1) through (5) can define pH changes as a function of mixing between initially uncontaminated, unconfined ground water and pore water contained in the tailings. Clearly, the pore water in the base of the pile is much more dilute than in the interior of the tailings pile. The RB-6 sample was assumed to be the end member tailings composition prior to mixing, with the P-16 sample used to represent the end member of unconfined ground-water composition.

Constraints on ground-water mixing simulations included continual equilibration with $Fe(OH)_3$ and $Al(OH)_3$ and equilibrium with gypsum after saturation has been achieved. The partial pressure of CO_2 was fixed at 0.1 atmosphere which is the average partial pressure. The Eh was not measured but was assumed to be oxidizing (0.4 volts) and controlled by Fe^{+2}/Fe^{+3} equilibrium.

The volume fraction of tailings water that mixed with the ground water was estimated from the intersection of the calcite equilibrated mixing curves with the pH range of the contaminated ground water beneath the tailings pile. As indicated in Figure C.2.38, the percentage of pore water can range from a minimum of 0.2 percent, assuming thermodynamic equilibration with calcite, to a maximum of 1.6 percent assuming maximum calcite supersaturation.

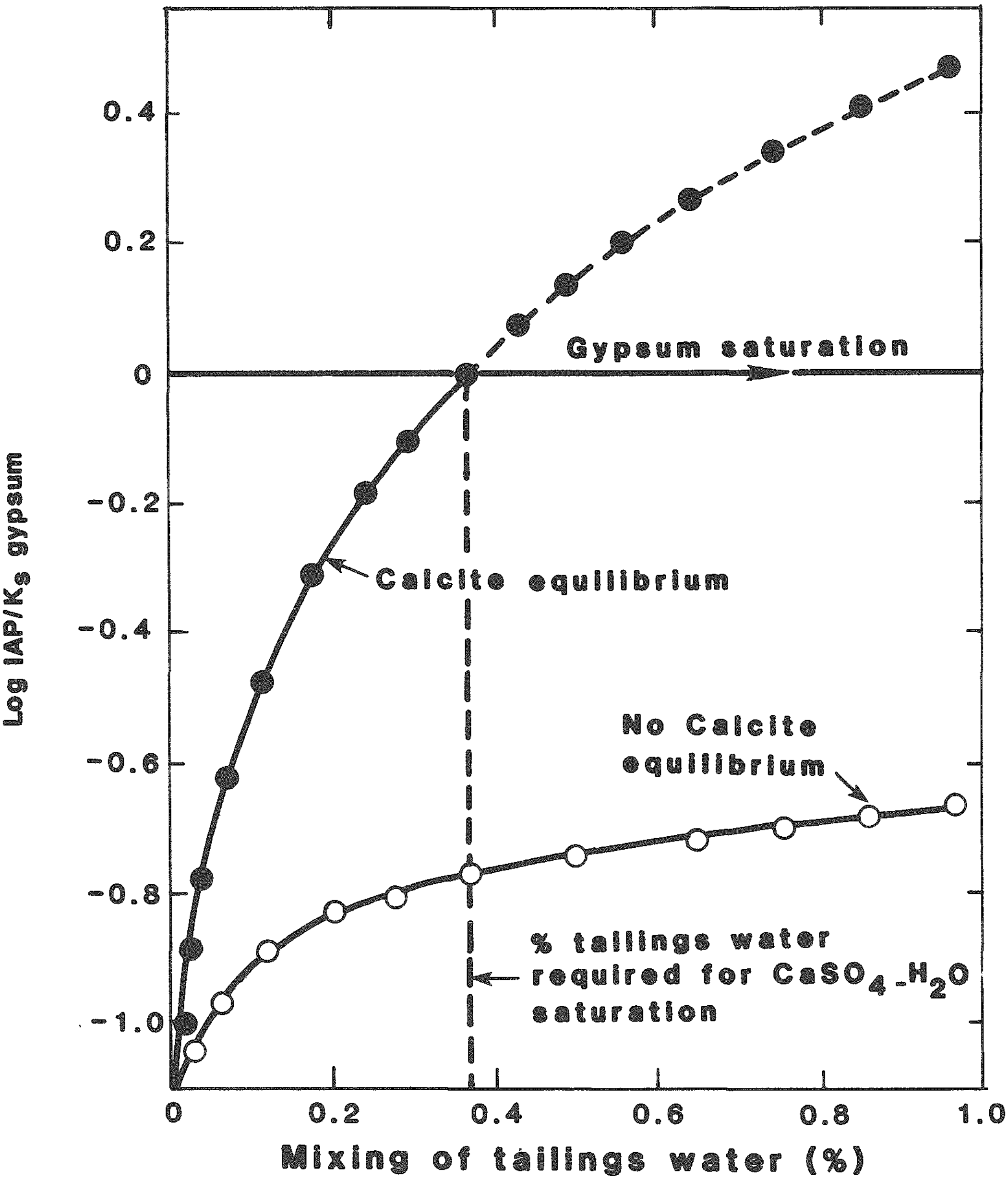
The two lower pH mixing curves assume continued calcite equilibrium and dissolution based on thermodynamic calcite saturation ($K_s = 10^{-8.45}$) and metastable calcite saturation ($K_s = 10^{-7.65}$). The third curve corresponds to pore water mixing with ground water without continued calcite saturation. The loss of such buffering, which corresponds to complete removal by dissolution of calcite from the aquifer, would result in rapid decreases in pH which, in turn, would increase the potential for transport of pH sensitive radionuclides and trace metals. Clearly, this has not occurred and is unlikely to occur at the Riverton site.

An independent check on the mixing fraction can be made by also considering the volume of tailings water required to produce gypsum saturation in the ground water as was documented for contaminated ground water. The logarithm of the IAP to K_s ratio (IAP/K_s) ratio for gypsum is plotted in Figure C.2.39 against the mixing fraction of pore water. As indicated, the ground water, saturated with calcite but initially undersaturated with gypsum, reaches gypsum saturation ($IAP/K_s = 0$) after mixing with approximately 0.4 percent tailings water. This volume percent is within the range predicted from the pH mixing model.



REF. LBL, 1984.

FIGURE C.2.38
RELATION BETWEEN MIXING AND pH
FOR THE RIVERTON TAILINGS-GROUNDWATER SYSTEM



REF. LBL, 1984.

FIGURE C.2.39
RELATION BETWEEN MIXING AND LOG IAP/K_S GYPSUM, RIVERTON SITE

Mixing percentages required to produce observed uranium concentrations in ground water beneath the tailings pile plot over a comparable mixing range of from 0.2 to 0.9 percent to that predicted from pH and gypsum saturation calculations (Figure C.2.40). This confirms that uranium behaves conservatively in the unconfined ground-water system and is subject only to concentration changes related to mixing. Soluble uranium represents one of the greatest potentials for contamination from mill tailings, particularly in shallow, oxidizing ground-water systems.

The following broad pattern of chemical changes was observed as the tailings water mixed with the ground water. Simulation of mixing was carried out using the DYNAMIX algorithm with the assumption of abundant calcite present in the soil. The mineral species of interest were gypsum, calcite, gibbsite, and iron hydroxide. During mixing, calcite was dissolved and gypsum, gibbsite, and iron hydroxide were all precipitated. The time steps chosen were on the order of a few months to a year, and the mixed water continuously moved downgradient.

Geochemical characteristics of the tailings water and the ambient unconfined ground water were specified with respect to concentrations of certain key elements shown in Table C.2.35. The tailings pile was idealized as a rectangle measuring 850 meters by 350 meters, and the mixing problem was done in two stages to reflect variable drainage patterns in time (Figure C.2.41). During the first stage, instantaneous mixing of percolating tailings water and ground water was assumed beneath the entire pile. The ground-water reservoir immediately below the tailings was treated as a single cell measuring 850 meters by 350 meters by 10 meters. In the second stage, differential mixing was initiated using these average concentrations from the first stage. The single cell of Stage 1 was divided into seven cells with their long dimensions oriented perpendicular to the direction of ground-water flow. Each upgradient cell acted as a source to the cell immediately downgradient. In both stages, the ground-water reservoir was considered to be 10 meters thick, with the tailings and the ambient ground water supplying chemical species at the concentrations given in Table C.2.35. In addition, the tailings were assumed to be 50 percent saturated.

Output from the mixing model consisted of sulfate precipitation rates that varied temporally and spatially across the pile. These precipitation rates constitute the sink terms for the TRUMP plume simulation. Advection of percolating tailings water with high sulfate concentrations represents the source mechanism for the subsequent TRUMP simulation. The average concentrations of the various species at the end of Stage 1 are listed in Table C.2.36. Time-dependent rates of sulfate precipitation generated during Stage 2 of the mixing procedure are shown in Figure C.2.42.

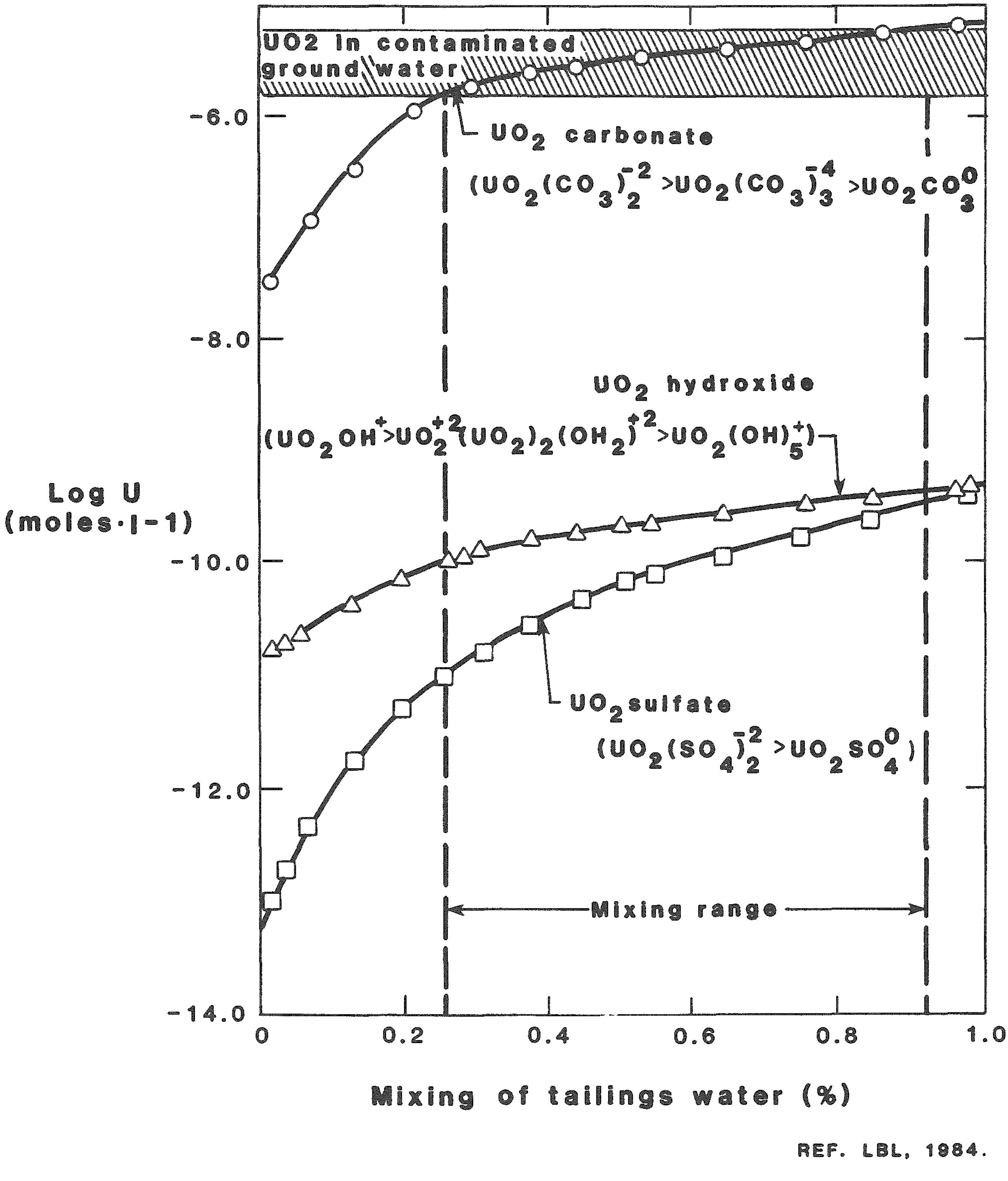


FIGURE C.2.40
RELATION BETWEEN MIXING AND LOG U, RIVERTON SITE

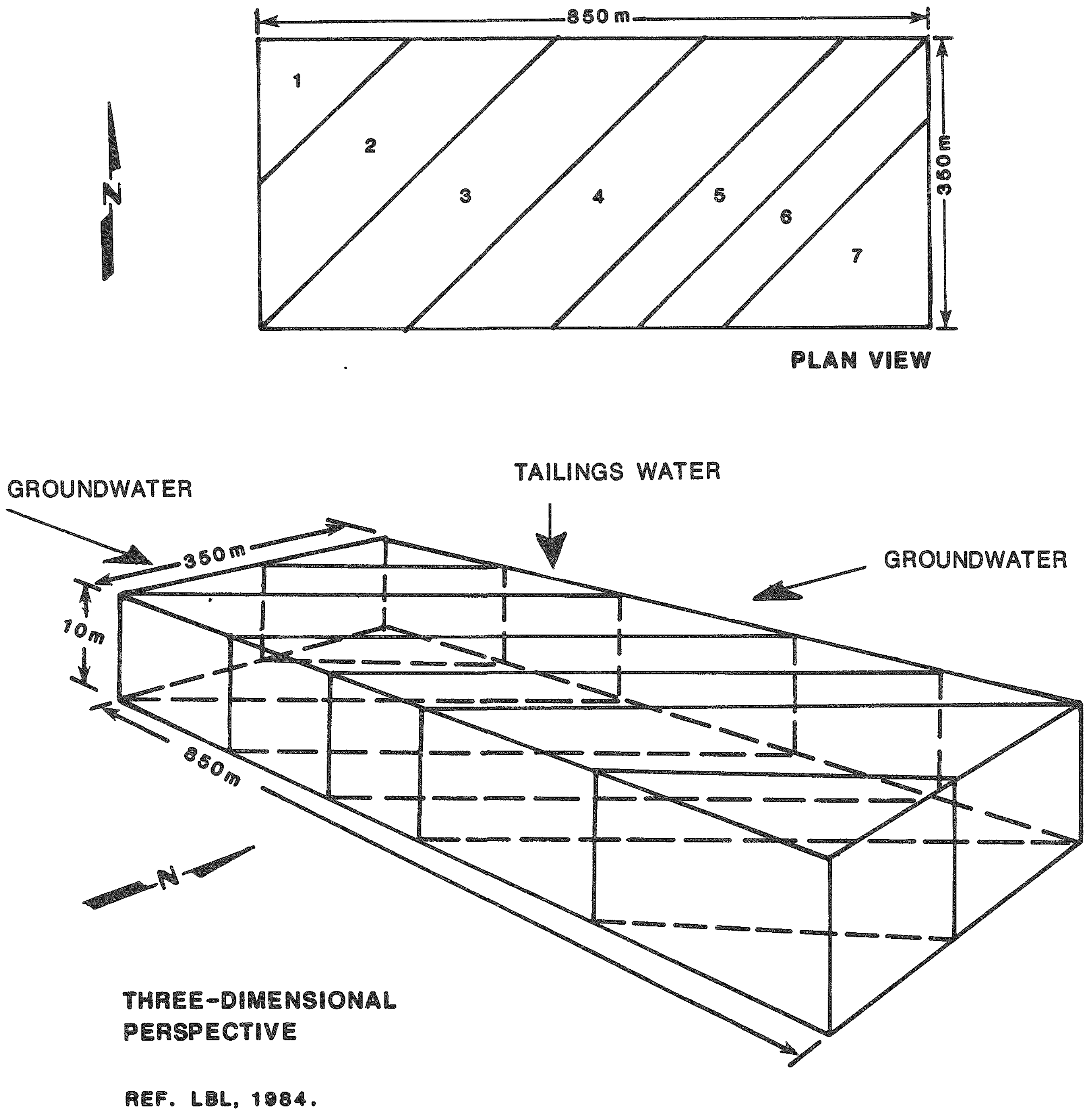


FIGURE C.2.41
GEOMETRY OF RIVERTON GROUNDWATER RESERVOIR FOR MIXING CALCULATIONS

Table C.2.35 Concentrations of key elements used for mixing calculations, Riverton site

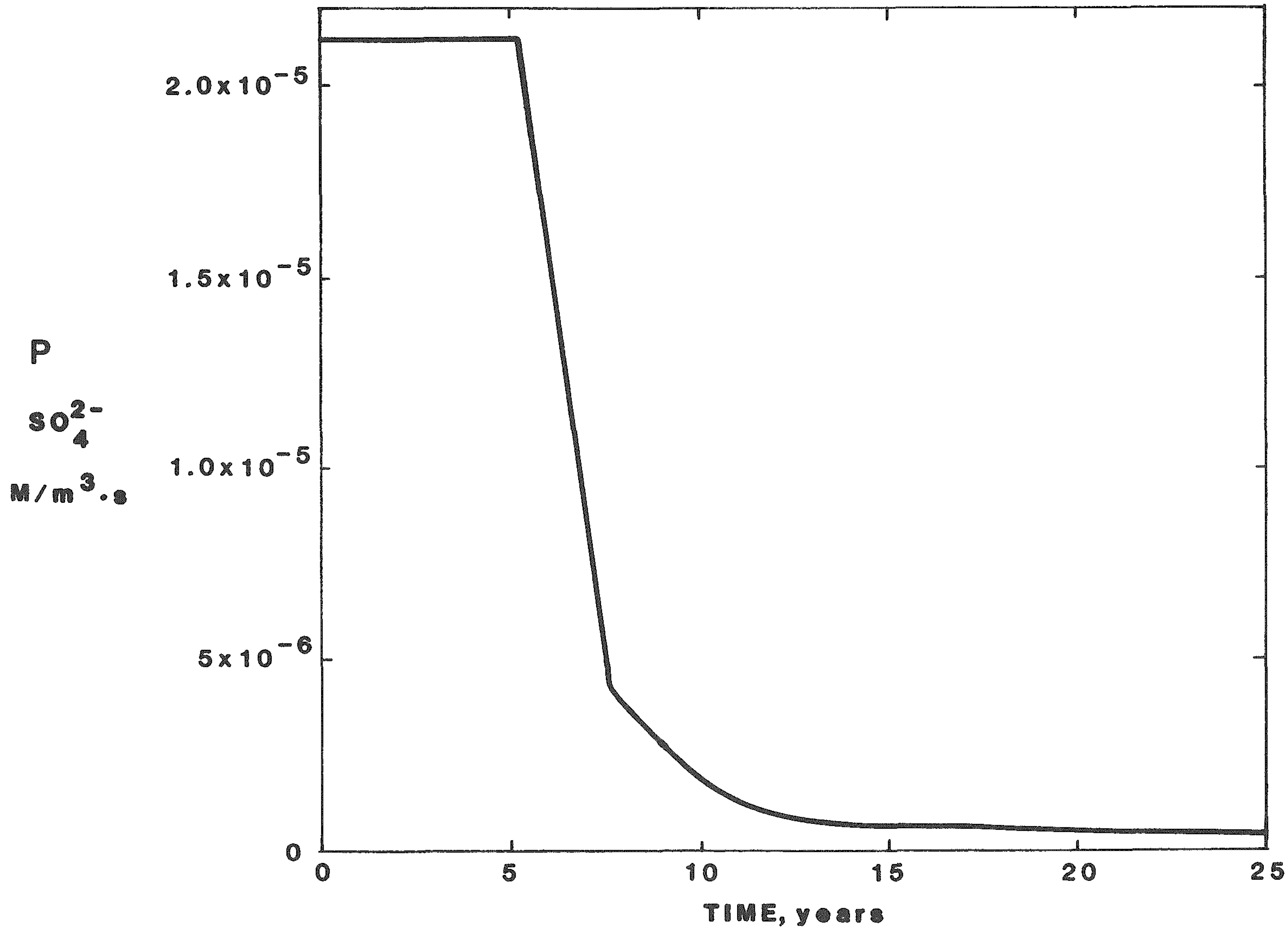
Element	Concentrations in millimoles per liter	
	Ground water	Tailings water
pH	7.6	1.43
Ca	1.76	3.70
Mg	0.905	78.6
Na	3.93	8.0
K	0.105	0.0056
Fe	0.003	773.0
Al	0.001	431.0
Si	0.548	1.53
Cl	0.8174	3.25
CO_3	4.73	0.001
SO_4	2.34	1,757.0

Ref. Narasimhan, 1984.

Table C.2.36 Concentrations of key elements after Stage 1 mixing, Riverton site

Element	Concentrations in millimoles per liter
pH	5.74
Ca	28.5
Mg	54.87
Na	6.961
K	0.0365
Fe	0.00033
Al	1.23
Si	2.507
Cl	1,238.0
S	22.6

Ref. Narasimhan, 1984.



REF. LBL, 1984.

FIGURE C.2.42
RATES OF SULFATE PRECIPITATION DURING STAGE 2 CALCULATIONS

Simulation of observed sulfate plume

Sulfate was chosen to perform the calibration for chemical transport through the unconfined aquifer because it is one of the least sensitive constituents with regard to changes in the geochemical environment and was therefore a good indication of advective, dispersive, and diffusive solute transport. After the PHREEQE and DYNAMIX codes were used to characterize geochemical conditions at the tailings-soil interface, the TRUMP code was executed by LBL in order to simulate the movement of sulfate from beneath the tailings pile through the unconfined aquifer. Initial concentrations of sulfate in the aquifer were selected as those which prevailed 25 years ago prior to emplacement of the tailings and essentially reflected background sulfate levels. Boundary conditions were also chosen to represent background sulfate concentration.

The integrated finite difference mesh used for the simulation was oriented in a direction parallel to the idealized streamlines as indicated in Figure C.2.43. Uncontaminated ground water entered the system across the northern and western edges of the tailings from the upgradient element at a Darcy flux of 20 meters per year (Narasimhan, 1984), and contaminated water discharged into the downgradient element at the same rate.

The upgradient and downgradient elements were specified to have sufficient volume so that the sulfate concentration at the boundaries would be maintained at background level despite outflux and influx of sulfate. Also, the tailings element was large enough to force sulfate concentrations in percolating water to be maintained at 1,757 moles per cubic meter during the simulation (Narasimhan, 1984). The dimensions of all aquifer elements were assigned on the basis of expected sulfate gradients; all elements located near the pile-aquifer interface were specified to be smaller than those located at a distance from the pile. Aquifer element heights were defined using a saturated thickness of 10 meters and a porosity of 30 percent.

The water table near the pile was insensitive to the percolation rate within the range of seasonal variation expected for the site. Hence, any seasonal changes in infiltration would have little effect on the hydraulic head distribution, and use of an "average" or steady state water table would have little bearing on characterization of solute transport mechanisms. Mounding and radial flow effects during active stages of disposal would probably have been significant during the first 5 to 10 years following pile disposal. However, relative to the dynamics of the flow regime, the hydrodynamic perturbation represented by such mounding would be minimal and would probably not significantly affect the modeling results.

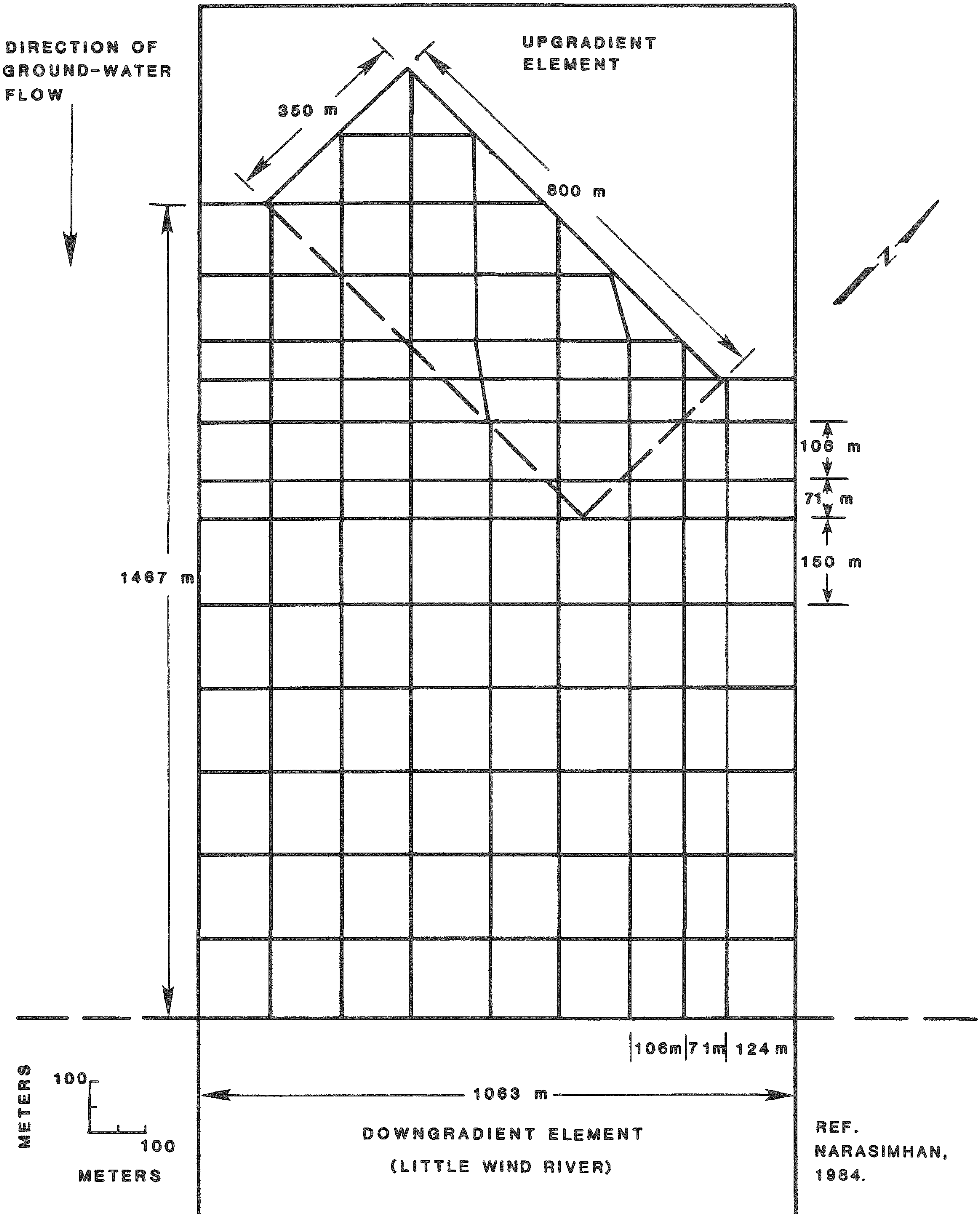


FIGURE C.2.43 TRUMP INTEGRATED FINITE DIFFERENCE MESH

Percolation was applied in TRUMP by inputting the infiltration function predicted by TRUST (Figure C.2.36). The rapid initial drainage and subsequent desaturation of the pile with increasing time were therefore explicitly considered during the history matching procedure. By the end of the 25-year simulation, the infiltration rate predicted by TRUST had stabilized at 2.15 centimeters per year (Narasimhan, 1984).

Sulfate precipitation was incorporated in the TRUMP model by inputting the DYNAMIX - generated function shown in Figure C.2.42. The predicted precipitation rate decreased to roughly a constant level at 25 years, reflecting an approach to chemical equilibrium in the mixed water.

The longitudinal and transverse hydrodynamic dispersion coefficients were calculated by the TRUMP algorithm using the relations:

$$D_L = a_L v + D^*$$

$$D_T = a_T v + D^*$$

where

D_L = the longitudinal dispersion coefficient describing dispersion along a given streamline (m^2/s).

D_T = the transverse dispersion coefficient describing dispersion perpendicular to a given streamline (m^2/s).

a_L = the longitudinal dispersivity (m).

a_T = the transverse dispersivity (m).

v = the average linear seepage velocity along a given streamline (m/s).

D^* = the diffusion coefficient (m^2/s).

The hydrodynamic dispersion coefficients describe the sum of mechanical dispersion, or dispersion caused by mixing of fluid elements, and molecular diffusion caused by chemical gradients. The two effects are additive and, together with the advection mechanism, characterize conservative solute transport properties of the flow medium.

Mechanical dispersion in both the longitudinal and traverse directions, which is described by the first term in both relations, is directly proportional to the average linear velocity along the streamlines. The factor of proportionality is equal to the dispersivity which is generally much smaller in the transverse direction than in the longitudinal direction. This parameter describes the "characteristic" mixing length involved in the mechanical mixing process, and is necessarily much smaller in the transverse direction due to lower mixing forces in this direction.

The second term in the dispersion coefficient reflects purely diffusive transport of sulfate under chemical gradients and is entirely independent of ground-water movement. This diffusion coefficient is theoretically a property of the solute only.

While the value of average linear velocity, v, was known with some certainty on the basis of pump test results and hydraulic gradients, the values of a_L and a_T and D^* were not known. In particular, a_L and a_T are scale dependent parameters that cannot be extracted from lab data and must be estimated through trial and error calibration. The value of D^* is more physically based but must still be estimated through trial and error adjustment. The history matching procedure ultimately involved simultaneous adjustment of D^* and a_L, with a_T estimated to be 10 percent of the value of a_L in accordance with observed field conditions (Freeze and Cherry, 1979). The final values of D^* were 1.6×10^{-9} m^2/s for sulfate in the aquifer and 2.6×10^{-9} m^2/s for sulfate in the tailings pile. The D^* value for the tailings was later increased at a time of 9 years to 3.0×10^{-9} m^2/s in order to maintain correspondence between simulated and observed plumes. Final estimates of a_L and a_T were 1.0 meter and 0.1 meter, respectively. These values of dispersivity effectively damped severe oscillations caused by numerical instability (Narasimhan, 1984).

The 25-year simulated sulfate plume obtained by LBL after trial and error adjustment of D^* and a_L is presented in Figure C.2.44 along with the observed sulfate plume. TRUMP accurately estimated the general configuration and some of the major features of the observed plume, particularly near the tailings. The predicted peak sulfate concentration near the Little Wind River was roughly twice the observed concentration but could not be reduced without changing the overall plume configuration.

An absence of significant lateral spreading of the sulfate plume was described using the TRUMP solute transport model. The elongated shape of the sulfate, molybdenum, and uranium plumes can be attributed to the directional nature of solute dispersive transport mechanisms and the relatively small value of transverse dispersivity.

The overall results of the plume simulation represent a semi-quantitative description of the various processes that occur. The exact numbers should be considered acceptable relative to the magnitudes observed in the field. Because the simulation tends to overestimate current sulfate levels, use of the calibrated models for predictive purposes should define upper bounds on future contaminant levels in the unconfined aquifer.

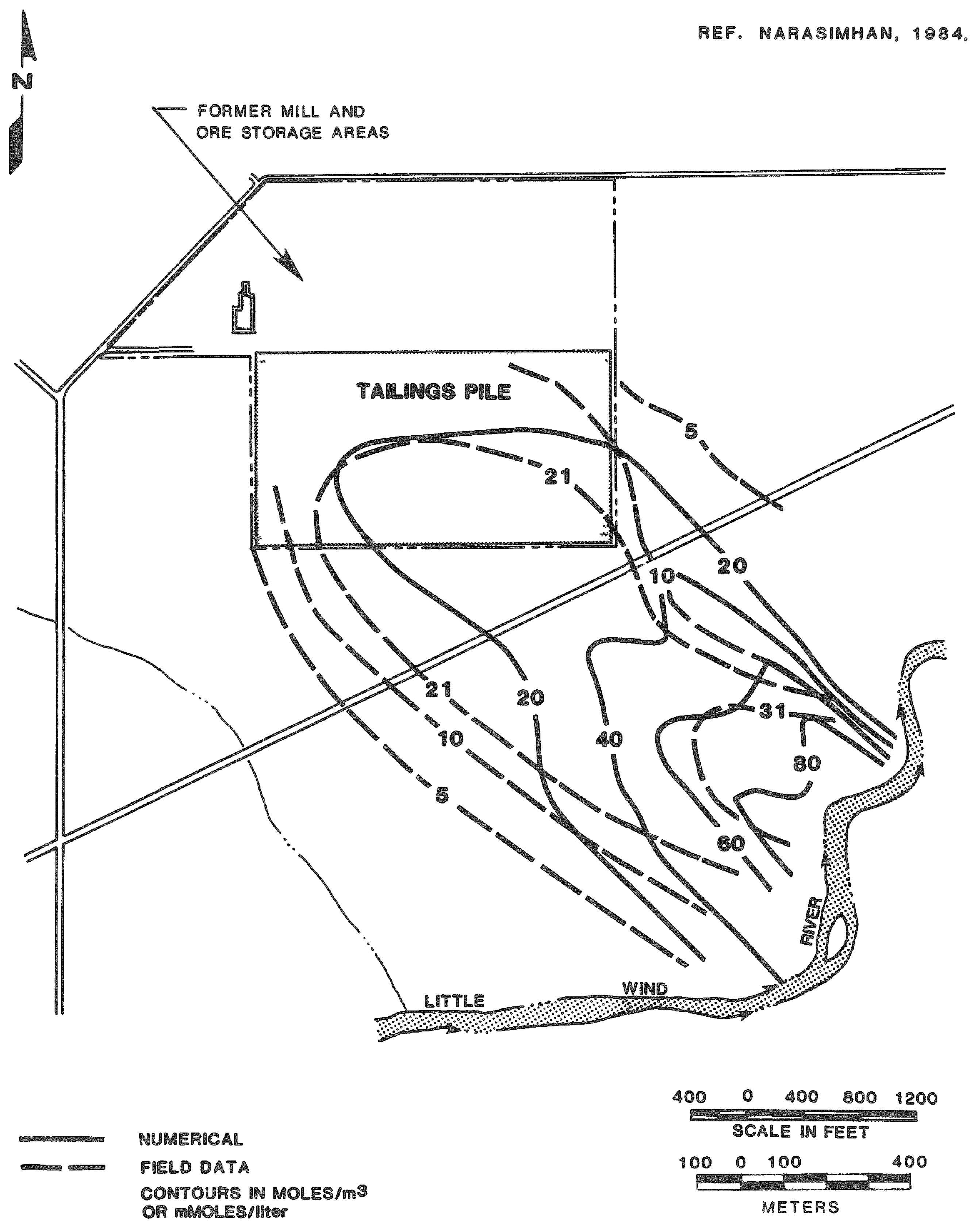


FIGURE C.2.44
COMPARISON OF CURRENT SIMULATED AND OBSERVED SULFATE PLUMES, RIVERTON SITE

Development of a calibrated finite difference ground-water model

Prior to prediction of the effects of slurry wall installation and aquifer restoration on the geochemical regime of the unconfined alluvial aquifer, it was necessary to develop a ground-water flow model which could be used to simulate the altered flow regime due to the existence of the wall. This altered flow regime was expected to cause significant changes in advective solute transport mechanisms and to strongly influence future contaminant migration in the unconfined aquifer.

The USGS three-dimensional finite difference algorithm (Trescott, 1976) was chosen for the design of a two-dimensional, steady state ground-water flow model of the unconfined aquifer. Given the lack of development in the aquifer and the predominance of horizontal hydraulic gradients, the assumptions of steady state conditions in a two-dimensional flow field were considered justified. The flow model was calibrated by reproducing the currently observed hydraulic head distribution through trial and error adjustment of aquifer parameters, subject to assumed boundary conditions. For the purposes of developing a long-term, steady state description of the flow regime, an average water table obtained from seasonal measurements in a series of roughly 30 piezometers was used for the trial and error calibration procedure (White et al., 1984). The "averaged" water table configuration is shown in Figure C.2.45.

A regular finite difference grid with variable spacing was superimposed on the unconfined flow domain. The grid shown in Figure C.2.46 was designed to be similar to the grid used in the TRUMP modeling of the first three remedial action scenarios. Continued use of the original TRUMP grid ensured that, in the event that slurry wall installation did not substantially deflect ground-water flow, the grid would not have to be redefined for predictive modeling of future plume movement. The 20 by 14 grid for the USGS simulation was oriented parallel to streamlines and perpendicular to equipotential lines and included all the nodes previously defined in the original grid, but was extended outward in three directions to minimize propagation of flow disturbances from the vicinity of the wall to the grid boundaries. A 18 by 12 grid of active nodes was defined, for a total of 216 nodes.

Boundary conditions were defined according to characteristics of the observed water table. From visual inspection of Figure C.2.45, it became apparent that, if the hydraulic gradient were extended downgradient from the 1,501.5-meter equipotential line, the Little Wind River would act as a constant head boundary of 1,501.01 meters, thereby acting as a discharge sink for unconfined ground water. Although the stage level of the river would tend to

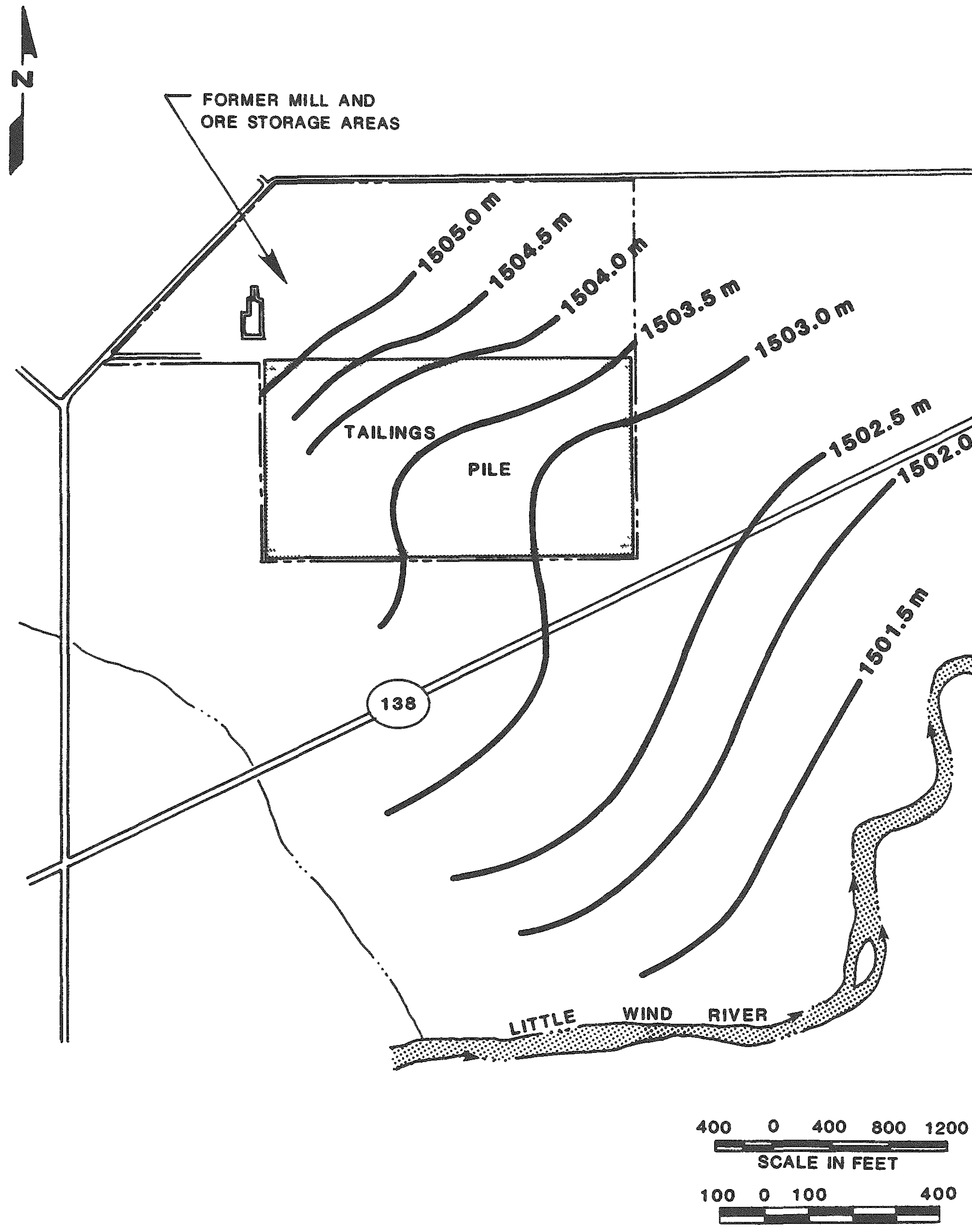


FIGURE C.2.45
AVERAGE WATER TABLE ELEVATION
IN THE UNCONFINED AQUIFER, RIVERTON SITE

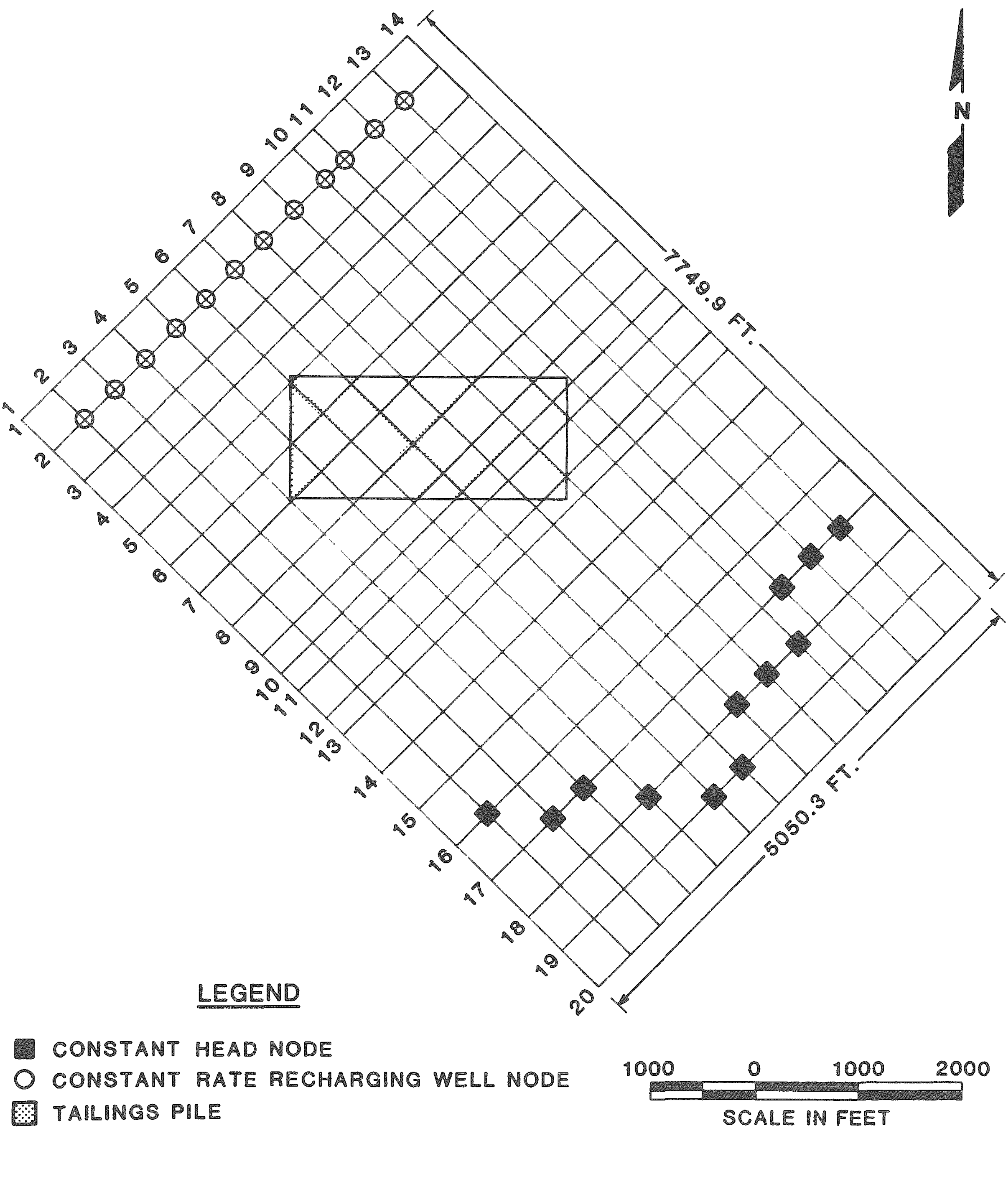


FIGURE C.2.46
FINITE DIFFERENCE FOR GROUNDWATER FLOW MODEL, RIVERTON SITE

fluctuate seasonally, the head level at the river was assumed, on the average, to be equal to 1,501.0 meters. A constant head boundary was therefore established at all nodes near the Little Wind River during the steady state calibration as shown in Figure C.2.46.

Along the northeastern and southwestern boundaries, it was assumed that flow streamlines would remain oriented in a northwesterly-southeasterly direction as long as the boundaries were located sufficiently far from the slurry wall to be unaffected by flow disturbances attributed to wall emplacement. Because, by definition, no flow occurs perpendicular to streamlines, the corresponding parallel northwesterly-southeasterly trending grid lines would act as no-flow boundaries. This was accomplished by setting aquifer transmissivity at all nodes along this boundary equal to zero.

The northwestern boundary was considered to supply all lateral ground-water inflow to the unconfined system because all water entering the model area would have to pass through this boundary. Under steady state conditions, the rate of inflow would be constant in time along this boundary and was assumed to be equal to a Darcy velocity of 20 m/yr obtained from plume migration calculations and from pump test results. This value of 20 m/yr was multiplied by the cross-sectional area associated with each node and assigned to the corresponding node as a constant rate recharging well as shown in Figure C.2.46. Precipitation recharge was assigned to all nodes underlying the pile using the estimated value of 2.15 cm/yr.

Under steady state conditions, the behavior of a confined system is equivalent to that of an unconfined system. In order to obtain instantaneous convergence to a steady state head distribution within a single time step, the storativity was set to zero, effectively forcing the time derivative to zero. This eliminated the need to iterate over a long period of time to obtain a long-term, steady state hydraulic response in the unconfined aquifer. Thus, the only unknowns in the set of differential equations and initial and boundary conditions were the transmissivity values $Txx(x,y) = Kxx(x,y)\, b(x,y)$ and $Tyy(x,y) = Kyy(x,y)\, b(x,y)$ where $Kxx(x,y)$ and $Kyy(x,y)$ are equal to the hydraulic conductivity (m/s) in the x and y directions, respectively, and $b(x,y)$ equals the saturated thickness of the unconfined aquifer.

The trial and error calibration procedure was initiated using arbitrary initial head values of 0.0 meter at nodes at which constant head conditions were not specified and transmissivities of 2.8222×10^{-3} m^2/s at all active nodes. This value of transmissivity was obtained using an estimated hydraulic conductivity of 80 ft/day or 2.8222×10^{-4} m/s and a saturated thickness of 10 m. Figure C.2.47 shows the steady state hydraulic head distri-

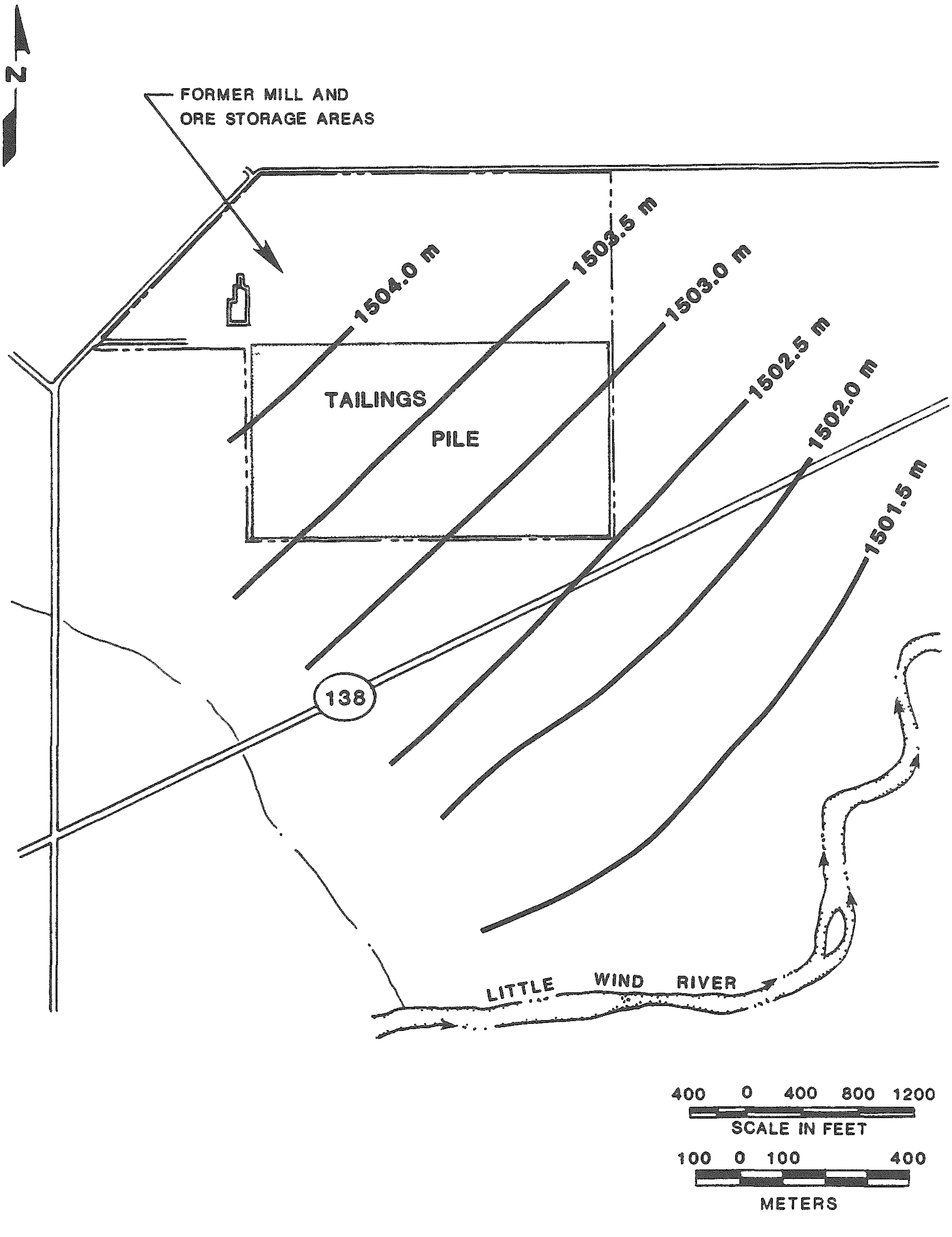


FIGURE C.2.47
STEADY STATE WATER TABLE SIMULATED FROM UNIFORM TRANSMISSIVITY DISTRIBUTION, RIVERTON SITE

bution generated using the USGS algorithm with a uniformly distributed transmissivity value of 2.8222 x 10^{-3} m^2/s. The simulated distribution appears to reasonably duplicate the observed hydraulic head distribution, with the exception of observed upgradient features beneath the pile area and closely spaced equipotentials located slightly north of the pile. Because these features were indicative of a low permeability region beneath the pile, transmissivity was continuously reduced at selected nodes under the pile area until flexures were simulated beneath the pile. However, even an order of magnitude reduction in transmissivity within this area did not entirely reproduce the observed sharp upgradient flexures (Figure C.2.48). Further reduction in transmissivity beneath the pile through the trial and error procedure was considered unjustifiable. It should be noted that reduction of transmissivity by a factor of 10 could be attributed to the combined effects of reduced hydraulic conductivity due to chemical precipitation filling pore spaces and decreased saturated thickness beneath the pile. It is also possible that the tailings pile represented an overburden stress on the floodplain alluvium that caused consolidation, reduced pore interconnection, and reduced conductivity of the alluvium beneath the pile.

C.2.6 IMPACTS ANALYSES

The two basic approaches to mitigation of ground-water contamination include ground-water protection and aquifer restoration. The former approach involves technologies that will preclude the spread of existing contamination within an aquifer or reduce the potential of future contamination. Low permeability covers and liners, slurry wall emplacement, and relocation to more innocuous locations are examples of ground-water protection measures. The technical feasibility of implementing these measures has been determined through remedial action impact modeling. Aquifer restoration involves physical removal and treatment of contaminated ground water, coupled with reinjection or surface discharge of the treated water. Restoration may be used to remove residual contamination in the unconfined aquifer after relocation, stabilization, or slurry wall containment methods have been implemented. A decision regarding the utility of aquifer restoration is to be made after the primary protection measure has been selected.

On September 3, 1985, the United States Tenth Circuit Court of Appeals set aside the EPA water protection standards for the UMTRA Project sites, 40 CFR Part 192.20(a)(2)-(3), and the EPA has not yet re-issued these standards. The water protection standards were remanded to the EPA for further consideration in light of the Court's opinion that the water standards promulgated by the EPA on March 7, 1983, were site specific rather than of general application as required by the legislation. The EPA has not identified a date for re-issuance of 40 CFR Part 192.20(a)(2)-(3), and it is anticipated that such re-issuance will not occur until after remedial action has been initiated at the Riverton tailings site.

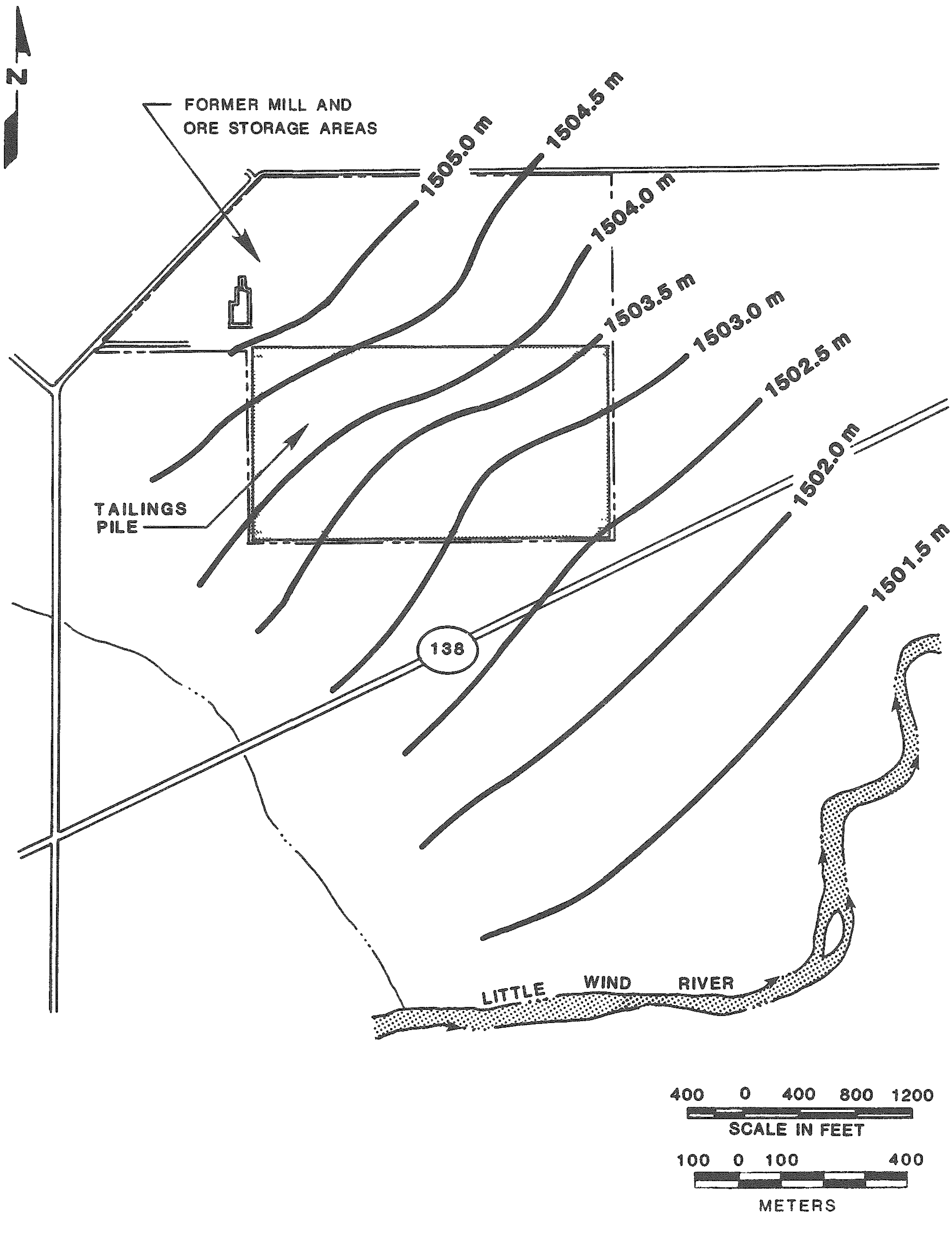


FIGURE C.2.48
STEADY STATE WATER TABLE SIMULATED FROM VARIABLE TRANSMISSIVITY DISTRIBUTION, RIVERTON SITE

At inactive (Title I) uranium mill tailings sites, the EPA standards (40 CFR Part 192, Subparts A, B, and C) require characterization of the hydrogeologic regime at and around each site. These standards state that "Judgements on the possible need for remedial or protective actions for ground-water aquifers should be guided by relevant considerations described in EPA's hazardous waste management system (47 FR 32274, July 26, 1982) and by relevant State and Federal Water Quality Criteria for anticipated or existing uses of water over the term of the stabilization." Until the EPA issues revisions to the water protection standards, the DOE will continue to be guided by these relevant considerations and criteria. When the EPA issues revisions to the water protection standards, the DOE will re-evaluate the ground-water issues at the Riverton site to assure that the revised standards are met. Performing remedial action to stabilize or relocate the tailings prior to the EPA issuing new standards will not affect the measures that are ultimately required to meet the revised EPA water protection standards. The DOE has characterized the conditions at the Riverton site and does not anticipate that any substantial changes to the remedial action will be required. However, after the EPA re-issues the water protection standards, the DOE will determine the need for institutional controls, aquifer restoration, or other controls and will take appropriate action so as to comply with the re-issued standards.

The history matching procedure discussed previously, which involved adjustment of certain hydrologic and geochemical variables and parameters until observed field conditions were adequately estimated, represented the foundation upon which predictive remedial action modeling was based. For purposes of remedial action impact modeling, it was assumed that physical and chemical properties of the site, as identified by the history matching procedure, continued to characterize the hydrologic and geochemical systems throughout the expected period of measurable impact. Several of these properties were systematically altered for each remedial action case in order to describe expected changes in the physical and chemical properties of the site attributable to the specific remedial action measure.

Sulfate concentrations were used to judge the effectiveness of relocation, no action, stabilization in place, and stabilization in place with a slurry wall because sulfate is a relatively conservative hydrochemical tracer. Use of sulfate distributions as a measure of performance was consistent with the application of sulfate as a means of calibrating the TRUMP solute transport algorithm, which served as a basis for subsequent remedial action simulations. Moreover, tracking of predicted contaminant movement was a direct indication of the extent to which future beneficial use of the unconfined ground water would be protected due to implementation of any given remedial action strategy.

C.2.6.1 Disposal at the Dry Cheyenne site

Relocation of the tailings and other contaminated materials to the Dry Cheyenne alternate disposal site would be accompanied by minimal impacts on the ground-water regime at the disposal site. The partially below-grade disposal area for the tailings would be excavated to an average depth of 16 feet and would not encounter any water-bearing formations. Although no field investigations have been conducted at the Dry Cheyenne site, and the exact depth to the uppermost water bearing formation is not known, information for water wells in the surrounding area indicates that the depth to ground water far exceeds the proposed depth of the tailings disposal area.

At the Riverton tailings site, consolidation and excavation of the tailings and other contaminated materials could cause a short-term increase in ground-water contamination, but this increase would be only until all of the materials were removed. The cleanup and excavation of the tailings and contaminated materials and the borrow activities at borrow site 2 could require some dewatering of the unconfined aquifer. This dewatering would be minimal and short-term, and this water would be used for compaction and dust control or evaporated. Ground-water contamination due to application of this water to the pile would be negligible. The only impact to the confined aquifer would be the increased demand for water for the remedial action activities and associated personal consumption. There are adequate local sources to supply this increased demand.

After remedial action, the impacts to the ground water at the Dry Cheyenne site would be minimal due to the absence of ground water at shallow depths. Emplacement of the relatively impermeable, earthen cover over the stabilized tailings would minimize percolation through the tailings and thereby minimize the leaching of contaminants into the underlying strata. Although the exact depth to ground water at the Dry Cheyenne site is not known, information for the surrounding area indicates that the minor seepage of contaminants from the stabilized tailings would not cause significant contamination of any water bearing formations. Due to the lack of surface-water supplies near the Dry Cheyenne site, the source of construction water at the site would probably be ground water from deep confined units.

At the Riverton tailings site, the impact to ground water after remedial action would consist of the reduction of the contaminant flux into the unconfined aquifer. Relocation of the tailings and contaminated materials to the Dry Cheyenne site would remove the source of future ground-water contamination. Existing contamination would continue to migrate downgradient and discharge into the Little Wind River until the concentrations of contaminants in the aquifer had returned to background levels.

Physical effects of tailings pile relocation on sulfate plume development were investigated using the TRUMP solute transport algorithm. The impacts of implementing the relocation alternative were predicted through continuation of the history matching simulation, with suitable modification of the input data to reflect the immediate relocation of the tailings pile and other contaminated materials.

Only the effects of relocation at the processing site were addressed during the modeling study.

Removal of the tailings implied removal of all contamination entering the aquifer through downward advecting percolation, as well as deletion of chemical precipitation mechanisms occurring within the pile prior to downward movement of contaminants. All other physical processes defined by the history matching procedures, including chemical boundary conditions and advective and dispersive transport parameters for sulfate currently in the aquifer, were continued during the relocation simulation. Because the simulation was initialized at the present time, initial concentrations in the aquifer were specified to be those that were simulated 25 years after the onset of active disposal.

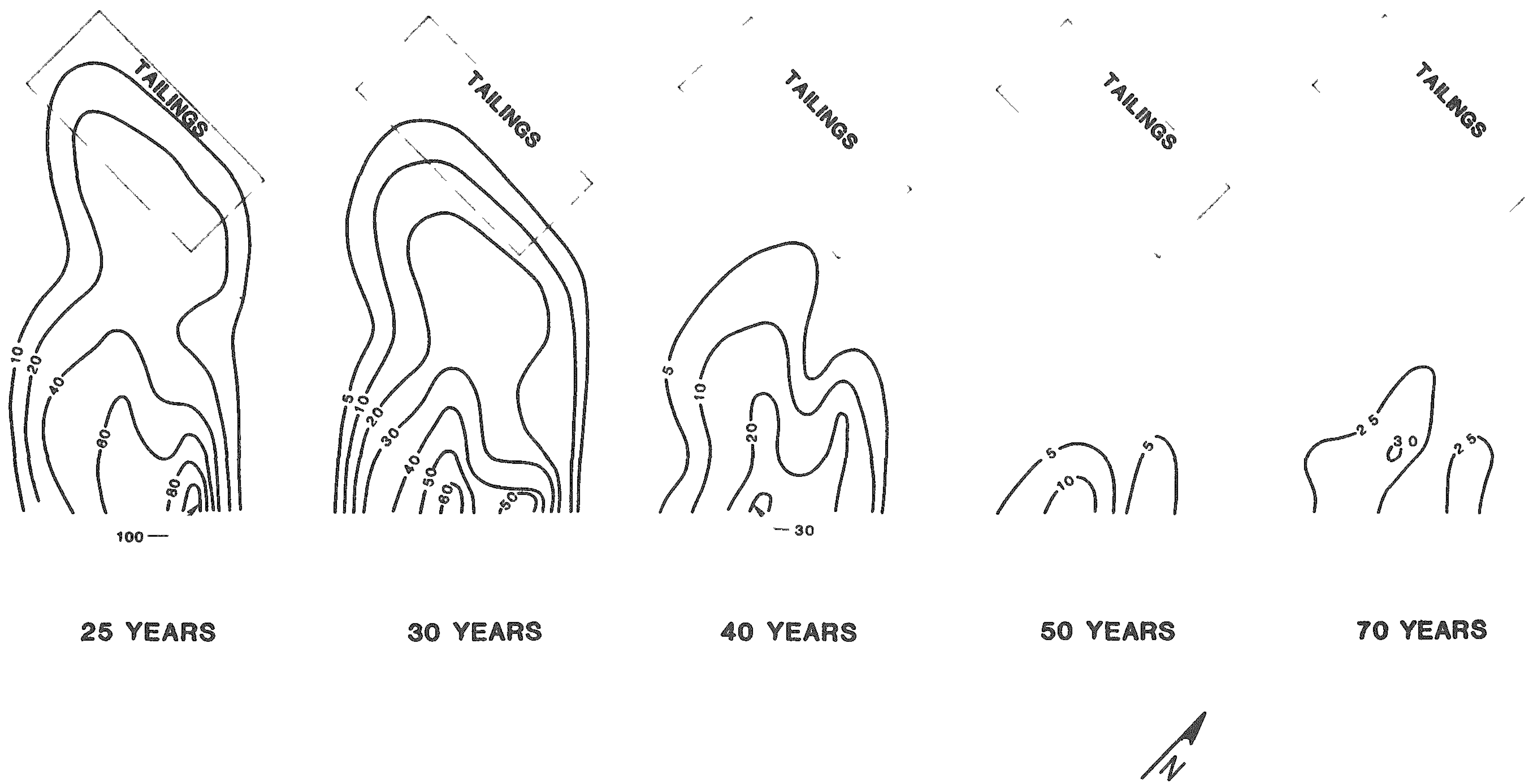
Given the uncertainty regarding future infiltration, the relocation option was simulated with 0.0 and 2.2 cm/yr net percolation rates. Simulation of no percolation and continued percolation at the present rate therefore placed bounds on the rate of time required for flushing the sulfate plume from the unconfined aquifer.

Results of the relocation impact modeling with the two percolation rates are shown in Figure C.2.49. There are no significant differences in sulfate plume development between the simulations performed with and without infiltration. The similarity of plume development was attributed to the negligible contribution of infiltrating water to the overall water balance within the aquifer. At the current rate of net percolation of 2.2 cm/yr, the vertical flux accounts for roughly 0.1 percent of the total flow through the aquifer system. Therefore, the rate of plume movement after relocation was insensitive to the rate of percolation within the range of 0.0 to 2.2 cm/yr, and the question of whether infiltration would continue after relocation was not relevant to the remedial action decision.

The TRUMP results indicated that current sulfate contamination would be completely flushed from the system to levels of 3.00 moles per cubic meter through natural advective and dispersive mechanisms after 45 years from the present time. Although the background level of sulfate is actually 2.34 moles per cubic meter, a value of 3.00 moles per cubic meter was chosen to determine the time of flushing because numerical instability caused slight oscillations at low concentrations. The time estimate of 45 years for flushing all sulfate and other mobile constituents is based on the assumptions that the pile would be completely relocated in the near future and that changes in the precipitation regime or significant increased development of the unconfined system would not occur during the next 45 years.

C.2.6.2 Relocation to Gas Hills

At the Riverton tailings site, consolidation and excavation of the tailings and other contaminated materials



NOTE: CONTOURS IN MOLES/m^3.

FIGURE C.2.49
SULFATE PLUME DEVELOPMENT AFTER PILE RELOCATION, RIVERTON SITE

could cause a short-term increase in ground-water contamination, but this increase would be only until all of the tailings and contaminated materials were removed. The cleanup and excavation of the tailings and contaminated materials could require some dewatering of the unconfined aquifer. This dewatering would be minimal and for a short duration, and this water would be used for dust control or evaporated. Ground-water contamination due to application of this water to the pile would be negligible. The only impact to the confined aquifer would be the increased demand for water for the remedial action activities and associated personal consumption. There are adequate local sources to supply this increased demand.

The impact to ground water at the Riverton tailings site after remedial action would consist of the reduction of the contaminant flux into the unconfined aquifer. Relocation of the tailings and contaminated materials to Gas Hills would remove the source of future ground-water contamination. Existing contamination would continue to migrate downgradient and discharge into the Little Wind River until the concentrations of contaminants in the aquifer had returned to background levels. The TRUMP solute transport modeling performed for the Dry Cheyenne disposal alternative would also apply to relocation to Gas Hills. The TRUMP results indicated that current sulfate contamination would be completely flushed from the system through natural advective and dispersive mechanisms after 45 years from the present time. The time estimate of 45 years for flushing all sulfate and other mobile constituents is based on the assumptions that the pile would be completely relocated in the near future and that changes in the precipitation regime or significant increased development of the unconfined system would not occur during the next 45 years.

The depth to ground water at the Little Wind borrow site is not known. However, the borrow activities at this site would not be expected to penetrate any water bearing formations, and, therefore, no ground-water impacts would be anticipated at the borrow site during and after remedial action.

C.2.6.3 No action

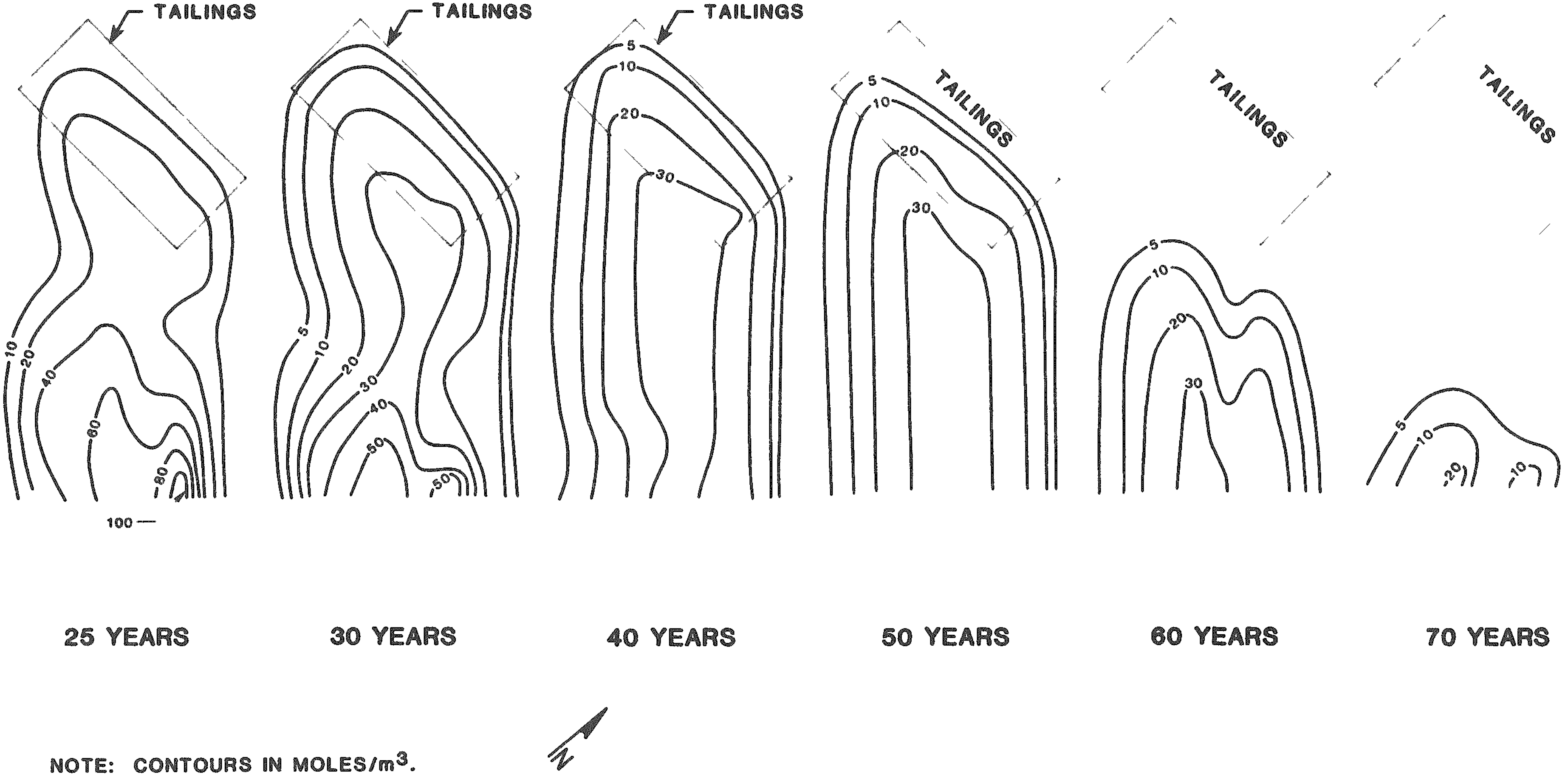
Effects of the no action strategy were simulated using the TRUMP solute transport algorithm by again modifying input data used for the history matching procedure. Modification included the extension of both current sulfate chemical precipitation rates and infiltration rates into the future. In addition, the rate of sulfate influx and chemical precipitation of sulfate was set to zero after a specified time that was calculated on the basis of observed dilution front movement throughout the pile. The existence of such a dilution front is believed to be governed by the continued downward flushing of pile contaminants by initially uncontaminated rainwater. It was assumed that under a no action strategy, infiltrating rainfall would continue to dilute sulfate generated in the pile and that the future rate of movement of the dilution front would be equal to the current rate of movement. Extrapolation of the current dilution front rate of movement into the future was considered to be a realistic means of describing the continued flushing action of downward percolating fresh rainwater, assuming that no major changes in the precipitation rate occur during the time period of predicted impact.

The present rate of dilution front movement was obtained by assuming that dilution has been migrating since active disposal began. Strictly speaking, the pile had not yet been completely formed until 5 years after the onset of active disposal. However, the method of disposal involved successive waste deposition and spigot movement, a situation in which the present pile thickness at any given point was attained soon after disposal began. Under the circumstances, the dilution front at any given point began forming almost immediately after disposal. Assuming that the point at which the current dilution front measurement was made had been subject to deposition soon after disposal began, a 25-year period could be used to calculate the rate of front movement.

According to Figure C.2.23, the present location of the front for sulfate dilution is roughly 1.5 meters or 4.92 feet below the top of the tailings. Assuming that 25 years were required for development of the dilution front to occur in response to infiltrating rainfall, the average rate of dilution front movement from the top of the pile would be equal to 0.197 ft/yr. Given a 9.5-foot pile thickness, the remaining thickness of the pile through which the dilution front would have to move before it dropped below the base of the tailings contaminant source would be equal to 4.58 feet. The length of time required for the front to drop below the tailings, assuming that it would continue to move at a rate equal to the current rate, would be roughly 23 years from the present time.

Using the 23-year estimate, the no action simulation was performed by eliminating both the sulfate concentration in the tailings fluid and the sulfate chemical precipitation rates in the pile after 23 years. As in the relocation simulation, all other physical processes defined during the history matching phase remained unchanged. Initial concentrations were again specified to reflect the present distribution of sulfate in the contaminated aquifer.

Sulfate plume development due to a no action policy is shown in Figure C.2.50. Plume development for this option appears to lag 20 years behind development for the relocation option. The time required to completely flush the plume from the aquifer would be 65 years from present time.



NOTE: CONTOURS IN MOLES/m^3.

FIGURE C.2.50
SULFATE PLUME DEVLOPMENT AFTER NO ACTION, RIVERTON SITE

The no action strategy would require a longer period of time for natural aquifer restoration because the contaminant source is not actually removed until 23 years from the present.

C.2.6.4 Stabilization in place

During stabilization in place, impacts to the unconfined and confined aquifers at the tailings site would be minimal. Consolidation and compaction of the tailings and contaminated materials could increase drainage from the tailings pile. This could cause a small short-term increase in contamination of the unconfined aquifer directly beneath the tailings pile. Cleanup of the windblown tailings and other contaminated areas could require some dewatering of the unconfined aquifer. This dewatering would be minimal and for a short time, and the water removed would be used for compaction and dust control purposes or evaporated. There is no ground water within 30 feet of the land surface at borrow site 10, and the borrow activities would not extend beyond that depth. Impacts associated with the percolation of contaminated, compaction, or dust control water to the ground water beneath and downgradient of the pile would tend to be minimal.

According to the TRUST estimation of water drainage from the compacted pile, roughly 0.5 meter per year would drain from the pile during the first 9 years following disposal. This rate of influx would not be sufficient to cause a measurable rise in the water table beneath the stabilized pile. No significant capillary rise of water beneath the site was predicted by the TRUST model. Given the lack of predicted capillary rise and the small amount of contamination in the compaction water relative to the current contamination in ground water beneath the site, the possibility of major changes in the redox potential or pH are unlikely.

Implementation of stabilization in place would cause an increase in water consumption for remedial action activities such as compaction and dust control and for personal consumption by the remedial action workers and any associated in-migrants. If this water were supplied from the confined aquifer, it could cause a small, short-term lowering of the local water level. A local well could adequately supply the increased demand without any major difficulty.

A conservative upper bound for percolation through the tailings would be 2.2 cm/yr, the same percolation rate calculated for present conditions. The actual percolation rate should be somewhat reduced because the 2-percent slope and the low permeability of the clay cover should cause increased runoff thus decreasing ponding, infiltration, and percolation. As a worst case, the plume migration shown in Figure C.2.50 and a time of 65 years for plume dissipation should be representative.

C.2.6.5 <u>Simulation of ground-water flow after slurry wall installation</u>

Deflection of ground water around the stabilized tailings pile due to slurry wall installation was numerically simulated with the calibrated USGS flow model in order to determine the ultimate effect of changing advective, dispersive, and diffusive solute transport mechanisms after wall emplacement. Changes in the ground-water flow regime were predicted by assigning expected transmissive properties of the wall to all finite difference nodes located near the proposed wall. The lowest hydraulic conductivity of the slurry wall material which could be practically attained in the field would be on the order of 10^{-9} m/s. This value was multiplied by an expected wall depth of 30 feet or 9 meters in order to obtain a transmissivity of 9.0 x 10^{-9} m^2/s which was considered the lower limit on wall transmissivity. Although assignment of this transmissivity value to each node near the slurry wall implied that the entire cell associated with the node would be characterized by this transmissivity, thereby underestimating the transmissivity at the periphery of the pile, the resulting simulation would predict a conservative estimate of sulfate migration from inside the confines of the wall.

Given that the greatest deflection of ground water around the pile would tend to cause greater isolation of contaminants, interest was initially focused on determining the effect of the lowest permeability wall material on pile integrity. Specifically, the possibility that mounding of percolating water within the confines of the wall had to be addressed. The steady state hydraulic head distribution generated using the minimum wall transmissivity of 9.0 x 10^{-9} m^2/s is shown in Figure C.2.51. Clearly, the wall would cause no significant mounding of percolating water over the long term. As indicated by the stream lines, which were constructed perpendicular to the equipotentials, most of the water that originally passed through the pile area would be deflected northeastward and southwestward around the pile (Figure C.2.52). Ground water passing beneath the pile does so at a greatly reduced velocity as a result of rapid divergence of stream lines originating along the northwestern boundary.

Due to the significant deflection of ground water as a result of the low permeability slurry wall, the directional aspect of advective and dispersive contaminant transport processes would become altered after well emplacement. The TRUMP solute transport grid therefore was redefined in order to reflect these new directional properties. A new grid was designed on the basis of the flow net shown in Figure C.2.52 such that the sides of each nodal element conformed to the direction of flow or to the direction perpendicular to flow. This eliminated the need to introduce a dispersivity tensor and allowed dispersion processes to be described solely on the basis of scalar longitudinal and

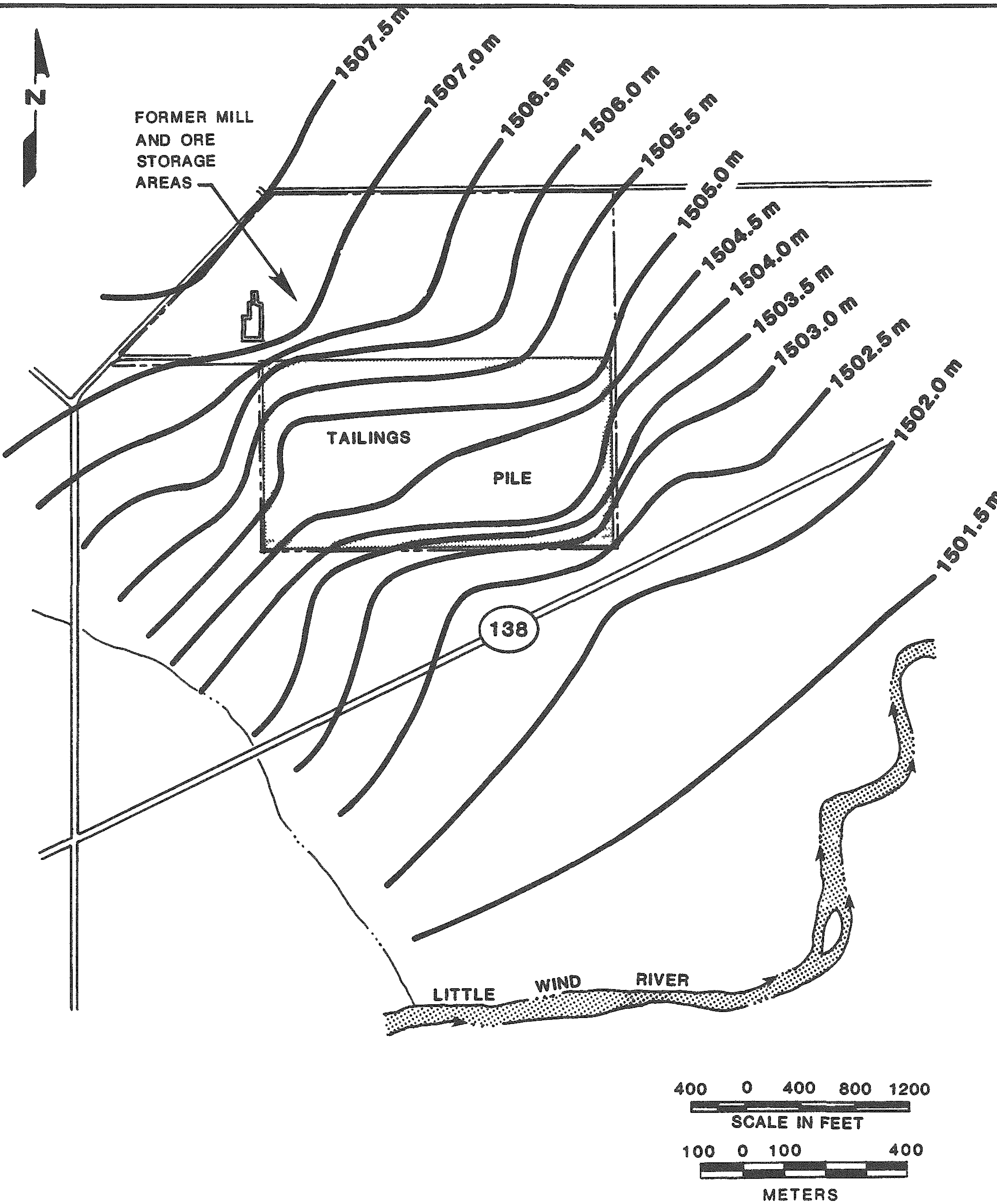


FIGURE C.2.51
STEADY STATE WATER TABLE AFTER SLURRY WALL INSTALLATION, RIVERTON SITE

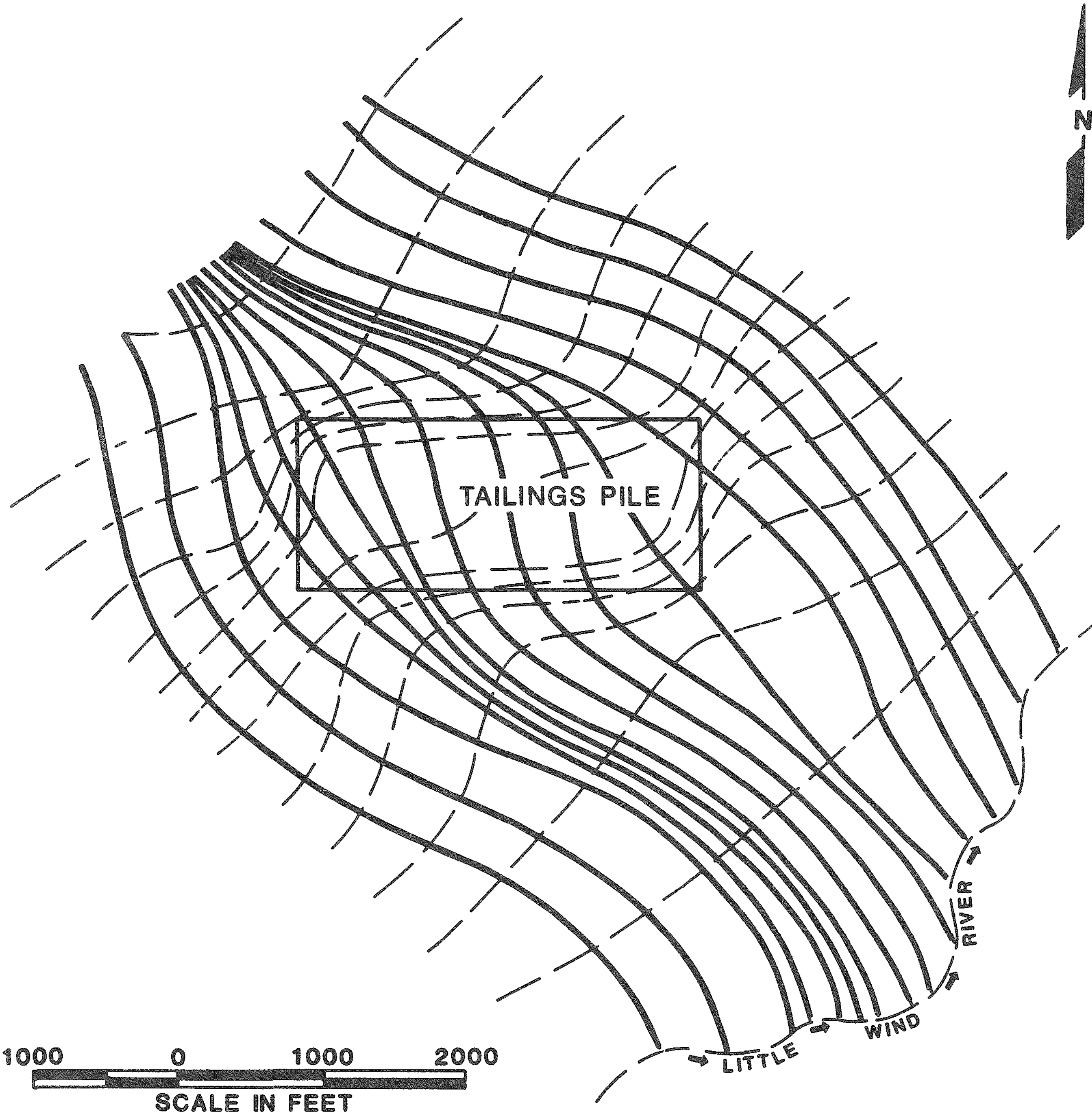


FIGURE C.2.52
FLOW NET FOR STEADY STATE GROUNDWATER REGIME AFTER SLURRY WALL INSTALLATION, RIVERTON SITE

transverse dispersion coefficients. The new TRUMP grid used to simulate contaminant migration after slurry wall construction is shown in Figure C.2.53.

The TRUMP simulation was initiated using the current sulfate distribution in the unconfined aquifer because this distribution reflected present geochemical conditions in the aquifer prior to installation of the wall. Sulfate influx and chemical precipitation were removed at 23 years after the current time to account for the dilution front drop mechanism.

Development of the sulfate plume after slurry wall construction is shown in Figure C.2.54. That part of the current plume which would be outside the confines of the wall would dissipate in 30 to 40 years. Within the wall, sulfate would continuously accumulate and would form a second plume. This plume would ultimately break through the wall and migrate downgradient very slowly due to the small velocities southeast of the wall, and this plume would be intensified due to the fact that there would be more time to add sulfate to the slowly moving plume. Concentrations above 3.00 moles per cubic meter would persist even 300 years following remedial action.

C.2.6.6 Aquifer restoration or ground-water protection

Specific criteria which should be used to judge the effectiveness of aquifer restoration or protection include technical feasibility, cost of implementation, future value of the affected ground-water resource, availability of alternative ground-water supplies, and the likely degree of human exposure which would occur without restoration or protection.

The first phase of aquifer restoration requires withdrawal of contaminated ground water from the aquifer. Either passive trench collection systems or active pumping well collection systems may be used to extract the contaminated ground water. Passive methods allow contaminated ground water to be intercepted and diverted to a treatment plant and are useful when the depth to the base of the aquifer is less than 30 feet, as is the case for the unconfined system at Riverton. Active methods involve pumpage of ground water from one or more wells completed in the contaminated portion of the aquifer. These methods are particularly attractive when management of the aquifer through hydraulic control is considered desirable. A system of pumping and injecting wells can be designed for purposes of locally controlling or reversing hydraulic gradients such that an equipotential ridge surrounds the area of contamination.

Either active or passive methods could be used in conjunction with the proposed remedial action of stabilization

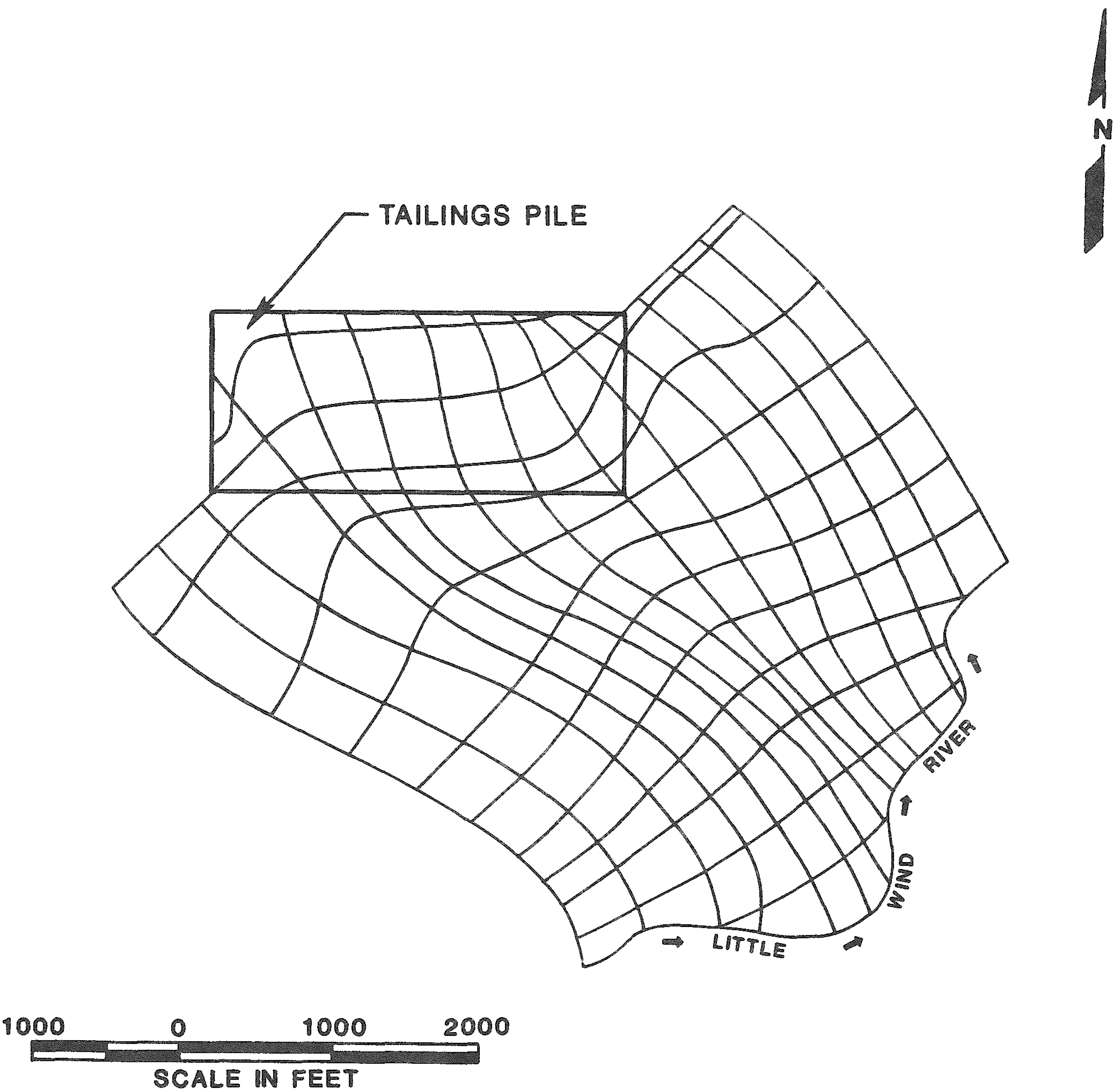
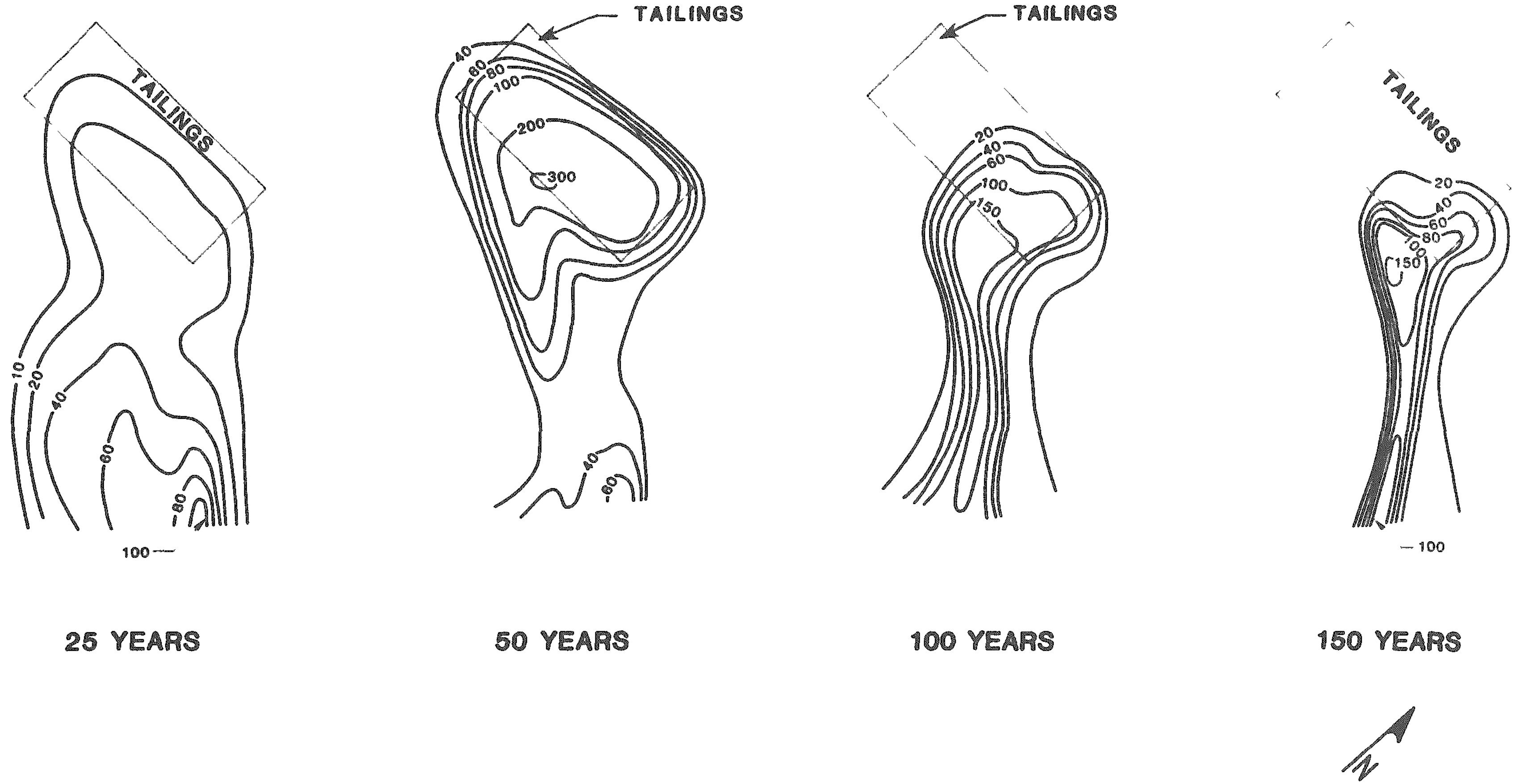
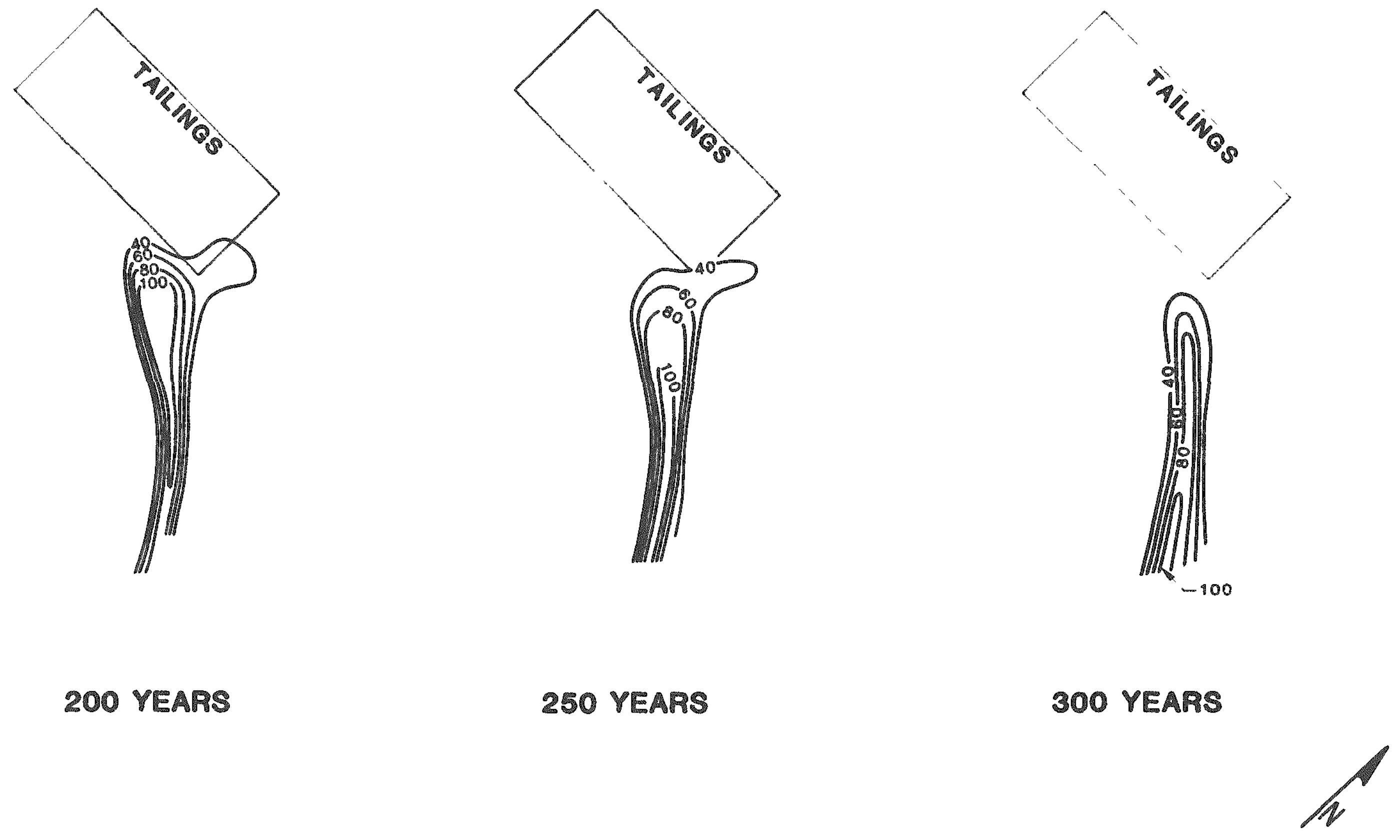


FIGURE C.2.53
TRUMP FINITE DIFFERENCE GRID FOR PREDICTION OF PLUME MIGRATION AFTER SLURRY WALL INSTALLATION, RIVERTON SITE



NOTE: CONTOURS IN MOLES/m^3.

FIGURE C.2.54
SULFATE PLUME DEVELOPMENT AFTER SLURRY WALL INSTALLATION, RIVERTON SITE



NOTE: CONTOURS IN MOLES/m^3.

FIGURE C.2.54 (concluded)
SULFATE PLUME DEVELOPMENT AFTER SLURRY WALL INSTALLATION, RIVERTON SITE

or physical subsurface containment using slurry walls. The intercepted water could then be diverted to a treatment plant and subsequently discharged into the Little Wind River or input back to the aquifer through artificial recharge or forced injection. Artificial recharge of the treated ground water into the unconfined aquifer or forced injection into the underlying confined system through well heads would allow greater control over the prevailing flow regime. For example, injection of the treated water into the confined units would replenish the fresh water supply and would lessen or reverse the downward hydraulic gradient between the confined and unconfined systems, thereby further protecting the fresh water resources. Injection wells also may be used to create ground-water mounds between the contaminant source and the Little Wind River discharge area, in effect serving to locally reverse the regional southeastward movement of contaminants until they can be withdrawn and treated. The amount of time required to completely flush the aquifer in the region outside of the containment area would depend on the natural hydraulic discharge. Advantages of the interception-injection strategy include high design flexibility and a high degree of reliability with proper monitoring. Disadvantages are high operating and maintenance costs.

Although the technical feasibility of aquifer restoration or protection has not yet been determined, a preliminary simulation to predict effects of applying interception pumpage in the unconfined aquifer along the downgradient edges of the pile suggests that over the long-term very small pumpage rates would be required to induce a hydraulic cone of depression around the tailings contaminant source. Because contamination of the confined aquifer does not appear to be extensive at the present time and is ultimately related to contamination of the overlying unconfined system, restoration of the unconfined aquifer was considered to be sufficient to protect all usable ground-water resources. Figure C.2.55 illustrates that, with 0.002 cubic meters per second (m^3/s) (31 gpm) of pumpage along the south and eastern edges of the pile, the calibrated USGS steady state flow model predicts a cone of depression that extends southward to the Little Wind River. While this intensity of pumpage would divert uncontaminated water outside the extent of the plume and is probably unwarranted, it does indicate that the effects of steady state pumping of just 0.002 m^3/s in the highly transmissive unconfined aquifer would, after a sufficiently long period of time, propagate significant distances from the site. The constant rate of pumping which would create a more localized cone of depression may be significantly less than 0.002 m^3/s.

Effects of aquifer restoration on sulfate plume development were simulated using the TRUMP solute transport algorithm. The cone of depression caused by continuous, steady state pumpage of 0.002 m^3/s along the southern and

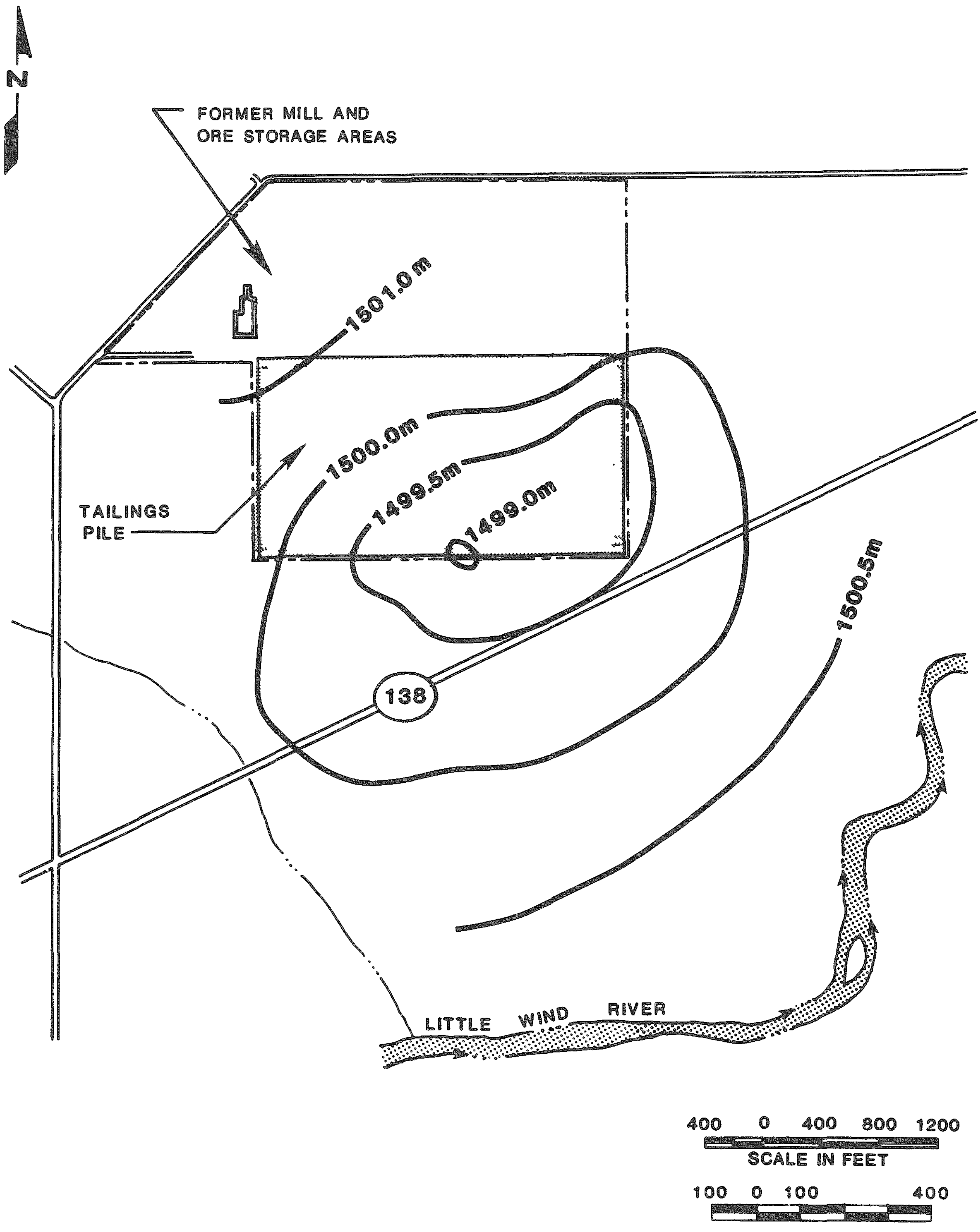


FIGURE C.2.55
PREDICTED STEADY STATE WATER TABLE DUE TO PUMPAGE OF 0.002m^3/s, RIVERTON SITE

eastern edges of the pile is shown in Figure C.2.55. This hydraulic depression was expected to act as a sulfate sink that would eventually draw all current sulfate contamination out of the unconfined aquifer and contain a zone of limited areal extent.

Input to the TRUMP simulation included ground-water flow rates between nodes which were calculated on the basis of the steady state hydraulic head distribution generated by the USGS model. The TRUMP grid used for the history matching and remedial action impact modeling simulations was used to perform the restoration plume simulation (Figure C.2.43). The simulation did not account for the effects of radial flow toward the interception wells. The sulfate precipitation rate was assumed to be constant at the 25-year rate shown in Figure C.2.42 until the dilution front dropped below the tailings base 23 years from the present time. Initial sulfate concentrations were specified to be those simulated for the present time by the history matching analysis.

Operation of the interception wells appears to effectively draw contaminated ground water south and east of the pile and also contains sulfate to the area beneath the pile. Comparison of the sulfate plume after 5 years of interception pumpage to the current sulfate plume also indicates that sulfate would tend to accumulate within the pile area due to reversal of the regional ground-water flow direction south and east of the pile. Sulfate that continues to enter the flow system from upgradient of the site would become stagnated beneath the pile and, in the absence of an advective flow path, would accumulate within the cone of depression. Also, there is evidence of some northwestward migration of sulfate that had previously been located near the Little Wind River. Clearly, the magnitude of pumping which would cause such migration is in excess of the amount that would actually be required to clean the aquifer of sulfate because flushing of most of the downgradient sulfate to the Little Wind River would occur naturally.

After 15 years, additional sulfate has accumulated beneath the pile area. This suggests that treatment of contaminated ground water would have to intensify over time in order to account for higher concentrations in intercepted waters; also, continued northwestward movement of sulfate that originated downgradient of the pile is indicated. The occurrence of a new plume south of the pile cannot be explained on the basis of physical processes and appears to be related to numerical instability of the TRUMP algorithm. It appears that steep chemical gradients near the periphery of the pile may have caused large oscillations of concentrations that propagate rapidly through the solute transport domain under conditions of intensive pumpage. The oscillations became excessive after 15 years and prohibited further evaluation of the restoration alternative.

While sulfate is an excellent tracer for determining the impacts of aquifer restoration with respect to conservative contaminants, its distribution does not reflect the geochemical behavior of major cations and trace metals. The behavior of these constituents is affected significantly by adsorption in addition to advection, dispersion, and diffusion. Adsorption may ultimately make complete aquifer restoration an unrealistic remedial action goal because no amount of pumping can remove adsorbed constituents unless geochemical conditions are artificially manipulated as part of the remedial action plan.

Following the collection of contaminated ground water, the next step in aquifer restoration would involve treatment of the water to suitable standards and the eventual reinfiltration or reinjection into an aquifer or discharge to the surface-water system. Depending on applicable regulations, the contaminated ground water must be physically treated to satisfy water quality standards prior to reintroduction into the hydrologic environment. Dilution is not considered to be a viable treatment alternative.

A variety of methods have been successfully employed in treating ground water contaminated with uranium, metals, sulfate, and dissolved solids. The water is first subjected to flow equilization, a procedure which dampens flow and concentration fluctuations, and is then routed through a treatment facility.

A typical treatment plant would involve the following processes:

- Neutralization to a pH of 8.0 to 9.0 in order to precipitate most metals and neutralize the residual acid. Lime could be used as a neutralization agent.

- Settling of the neutralized sludge generated in the neutralization step by settling, and then chemically stabilizing the sludge after dewatering. It could then be handled by normal construction equipment for disposal.

- Reverse osmosis to remove TDS and sulfate so that the treatment plant effluent would meet site-specific effluent limitations (WDEQ, 1980) for the Little Wind River.

A hydrated lime ($Ca(OH)_2$) precipitation-filtration plant would be adequate for removal of contaminants to acceptable concentrations. After treatment, concentrated contaminants would usually be in solid form as either a sludge or a coating on the exchange material. The sludge would then be dried by natural evaporation in lined ponds at the treatment plant. Within 2 years after completion of treatment, these solids could be buried at a specified disposal site. Treated ground water would be routed to bodies of surface water or allowed to infiltrate or be injected into the unconfined or confined aquifer. While injection is usually more expensive due to both high fixed and operating costs, it can be used as a tool for residual plume containment.

In view of the negligible quantities of irrigation and livestock watering supplies that are obtained from the unconfined aquifer downgradient of the site, replacement water could probably be most easily obtained from unclaimed water in either the Wind or Little Wind Rivers or by obtaining uncontaminated water from deeper confined aquifers. The increased demand could also be accommodated by expansion of the municipal water service. The cost of water from the municipal field, based on the user's ability to pay, would be a maximum of $20 per acre-foot (Penz, 1985).

A technically feasible and realistic aquifer restoration approach was devised for the contaminated portion of the unconfined aquifer beneath and downgradient of the Riverton tailings site. Sulfate, iron, manganese, and probably uranium would be removed effectively. The removal of molybdenum would be less certain because of its attenuation in the solid phase.

The aquifer restoration system would include:

- Eight wells to pump 31 gpm each for 20 years.
- Eight initial pumps and eight replacement pumps.
- Ten additional monitor wells.
- One central water treatment plant.
- One evaporation pond.
- One collection system to route water from the production wells to the treatment plant, to the evaporation pond, and to the Little Wind River.
- An average of 100 water quality analyses per year for 20 years.
- Operation and maintenance of all facilities and wells.

The total system cost is estimated to be $4.4 million.

The monetary benefit of this system can be estimated as the value of the total volume of ground water extracted, treated, and discharged through the 20-year treatment period. To calculate this benefit:

- 31 gpm per well x 8 wells = total discharge of 248 gallons per minute.

- The total volume produced in 20 years is 248 gallons/minute x 0.133 ft^3/gal x 60 mins/hr x 24 hrs/day x 365 days/yr x 20 years = 3.47 x 10^8 ft^3 x 2.3 x 10^{-5} acre-ft/ft^3 = 7.98 x 10^3 acre-feet.

- At a value of $20/acre-foot, the total monetary benefit would be $160,000.

A cost of $4.4 million and a benefit of $160,000 results in a cost-benefit ratio of 27.5.

Aquifer restoration would not be a cost effective means of controlling or cleaning up the contaminated ground water at the Riverton tailings site due to the following considerations.

- The lack of known health effects associated with the contamination.

- The limited present and expected use of the unconfined ground water.

- The long, calculated travel time (1,700 years) for water to move from the unconfined aquifer to the more prolific confined sandstones at depths greater than 200 feet.

- The availability of alternative water supplies.

- The larger cost-benefit ratio for a realistic treatment system and a realistic monetary benefit.

More realistic means of controlling or cleaning up the contamination could include:

- Allowing the contaminated ground water to continue to discharge naturally to the Little Wind River.

- Restricting the uses of the contaminated ground water.

- Requiring well head treatment of the contaminated ground water to meet applicable water quality standards if wells are to be used.

Regardless, when the EPA issues revisions to the water protection standards (40 CFR Part 192.20 (a)(2)-(3)) that were remanded by the U.S. Tenth Circuit Court of Appeals, the DOE will re-evaluate the ground-water issues at the Riverton site to assure that the revised standards are met. Performing remedial action to stabilize or relocate the tailings prior to the EPA issuing new standards will not affect the measures that are ultimately required to meet the revised EPA water protection standards. The DOE has characterized the conditions at the Riverton site and does not anticipate that any substantial changes to the remedial action will be required. However, after the EPA re-issues the water protection standards, the DOE will determine the need for institutional controls, aquifer restoration, or other controls and will take appropriate action so as to comply with the re-issued standards.

REFERENCES FOR APPENDIX C

Anderson and Kelly (Anderson and Kelly, Consultants in Engineering and Geology), 1976. "Water Supply Study, City of Riverton, Wyoming," Riverton, Wyoming.

Baes, D.F., and R.E. Messmer, 1976. The Hydrolysis of Cations, Wiley Interscience, New York, New York.

Bouwer, H., 1978. Ground Water Hydrology, McGraw-Hill Book Company, New York, New York.

COE (U.S. Army Corps of Engineers), 1982. HEC-2 Water Surface Profiles, User's Manual, Computer Program 723-X6-L202A, Water Resources Support Center, Hydrology Engineering Center, Davis, California.

COE (U.S. Army Corps of Engineers), 1981. HEC-1 Flood Hydrograph Package, User's Manual, Computer Program 723-X6-L2010, Water Resources Support Center, Hydrology Engineering Center, Davis, California.

CSU (Colorado State University), 1983a. "Characterization of Inactive Uranium Mill Tailings Sites: Riverton, Wyoming," draft report prepared by CSU, Fort Collins, Colorado, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

CSU (Colorado State University), 1983b. "CSU/HGCC Report, Interim Draft," draft report prepared by CSU, Fort Collins, Colorado, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Cothern et al. (C.R. Cothern, W.L. Lappenbusch, and J.A. Cotruvo), 1983. "Health Effects Guidance for Uranium in Drinking Water" in "Radiobiology of Radium and the Actinides in Man," Health Physics, Volume 44, Supplement No. 1, Pergamon Press, New York, New York.

Crippen, J.R., and C.D. Bue, 1977. Maximum Flood Flows in the Conterminous United States, U.S. Geological Survey Water-Supply Paper 1887, U.S. Department of the Interior, Washington, D.C.

DOI (U.S. Department of the Interior), 1981a. Wind River Basin Water Supply Study, Wyoming, Bureau of Reclamation, Field Planning Branch, Billings, Montana.

DOI (U.S. Department of the Interior), 1981b. Guidelines for Determining Flood Frequency, Bulletin No. 17B of the Hydrology Subcommittee, Interagency Advisory Committee on Water Data, Reston, Virginia.

DOI (U.S. Department of the Interior), 1977. Design of Small Dams, Water Resources Technical Publication, Bureau of Reclamation, Washington, D.C.

DOI (U.S. Department of the Interior), 1944. Memorandum to Hydraulic Engineer, Bureau of Reclamation, Upper Missouri Region; Subject: Spillway design flood for Boysen Dam site - Big Horn Project Investigation - Missouri River Basin; dated November 13, 1944.

Darr, Paul, 1985. Memorandum from Paul Darr, Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico; Subject: Trip Report - Riprap Reconnaissance - Riverton; dated February 28, 1985.

Davis, S.N., and R.J.M. DeWiest, 1966. Hydrology, John Wiley & Sons, Inc., New York, New York.

EPA (U.S. Environmental Protection Agency), 1983. Methods for Chemical Analysis for Water and Waste, EPA-600/4-79-020, Washington, D.C.

Edwards, A.L., 1972. TRUMP: A Computer Program for Transient and Steady State Temperature Distributions in Multi-Dimensional Systems, UCRL-4754, Rev. 3, Lawrence Livermore Laboratory, University of California, Livermore, California.

FBDU (Ford, Bacon & Davis Utah Inc.), 1981. Engineering Assessment of Inactive Uranium Mill Tailings, Riverton Site, Riverton, Wyoming, DOE/UMT0106, FBDU-360-19, UC 70, prepared by FBDU, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Ferris et al. (J.G. Ferris, D.B. Knanles, R.H. Brown, and R.W. Stallman), 1962. Theory of Aquifer Tests, USGS Water-Supply Paper 1536-E, U.S. Department of the Interior, Washington, D.C.

Freeze, R.A., and J.A. Cherry, 1979. Groundwater, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

GECR (Geochemistry and Environmental Chemistry Research, Inc.), 1983. Geochemical Investigation of UMTRAP Designated Site at Riverton, Wyoming, UMTRA DOE/ALO-0229, prepared by GECR, Rapid City, South Dakota, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Henry et al. (C.D. Henry, W.E. Galloway, G.E. Smith, C.L. Ho, J.A. Morton, and J.K. Gluck), 1982. Geochemistry of Ground Water in the Miocene Oakville Sandstone - A Major Aquifer and Uranium Host of the Texas Coastal Plain, Bureau of Economic Geology Report of Investigations No. 118.

Junge, W.R., and L.E. Dezman, 1983. An Analysis of Control Standards for the Long-Term Containment of Uranium Tailings, Colorado Geological Survey and Colorado Division of Water Resources, Denver, Colorado.

Kelly, Jack, 1984. Personal communication with Jack Kelly, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated August 1, 1984.

Kruseman, G.P., and N.A. DeRidder, 1976. Analysis and Evaluation of Pumping Test Data, International Institute for Land Reclamation and Improvement, Wegeninger, Netherlands.

LBL (Lawrence Berkeley Laboratory, University of California), 1984. "Hydrology and Geochemistry of the Uranium Mill Tailings Pile at Riverton, Wyoming," draft report prepared by LBL, Berkeley, California, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Larson, Kyle, 1987. Personal communication with Kyle Larson, Chemical Marketing Services, Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 14, 1987.

Lewis, G.J., and D.B. Stephens, 1985. "Analysis of Infiltration Through Mill Tailings Using a Bromide Tracer," Proceedings of the Seventh Annual Symposium on Management of Uranium Mill Tailings, Low-Level Waste and Hazardous Waste, Colorado State University, Civil Engineering Department, Geotechnical Engineering Program, Fort Collins, Colorado.

Lohman, S.W., 1972. Groundwater Hydraulics, U.S. Geological Survey Professional Paper 708, U.S. Department of the Interior, Washington, D.C.

MBIAC (Missouri Basin Interagency Committee), 1966. "Soil Infiltration By Generalized Soil Groupings," Task Force on Infiltration.

McGreevy et al (L.J. McGreevy, W.G. Hodson, and S.J. Rucker, IV), 1969. Ground-Water Resources of the Wind River Indian Reservation, Wyoming, U.S. Geological Survey Water-Supply Paper 1576-I, U.S. Department of the Interior, Washington, D.C.

McFarland, Charles, 1987. Personal communication with Charles McFarland, Riverton Country Club, Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 15, 1987.

Morton, F.I., 1978. "Estimation of Evapotranspiration from Potential Evaporation: Practicality of an Iconoclastic Approach," Journal of Hydrology, Vol. 38.

NOAA (National Oceanic and Atmospheric Administration), 1984. Hydrometeorological Report No. 55, Probable Maximum Precipitation Estimates - United States Between the Continental Divide and the 103rd Meridian, Silver Spring, Maryland.

NOAA (National Oceanic and Atmospheric Administration), 1982. Hydrometeorological Report No. 52, Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian, Washington, D.C.

Narasimhan, T.N., 1984. Personal communication with T.N. Narasimhan, Lawrence Berkeley Laboratory, University of California, Berkeley, California, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated August 27, 1984.

Narasimhan et al. (T.N. Narasimhan, T. Tokunaga, A.F. White, and A.R. Smith), 1984. "Mathematical Simulation of Contaminant Distribution in and Around the Uranium Mill Tailings Pile, Riverton, Wyoming," Proceedings of the Sixth Annual Symposium on Management of Uranium Mill Tailings, Low-Level Waste and Hazardous Waste, Colorado State University, Civil Engineering Department, Geotechnical Engineering Program, Fort Collins, Colorado.

Narasimhan et al. (T.N. Narasimhan, R.M. Galbraith, A. White, A. Smith, H. Schmidt, B. Moed, and T. Tokunga), 1982. Hydro-Geochemical Studies of Uranium Mill Tailings Piles at Riverton, Wyoming, and Maybell, Colorado, Annual Report for Fiscal Year 1981, Contract No. DE-AC03-76SF00098, prepared for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Narasimhan, T.N., and P.A. Witherspoon, 1978. "Numerical Model for Saturated - Unsaturated Flow in Deformable Media, 3 Applications," Water Resources Research, Vol. 14, No. 6.

ORNL (Oak Ridge National Laboratory), 1980. Radiological Survey of the Inactive Uranium Mill Tailings at Riverton, Wyoming, ORNL-5461, prepared by ORNL, Oak Ridge, Tennessee, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Packer, Ray, 1984. Personal communication with Ray Packer, Bureau of Land Management, Lander Resource Area, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated June 14, 1984.

Parkhurst et al. (D.L. Parkhurst, D.C. Thorstenson, and L.N. Plummer), 1980. PHREEQE: A Computer Program for Geochemical Calculations, U.S. Geological Survey Water Resources Investigation 80-96, U.S. Department of the Interior, Washington, D.C.

Penz, Mike, 1985. Personal communication with Mike Penz, Wyoming State Engineer's Office, Cheyenne, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated March 12, 1985.

Pyrih, R.Z., 1983. Personal communication with R.Z. Pyrih, Roman Z. Phyrih & Associates, Inc., Golden, Colorado, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated February, 1983.

Pyrih, R.Z., 1982. Personal communication with R.Z. Pyrih, Roman Z. Pyrih & Associates, Inc., Golden Colorado, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated November, 1982.

Reisenauer et al. (A.E. Reisenauer, K.T. Key, T.N. Narasimhan, and R.W. Nelson), 1982. TRUST: A Computer Program for Variably Saturated Flow in Multidimensional, Deformable Media, NUREG/CR-2360, prepared for the U.S. Nuclear Regulatory Commission, Washington, D.C.

SHB (Sergent, Hauskins & Beckwith), 1985. "Geomorphic Evaluation, Riverton Uranium Mill Tailings Site, Uranium Mill Tailings Remedial Action Project," unpublished report prepared by SHB, Albuquerque, New Mexico, for the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico.

SHB (Sergent, Hauskins & Beckwith), 1984. "Geologic Hazard Evaluation, Riverton Site, Uranium Mill Tailings Remedial Action Project," unpublished report prepared by SHB, Albuquerque, New Mexico, for the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico.

Scott, Bernard, 1987. Personal communication with Bernard Scott, City of Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 15, 1987.

Scott, Bernard, 1985. Personal communication with Bernard Scott, City of Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated March 20, 1985.

Tokunaga, T., and T.N. Narasimhan, 1982. "Recent Hydrologic Observations from the Riverton and Maybell Tailings Piles," Proceedings of the Fifth Annual Symposium on Management of Uranium Mill Tailings, Low-Level Waste and Hazardous Waste, Colorado State University, Civil Engineering Department, Geotechnical Engineering Program, Fort Collins, Colorado.

Trescott, P.C., 1976. Documentation of Finite Difference Model for Simulation of Three-Dimensional Ground-Water Flow, U.S. Geological Survey Open File Report 75-438, U.S. Department of the Interior, Washington, D.C.

USGS (U.S. Geological Survey), 1984a. WATSTORE Data Retrieval, May 1984. Water Resources Division, New Mexico District Office, Albuquerque, New Mexico.

USGS (U.S. Geological Survey), 1984b. WATSTORE Data Retrieval, August 1984. Water Resources Division, New Mexico District Office, Albuquerque, New Mexico.

USGS (U.S. Geological Survey), 1984c. WATSTORE Data Retrieval, June 1984. Water Resources Division, New Mexico District Office, Albuquerque, New Mexico.

WDEQ (Wyoming Department of Environmental Quality), 1983. "Quality Standards for Wyoming Surface Waters," Water Quality Rules and Regulations, State of Wyoming, Cheyenne, Wyoming.

WDEQ (Wyoming Department of Environmental Quality), 1980. "Quality Standards for Wyoming Ground Waters," Water Quality Rules and Regulations, Chapter VIII, State of Wyoming, Cheyenne, Wyoming.

Walton, W.C., 1970. Groundwater Resource Evaluation, McGraw-Hill Book Company, New York, New York.

Whitcomb, H.A., and M.E. Lowry, 1968. Ground-Water Resources and Geology of the Wind River Basin Area, Central Wyoming, U.S. Geological Survey Hydrologic Investigations Atlas HA-270, U.S. Department of the Interior, Washington, D.C.

White et al. (A.F. White, J.M. Delany, T.N. Narasimhan, and A. Smith), 1984. "Groundwater Contamination from an Inactive Uranium Mill Tailings Pile, Application of a Chemical Mixing Model," Water Resource Research, Vol. 20, No. 11.

APPENDIX D

ECOSYSTEMS

TABLE OF CONTENTS

LIST OF TABLES

D.1 BIOLOGY

This appendix contains listings of plant and animal species that occur at or in the vicinity of the Riverton tailings site, the Dry Cheyenne alternate disposal site, borrow sites 2 and 10, and the Little Wind and Boulder Flats borrow sites. Many of the plant species (Table D.1.1) are common to all of the sites. The habitat in the vicinity of the tailings site, borrow site 2, and the Little Wind borrow site includes the Wind and Little Wind Rivers, and the list of wildlife for this area (Table D.1.2) contains many riparian species. The Dry Cheyenne alternate disposal site and borrow site 10 have similar sagebrush-shrubland habitats, and the wildlife list for these sites (Table D.1.3) contains species adapted primarily to xeric conditions.

The Boulder Flats borrow site is located in a transition zone between the sagebrush-shrubland habitat of the Sand Hills to the northeast and the riparian habitat of the North Popo Agie River to the southwest. Therefore, the Boulder Flats borrow site could have a mixture of plant and animal species common to all of the other sites (Baldes, 1985; Hockley, 1985). The area adjacent to Wyoming State Highway 136 between the Riverton tailings site, Dry Cheyenne alternate disposal site, and Gas Hills is also expected to contain a mixture of plant and animal species common to all of the other sites.

Table D.1.1 Plant species found in the Riverton, Wyoming, area

Site location	Scientific name	Common name
	TREES	
1	Elaegnus angustifolia	Russian olive
2	Juniperus sp.	Juniper
1	Populus fremontii	Fremont cottonwood
1	Populus tremuloides	Quaking aspen
1	Salix amygdaloides	Peachleaf willow
1	Tamarix pentandra	Saltcedar tamarisk
	SHRUBS AND SUCCELENTS	
2	Artemisia arbuscula	Low sagebrush
2	Artemisia frigida	Fringed sagewort
1, 2	Artemisia tridentata	Basin big sagebush
2	Atriplex confertifolia	Shadscale saltbush
2	Atriplex flacata	Sickle saltbush
1	Atriplex rosea	Redscale
1	Brickellia longifolia	Longleaf brickellbush
2	Chrysothamnus greenei	Green rabbitbrush
1, 2	Chrysothamnus nauseosus	Rubber rabbitbrush
2	Chrysothamnus viscidiflorus	Douglas rabbitbrush
2	Eriogonum leptocladon	Finebranched buckwheat
2	Gutierrezia microcephala	Threadleaf snakeweed
2	Gutierrezia sarothrae	Broom snakeweed
2	Leptodactylon pungens	Granite pricklygilia
1	Lonicera sp.	Honeysuckle
1	Opuntia fragilis	Brittle pricklypear

Table D.1.1 Plant species found in the Riverton, Wyoming, area (Continued)

Site location	Scientific name	Common name
	SHRUBS AND SUCCULENTS (Concluded)	
1, 2	Opuntia polyacantha	Plains pricklypear
1	Rhus trilobata	Skunkbush sumac
2	Ribes cereum	Wax currant
1	Salix sp.	Willow
1	Salix bebbiana	Beaked willow
1	Salix exigua	Coyote willow
1, 2	Sarcobatus vermiculatus	Black greasewood
1	Shepherdia argentea	Silver buffaloberry
2	Yucca sp.	Yucca
	GRASSES AND GRASS-LIKE PLANTS	
1, 2	Agropyron cristatum	Crested wheatgrass
1	Agropyron dasystachyum	Thickspike wheatgrass
2	Agropyron smithii	Western wheatgrass
2	Agropyron spicatum	Bluebunch wheatgrass
1	Agrostis alba	Redtop bentgrass
2	Bouteloua gracilis	Blue grama
1, 2	Bromus tectorum	Cheatgrass brome
1	Distichlis stricta	Inland saltgrass
1	Echinochloa crusgalli	Barnyard grass
1, 2	Elymus cinereus	Basin wildrye
1	Eragrostis sp.	Lovegrass
2	Festuca sp.	Fescue
2	Hesperochloa kingii	King spikefescue

Table D.1.1 Plant species found in the Riverton, Wyoming, area (Continued)

Site location	Scientific name	Common name
	GRASSES AND GRASS-LIKE PLANTS (Concluded)	
2	*Hilaria jamesii*	Galleta grass
1	*Hordeum brachyantherum*	Meaaow barley
1	*Hordeum jubatum*	Foxtail barley
1	*Juncus torreyi*	Torrey rush
1	*Muhlenbergia asperifolia*	Scratch grass
2	*Oryzopsis hymenoides*	Indian ricegrass
1	*Sitanion hystrix*	Bottlebrush squirreltail
1	*Sporobolus airoides*	Alkali sacaton
1	*Sporobolus cryptandrus*	Sand dropseed
1	*Stipa comata*	Neddle-and-thread grass
1	*Triticum aestivum*	Cultivated wheat
	FORBS	
2	*Antennaria parvifolia*	Small-leaf pussytoes
1	*Arctium minus*	Common burdock
1	*Asclepias speciosa*	Showy milkweed
1	*Asparagus officinale*	Garden asparagus
1, 2	*Aster* sp.	Aster
2	*Astragalus kentropnyta*	Spiny milkvetch
2	*Astragalus praelongus*	Stinking milkvetch
1	*Bassia hyssopifolia*	Fivehook bassia
1	*Cardaria draba*	Whitetop pepperweed
1	*Centaurea repens*	Russian knapweed

Table D.1.1 Plant species found in the Riverton, Wyoming, area (Continued)

Site location	Scientific name	Common name
	FORBS (Continued)	
1	Chenopodium album	Lambsquarters goosefoot
1	Cirsium arvense	Canada thistle
2	Cleome lutea	Yellow beeplant
1, 2	Comandra pallida	Bastard toadflax
1	Convolvulus arvensis	Field bindweed
1	Conyza canadensis	Canada horseweed
1	Crepis acuminata	Tapertip hawksbeard
2	Cryptantha sp.	Cryptantha
1	Delphinium sp.	Larkspur
2	Descuraninia pinnata	Tansymustard
1	Epilobium sp.	Willow weed
1	Equisetum sp.	Horsetail
2	Erigeron divergens	Spreading fleabane
2	Eriogonum sp.	Buckwheat
1, 2	Eupnorbia fendleri	Fendler spurge
2	Gilia congesta	Ballhead gilia
1	Glycyrrhiza lepidota	American licorice
1, 2	Grindelia squarrosa	Curlycup gumweed
1, 2	Haplopappus sp.	Goldenweed
1, 2	Helianthus annuus	Common sunflower
2	Hymenoxys acaulis	Stemless actinea
1	Iva axillaris	Poverty sumpweed
1	Iva xanthifolia	Rag sumpweed

Table D.1.1 Plant species found in the Riverton, Wyoming, area (Continued)

Site location	Scientific name	Common name
	FORBS (Continued)	
1, 2	Kochia scoparia	Fireweed summercypress
1	Lactuca serriola	Prickly lettuce
2	Lepidium densiflorum	Prairie pepperweed
2	Lesquerella sp.	Bladderpod
2	Lygodesmia sp.	Skeleton weed
1, 2	Machaeranthera parviflora	Smallflower machae-ranthera
1	Machaerantnera tanacetifolia	Tansyleaf aster
2	Malacothrix sonchoides	Sowthistle desert dandelion
1	Melilotus alba	White sweetclover
1	Melilotus officinalis	Yellow sweetclover
1	Mentha arvensis	Field mint
1	Oenothera hookeri	Hooker's evening primrose
2	Penstemon sp.	Beardtongue
2	Phlox hoodii	Hood's phlox
1	Physalis longifolia	Longleaf groundcherry
2	Plantago patagonica	Patagonia Indian wheat
1	Polygonum douglasii	Douglas knotweed
1	Polygonum lapathifolium	Curlythumb knotweed
1	Polygonum ramosissimum	Bushy knotweed
1	Portulaca oleracea	Common purslane
1	Potentilla biennis	Biennial cinquefoil

Table D.1.1 Plant species found in the Riverton, Wyoming, area (Concluded)

Site location	Scientific name	Common name
	FORBS (Concluded)	
1	*Psoralea lanceolata*	Lemon scurfpea
1	*Ranunculus* sp.	Buttercup
1	*Rumex crispus*	Curly dock
1	*Salsola kali*	Russian thistle
1, 2	*Sisymbrium altissimum*	Tumblemustard
1	*Solidago canadensis*	Canada goldenrod
1	*Solidago occidentalis*	Western goldenrod
2	*Sphaeralcea coccinea*	Scarlet globemallow
1	*Sphaerophysa salula*	Swainson's pea
1	*Suaeda torreyana*	Torrey seepweed
2	*Vicia americana*	American vetch

[a]Site location: (1) Riverton tailings site, Little Wind borrow site, and borrow site 2; (2) Dry Cheyenne alternate disposal site and borrow site 10.

Ref. FBD, 1983.

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site

Scientific name	Common name
	MAMMALS
Antilocapra americana	Pronghorn antelope
Arvicola richardsoni[a]	Water vole
Canis latrans	Coyote
Castor canadensis[a]	Beaver
Clethrionomys gapperi	Gapper's red-backed vole
Cynomys leucurus	White-tailed prairie dog
Dipodomys ordii	Ord's kangaroo rat
Eptesicus fuscus	Big brown bat
Erethizon dorsatum	Porcupine
Eutamias minimus	Least chipmunk
Eutamias umbrinus	Uinta chipmunk
Lagurus curtatus	Sagebrush vole
Lepus townsendii	White-tailed jackrabbit
Lynx rufus	Bobcat
Martes americana	Marten
Mephitis mephitis	Striped skunk
Microtus longicaudus	Long-tailed vole
Microtus montanus[a]	Montane vole
Microtus pennsylvanicus[a]	Meadow vole
Mus musculus	House mouse
Mustela erminea[a]	Ermine
Mustela frenata	Long-tailed weasel
Mustela vison	Mink

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site (Continued)

Scientific name	Common name
MAMMALS (Continued)	
Myotis evotis	Long-eared myotis
Myotis leibii	Small-footed myotis
Myotis lucifugus	Little brown myotis
Neotoma cinerea	Bushy-tailed woodrat
Odocoileus hemionus	Mule deer
Odocoileus virginianus	White-tailed deer
Ondatra zibethicus[a]	Muskrat
Onychomys leucogaster	Northern grasshopper mouse
Perognathus fasciatus	Olive-backed pocket mouse
Peromyscus maniculatus	Deer mouse
Procyon lotor	Raccoon
Reithrodontomys megalotis	Western harvest mouse
Sciurus niger	Fox squirrel
Sorex cinereus[a]	Masked shrew
Sorex obscurus	Dusky shrew
Sorex palustris[a]	Water shrew
Spermophilus ricnardsonii	Richardson's ground squirrel
Spermophilus tridecemlineatus	Thirteen-lined ground squirrel
Spilogale putorius	Spotted skunk
Sylvilagus audubonii	Desert cottontail
Sylvilagus nuttallii	Mountain cottontail
Taxidea taxus	Badger
Thomomys talpoides	Northern pocket gopher

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site (Continued)

Scientific name	Common name
MAMMALS (Concluded)	
Vulpes velox	Swift fox
Vulpes vulpes	Red fox
Zapus princeps[a]	Western jumping mouse
REPTILES	
Crotalus viridis	Prairie rattlesnake
Pituophis melanoleucus	Bullsnake
Phrynosoma douglasi	Short-horned lizard
Sceloporus graciosus	Sagebrush lizard
AMPHIBIANS	
Ambystoma tigrinum	Tiger salamander
Bufo cognatus	Great plains toad
Pseudacris triseriata	Boreal chorus frog
Rana pipiens	Leopard frog
Scaphiopus intermontanus	Great basin spadefoot toad
BIRDS	
Accipiter cooperii	Cooper's hawk
Accipiter striatus	Sharp-shinned hawk
Actitis macularia[a]	Spotted sandpiper
Aechmophorus occidentalis[a]	Western grebe
Aeronautes saxatalis	White-throated swift
Agelaius phoeniceus[a]	Red-winged blackbird

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site (Continued)

Scientific name	Common name
BIRDS (Continued)	
Alectoris chukar	Chukar
Ammodramus savannarum	Grasshopper sparrow
Amphispiza belli	Sage sparrow
Anas acuta[a]	Pintail
Anas americana[a]	American widgeon
Anas clypeata	Northern shoveler
Anas crecca[a]	Green-winged teal
Anas cyanoptera[a]	Cinnamon teal
Anas discors[a]	Blue-winged teal
Anas platyrhynchos[a]	Mallard
Anas strepera[a]	Gadwall
Anthus spinoletta[a]	Water pipit
Aquila chrysaetos	Golden eagle
Ardea herodias	Great blue heron
Arenaria interpres	Ruddy turnstone
Asio flammeus	Short-eared owl
Asio otus	Long-eared owl
Aythya americana[a]	Redhead
Aythya affinis[a]	Lesser scaup
Aythya collaris[a]	Ring-necked duck
Aythya marila[a]	Greater scaup
Aythya valisineria[a]	Canvasback
Bartramia longicauda	Upland sandpiper

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site (Continued)

Scientific name	Common name
BIRDS (Continued)	
Bombycilla cedrorum	Cedar waxwing
Bombycilla garrula	Bohemian waxwing
Botaurus lentiginosus[a]	American bittern
Branta canadensis	Canada goose
Bubo virginianus	Great horned owl
Bucephala albeola[a]	Bufflehead
Bucephala clangula[a]	Common goldeneye
Bucephala islandica[a]	Barrow's goldeneye
Buteo jamaicensis	Red-tailed hawk
Buteo lagopus	Rough-legged hawk
Buteo regalis	Ferruginous hawk
Buteo swainsoni	Swainson's hawk
Calamospiza melanocorys	Lark bunting
Calcarius lapponicus	Lapland longspur
Calcarius mccownii	McCown's longspur
Calcarius ornatus	Chestnut-collared longspur
Calidris alba	Sanderling
Calidris bairdii	Baird's sandpiper
Calidris mauri	Western sandpiper
Calidris melanotos	Pectoral sandpiper
Calidris minutilla	Least sandpiper
Calidris pusilla	Semipalmated sandpiper
Capella gallinago	Common snipe

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site (Continued)

Scientific name	Common name
BIRDS (Continued)	
Carpodacus cassinii	Cassin's finch
Carpodacus mexicanus	House finch
Cathartes aura	Turkey vulture
Catharus guttatus	Hermit thrush
Catharus ustulatus	Swainson's thrush
Catherpes mexicanus	Canyon wren
Catoptrophorus semipalmatus[a]	Willet
Contopus sordidulus	Western wood pewee
Centrocercus urophasianus	Sage grouse
Certhia familiaris	Brown creeper
Charadrius montanus	Mountain plover
Charadrius semipalmatus	Semipalmated plover
Charadrius vociferus	Killdeer
Chlidonias niger	Black tern
Chondestes grammacus	Lark sparrow
Chordeiles minor	Common nighthawk
Chen caerulescens	Snow goose
Circus cyaneus	Marsh hawk
Coccyzus americanus[a]	Yellow-billed cuckoo
Coccyzus erythropthalmus[a]	Black-billed cuckoo
Colaptes auratus	Common flicker
Corvus brachyrhynchos	Common crow
Corvus corax	Common raven

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site (Continued)

Scientific name	Common name
BIRDS (Continued)	
Cyanoitta stelleri	Steller's jay
Dendrocopos pubescens	Downy woodpecker
Dendrocopos villosus	Hairy woodpecker
Dendroica coronata	Yellow-rumped warbler
Dendroica fusca	Blackburnian warbler
Dendroica townsendi	Townsend's warbler
Dendroica petechia	Yellow warbler
Dolichonyx oryzivorus	Bobolink
Dumatella carolinensis	Gray catbird
Egretta thula[a]	Snowy egret
Empidonax difficilis	Western flycatcher
Empidonax minimus	Least flycatcher
Empidonax obernolseri	Dusky flycatcher
Empidonax traillii[a]	Willow flycatcher
Eremophila alpestris	Horned lark
Euphagus cyanocephalus	Brewer's blackbird
Falco columbarius	Merlin
Falco mexicanus	Prairie falcon
Falco peregrinus	Peregrine falcon
Falco sparverius	American kestrel
Fulica americana[a]	American coot
Geothlypis trichas[a]	Common yellowthroat
Grus canadensis[a]	Sandhill crane

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site (Continued)

Scientific name	Common name
BIRDS (Continued)	
Haliaeetus leucocephalus[a]	Bald eagle
Hesperiphona vespertina	Evening grosbeak
Himantopus mexicanus	Black-necked stilt
Hirundo rustica	Barn swallow
Histrionicus histrionicus[a]	Harlequin duck
Hydroprogne caspia	Caspian tern
Icteria virens[a]	Yellow-breasted chat
Icterus galbula	Northern oriole
Iridoprocne bicolor	Tree swallow
Junco hyemalis	Dark-eyed junco
Lanius excubitor	Northern shrike
Lanius ludovicianus	Loggerhead shrike
Larus californicus	California gull
Larus delawarensis	Ring-billed gull
Leucosticte tephrocotis	Gray-crowned rosy finch
Limnodromus scolopaceus	Long-billed dowitcher
Limosa fedoa	Marbled godwit
Limosa haemastica	Hudsonian godwit
Lophodytes cucullatus[a]	Hooded merganser
Megaceryle alcyon[a]	Belted kingfisher
Melanerpes erythrocephalus	Red-headed woodpecker
Melospiza georgiana	Swamp sparrow
Melospiza lincolnii[a]	Lincoln's sparrow

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site (Continued)

Scientific name	Common name
BIRDS (Continued)	
Melospiza melodia	Song sparrow
Mergus merganser[a]	Common merganser
Mergus serrator[a]	Red-breasted merganser
Mimus polyglottos	Mockingbird
Molothrus ater	Brown-headed cowbird
Myadestes townsendi	Townsend's solitaire
Myiarchus cinerascens	Ash-throated flycatcher
Numenius americanus[a]	Long-billed curlew
Numenius phaeopus[a]	Whimbrel
Nycticorax nycticorax[a]	Black-crowned night heron
Oporornis tolmiei[a]	MacGillivray's warbler
Oreoscoptes montanus	Sage thrasher
Otus asio	Screech owl
Oxyura jamaicensis[a]	Ruddy duck
Pandion haliaetus[a]	Osprey
Parus atricapillus	Black-capped chickadee
Passer domesticus	House sparrow
Passerculus sandwichensis	Savannah sparrow
Passerina amoena	Lazuli bunting
Pelecanus erythrorhynchos	White pelican
Perdix perdix	Gray partridge
Petrochelidon pyrrhonota	Cliff swallow
Phalacrocorax auritus[a]	Double-crested cormorant

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site (Continued)

Scientific name	Common name
BIRDS (Continued)	
Phalaenoptilus nuttallii	Poor-will
Phasianus colchicus	Ring-necked pheasant
Pheucticus melanocephalus	Black-headed grosbeak
Pica pica	Black-billed magpie
Pipilo cnlorura	Green-tailed towhee
Pipilo erythrophthalmus	Rufus-sided towhee
Piranga ludoviciana	Western tanager
Plegadis chihi[a]	White-faced ibis
Pluvialis dominica	American golden plover
Pluvialis squatarola	Black-bellied plover
Podiceps auritus	Horned grebe
Podiceps nigricollis	Eared grebe
Podilymbus podiceps[a]	Pied-billed grebe
Pooecetes gramineus	Vesper sparrow
Porzana carolina[a]	Sora
Quiscalus quiscalus	Common grackle
Rallus limicola[a]	Virginia rail
Recurvirostra americana	American avocet
Riparia riparia[a]	Bank swallow
Salpinctes obsoletus	Rock wren
Sayornis saya	Say's phoebe
Seiurus noveboracensis	Northern waterthrush
Sialia currucoides	Mountain bluebird

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site (Continued)

Scientific name	Common name
BIRDS (Continued)	
Selasphorus platycercus	Broad-tailed hummingbird
Setophaga ruticilla[a]	American redstart
Sialia sialis	Eastern bluebird
Sitta canadensis	Red-breasted nuthatch
Sitta carolinensis	White-breasted nuthatch
Sitta pygmaea	Pygmy nuthatch
Speotyto cunicularia	Burrowing owl
Spinus tristis	American goldfinch
Spizella breweri	Brewer's sparrow
Spizella passerina	Chipping sparrow
Sphyrapicus varius	Yellow-bellied sapsucker
Steganopus tricolor	Wilson's phalarope
Stelgidopteryx ruficollis[a]	Rough-winged swallow
Sterna forsteri	Forster's tern
Sturnella neglecta	Western meadowlark
Sturnus vulgaris	Starling
Tachycineta thalassina	Violet-green swallow
Telmatodytes palustris[a]	Long-billed marsh wren
Toxostoma rufum	Brown thrasher
Tringa flavipes	Lesser yellowlegs
Tringa melanoleuca[a]	Greater yellowlegs
Tringa solitaria[a]	Solitary sandpiper
Troglodytes aedon	House wren

Table D.1.2 Wildlife at or in the vicinity of the Riverton tailings site (Concluded)

Scientific name	Common name
BIRDS (Concluded)	
Turdus migratorius	American robin
Tyrannus tyrannus	Eastern kingbird
Tyrannus verticalis	Western kingbird
Vermivora celata	Orange-crowned warbler
Vireo gilvus	Warbling vireo
Wilsonia pusilla[a]	Wilson's warbler
Xanthocephalus xanthocephalus[a]	Yellow-headed blackbird
Zenaida macroura	Mourning dove
FISHES	
Catostomus catostomus	Longnose sucker
Catostomus commersoni	White sucker
Catostomus platyrhynchus	Mountain sucker
Cyprinus carpio	Carp
Hybopsis gracilis	Flathead chub
Rhinichthys cataractae	Longnose dace
Salmo gairdneri	Rainbow trout
Salmo trutta	Brown trout
Salvelinus fontinalis	Brook trout

[a]A riparian species.

Ref. WGFD, 1983; BLM, 1984.

Table D.1.3 Wildlife at or in the vicinity of the Dry Cheyenne alternate disposal site and borrow site 10

Scientific name	Common name
MAMMALS	
Antilocapra americana	Pronghorn antelope
Canis latrans	Coyote
Cynomys leucurus	White-tailed prairie dog
Dipodomys ordii	Ord's kangaroo rat
Equus cabalus	Wild horse
Eutamias minimus	Least chipmunk
Lagurus curtatus	Sagebrush vole
Lepus townsendii	White-tailed jackrabbit
Lynx rufus	Bobcat
Mephitis mephitis	Striped skunk
Microtus sp.	Vole
Mustela frenata	Long-tailed weasel
Mustela nigripes	Black-footed ferret
Myotis lucifugus	Little brown myotis
Neotoma cinerea	Bushy-tailed woodrat
Odocoileus hemionus	Mule deer
Onychomys leucogaster	Northern grasshopper mouse
Perognathus fasciatus	Olive-backed pocket mouse
Peromyscus maniculatus	Deer mouse
Reithrodontomys megalotis	Western harvest mouse
Sorex sp.	Shrew
Spermophilus richardsonii	Richardson's ground squirrel

Table D.1.3 Wildlife at or in the vicinity of the Dry Cheyenne alternate disposal site and borrow site 10 (Continued)

Scientific name	Common name
MAMMALS (Concluded)	
Spermophilus tridecemlineatus	Thirteen-lined ground squirrel
Sylvilagus audubonii	Desert cottontail
Sylvilagus nuttallii	Mountain cottontail
Taxidea taxus	Badger
Thomomys talpoides	Northern pocket gopher
Vulpes vulpes	Red fox
REPTILES	
Crotalus viridis	Prairie rattlesnake
Pituophis melanoleucus	Bullsnake
Phrynosoma douglasi	Short-horned lizard
Sceloporus graciosus	Sagebrush lizard
AMPHIBIANS	
Ambystoma tigrinum	Tiger salamander
Bufo cognatus	Great plains toad
Pseudacris triseriata	Boreal chorus frog
Rana pipiens	Leopard frog
Scaphiopus intermontanus	Great basin spadefoot toad
BIRDS	
Amphispiza belli	Sage sparrow
Aquila chrysaetos	Golden eagle

Table D.1.3 Wildlife at or in the vicinity of the Dry Cheyenne alternate disposal site and borrow site 10 (Continued)

Scientific name	Common name
BIRDS (Continued)	
Asio flammeus	Short-eared owl
Bubo virginianus	Great horned owl
Buteo jamaicensis	Red-tailed hawk
Buteo lagopus	Rough-legged hawk
Buteo regalis	Ferruginous hawk
Buteo swainsoni	Swainson's hawk
Calamospiza melanocorys	Lark bunting
Centrocercus urophasianus	Sage grouse
Chordeiles minor	Common nighthawk
Chlorura chlorura	Green-tailed towhee
Circus cyaneus	Marsh hawk
Corvus corax	Common raven
Eremophila alpestris	Horned lark
Euphagus cyanocephalus	Brewer's blackbird
Falco mexicanus	Prairie falcon
Falco peregrinus	Peregrine falcon
Falco sparverius	American kestrel
Haliaeetus leucocephalus[a]	Bald eagle
Lanius ludovicianus	Loggerhead shrike
Oreoscoptes montanus	Sage thrasher
Petrochelidon pyrrhonota	Cliff swallow
Pooecetes gramineus	Vesper sparrow
Riparia riparia[a]	Bank swallow

Table D.1.3 Wildlife at or in the vicinity of the Dry Cheyenne alternate disposal site and borrow site 10 (Concluded)

Scientific name	Common name
BIRDS (Concluded)	
Salpinctes obsoletus	Rock wren
Sayornis saya	Say's phoebe
Speotyto cunicularia	Burrowing owl
Spizella breweri	Brewer's sparrow
Sturnella neglecta	Western meadowlark
Zenaida macroura	Mourning dove

[a]A riparian species.

Ref. BLM, 1984.

REFERENCES FOR APPENDIX D

Baldes, Dick, 1985. Personal communication with Dick Baldes, U.S. Fish and Wildlife Service, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 8, 1985.

BLM (Bureau of Land Management), 1984. "Moneta, URA Step II," 4773, Lander Resource Area, Lander, Wyoming.

FBD (Ford, Bacon & Davis, Inc.), 1983. "Environmental Assessment of Remedial Actions on the Uranium Mill Tailings at the Riverton Site, Fremont County, Wyoming," unpublished preliminary draft prepared by the FBD, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Hockley, Marvin, 1985. Personal communication with Marvin Hockley, Wyoming Game and Fish Department, Lander, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 4, 1985.

WGFD (Wyoming Game and Fish Department), 1983. "Riverton Valley Project, Level III Terrestrial Wildlife Impact Report," Pinedale, Wyoming.

APPENDIX E

SOCIOECONOMICS

TABLE OF CONTENTS

LIST OF TABLES

E.1 SOCIOECONOMIC CONDITIONS

The following sections describe socioeconomic conditions in the Riverton area of Fremont County, Wyoming. Brief discussions are provided on population, housing, employment and the local economic base, public finance, transportation, recreation, and a variety of governmental service systems (e.g., police and fire protection, schools, water, and sewer).

E.1.1 POPULATION

The rate of population growth or decline in Fremont County has fluctuated considerably over the years. The most dramatic growth occurred between 1970 and 1980 (from 28,352 to 38,992, an increase of 37.5 percent) when mining activities increased significantly. During the 1970s, the population of the city of Riverton increased by 19.9 percent from 7,995 (1970) to 9,588 (1980). From 1980 to 1983, the county population increased by 5 percent to 41,071, and Riverton's population increased by 9 percent to 10,438 (Fremont County Planning Commission, 1984).

State of Wyoming projections forecast steady growth into the 1990s for Fremont County, with the 1993 population expected to be over 47,600 (WDAFC, 1983). It should be noted that these projections may understate future population, as the projection series from which the 1993 value was taken estimated the 1985 population at 37,022 which is approximately 4,000 less than the estimated actual 1983 county population.

E.1.2 HOUSING

In 1980, the city of Riverton had a total housing stock of 3,653 units. There were also over 500 motel-type rooms. The vacancy rate for rental units was 7.3 percent in 1980. The total Fremont County housing stock in 1980 was 14,570 units. County-wide vacancy rates were 8.5 percent for rental units and 1.7 percent for owner-occupied units. About 80 percent of county residents lived in single family dwellings, 6 percent in multi-family residences, and 13 percent in mobile homes (DOC, 1982).

E.1.3 EMPLOYMENT AND ECONOMIC BASE

The Fremont County economy is comprised of a number of major elements. Agriculture is a basic element in the county economy. Between 1977 and 1983, livestock production declined while crop production has remained relatively stable (Fremont County Planning Commission, 1984).

The production of minerals (iron and uranium), oil, and gas has been a mainstay of the local economy, particularly in the last decade. The mining sector is characterized by frequent boom and bust conditions. For example, because of declines in the markets for steel and uranium, current mining employment in Fremont County is less than half of 1979 levels. There are 29 firms in the county that are classified as manufacturing concerns, manufacturing products such as meat and dairy products, wood and concrete products, fabricated steel, and computer printer parts (Fremont County Planning Commission, 1984).

Data on Fremont County employment trends are presented in Table E.1.1. As shown in this table, the county's 1982 employment base included over 13,300 workers, although because of continuing declines in the mining industry, total local employment decreased (total employment is projected at 12,407 for 1984) (Fremont County Planning Commission, 1984).

In terms of employment, the largest sectors of the local economy are services and retail trade. As discussed above, mining has been a major employer in much of the last decade, although it has been declining sharply. The average county unemployment rate for 1983 was 10.8 percent, which was considerably higher than the statewide average of 8.4 percent (WESC, 1984).

E.1.4 PUBLIC FINANCE

Assessed valuation of real and personal property for 1983 in Fremont County as a whole was $512,014,667 while the city of Riverton's assessed valuation was $23,710,124. These represent increases over the 1982 countywide assessed valuation of $491,751,117 and Riverton 1982 assessed valuation of $22,597,328 (WDRT, 1982a; 1983).

The total 1983 tax levy for the city of Riverton was 84.970 mills per $1,000 in assessed valuation, or $20,146.50. This includes the county tax levy (21.040 mills or $4,988.61) which covers a number of special districts (fire, cemetery, recreation, weed and pest control, and solid waste). Also included in this total are the school tax levy of 55.020 mills ($13,045.31) and the municipal tax levy of 8.910 mills ($2,112.58). The 1983 total Riverton tax levy represents an increase over the total levy for 1982 of 77.680 mills. However, the 1982 levy represented a decrease from the 1981 total levy of 85.730 mills (WDRT, 1981; 1982a; 1983).

Wyoming has no state income tax. Two percent of sales tax collections are returned to the city or county of origin. Sales tax collections in Fremont County in fiscal year 1982 were $10,369,648, up from $9,973,750 in fiscal year 1981 (WDRT, 1982b).

E.1.5 PUBLIC SERVICES

The city of Riverton's police department includes 20 sworn officers and 11 other law enforcement employees. The Fremont County Sheriff's Department, which serves the unincorporated areas outside the city limits, also maintains nine officers in Riverton. Fire protection in the Riverton area is provided by a 52-person volunteer force which is housed in two fire stations. The force's equipment includes six engines, two tankers, an 85-foot aerial rescue unit, and a heavy rescue unit (FBD, 1983).

Table E.1.1 Employment trends, Fremont County, Wyoming

Industrial classification	1978	1980	1982	1984[a]	1986[a]
Agriculture	86	71	144	175	205
Mining	3,564	3,887	2,453	640	881
Construction	984	1,103	888	845	802
Manufacturing	718	589	514	640	669
Transportation, utilities, and communications	658	707	734	777	820
Wholesale trade	320	404	477	572	667
Retail trade	2,476	2,684	2,484	2,498	2,512
Finance, insurance, and real estate	334	550	426	439	453
Services	3,622	4,324	4,602	5,151	5,699
Public administration	490	638	608	670	732
Totals	13,252	14,957	13,330	12,407	13,440

[a]Projected employment.

Ref. Fremont County Planning Commission, 1984.

There are seven public schools and a junior college (Central Wyoming College) in the city of Riverton. Enrollment at the various institutions exceeds 4,100 pupils, as follows (FBD, 1983):

- o Elementary schools (5) - 1,500 pupils.
- o Middle school (1) - 820 pupils.
- o High school (1) - 1,000 pupils.
- o Central Wyoming College - 800 pupils.

There also is a Bureau of Indian Affairs (BIA) contract school, the St. Stephen's Mission School, just outside Riverton.

There is one 70-bed, privately owned hospital in Riverton (Scott, 1987) that is served by 27 physicians. There are also 12 dentists and five optometrists in Riverton. Other local health care facilities in Riverton include the 90-bed Fremont Manor Nursing Home and three medical clinics. Ambulance service is provided by a volunteer service dispatched through the local police department. The city maintains two ambulances and three other medically equipped rescue vehicles (FBD, 1983).

The city of Riverton water distribution system can supply 4 million gallons per day (gpd); with expenditures of approximately $2 million for additional water lines, this system's capacity could be doubled. During the fall and winter, water supplies are provided by 13 wells; during the rest of the year, supplies are obtained from the Wind River. Assuming a 3 percent annual population growth rate, the city water system is considered adequate through the year 2000 (FBD, 1983).

The city of Riverton sewage treatment system is a trickling filter system that was expanded in 1986 to a capacity of 5 million gpd. Flows into the system increase from approximately 1.85 million gpd in the winter to approximately 3 million gpd in the summer when irrigation causes the ground-water level to rise into the sewer system (Scott, 1987).

Major vehicular transportation routes in the Riverton area include U.S. Highway 26 which runs east-west and Wyoming State Highway 789 which runs north-south. Rail transportation is provided by the Chicago and Northwestern Railroad (C&NWRR) that terminates in Riverton, and there is a regional airport in Riverton that provides commercial service.

There are five parks in Riverton, in addition to a swimming pool, bowling alley, tennis courts, a roller rink, and a private golf course. There are also outdoor recreational opportunities (e.g., hunting and fishing) in the area.

E.2 SOCIOECONOMIC IMPACTS

E.2.1 POPULATION AND WORK FORCE

The following section analyzes the impacts of the remedial action alternatives on the local Fremont County population and work force. The no action alternative would not involve remedial action and would, of course, have no impact on the local population and work force.

The three action alternatives would have different durations (Gas Hills - 31 months, stabilization in place - 24 months, and Dry Cheyenne - 30 months), as well as different labor requirements. Rather than assessing impacts in terms of average labor requirements over the entire project duration or in terms of maximum employment in a single peak month, an extended period during each of the alternatives when remedial action activities (and consequently labor and population impacts) would be at a relatively high level was selected. The extended peak periods for which impacts are assessed below are: Gas Hills, a 12-month period; stabilization in place, an 18-month period; and Dry Cheyenne, a 19-month period.

The following assumptions were made in estimating local versus imported labor requirements. Each action alternative would involve a "general" work force (e.g., truck drivers, heavy equipment operators), and a "supervisory" work force that would include a project manager, a project engineer, health physics personnel, and surveyors, as well as a small supervisory support staff (e.g., security guards and secretary). With the exception of the supervisory support staff (which would range from six to nine persons depending on the particular alternative), the supervisory work force was assumed to come from outside Fremont County.

It is assumed that workers in the mining and construction sectors of the local economy would have the skills needed for the "general" work force. In 1982, there were 3,331 workers employed in mining and construction in Fremont County. This represented a decrease of approximately 1,000 from 1981 levels; it is estimated that perhaps another 1,700 jobs were lost in the mining sector in 1983 (Fremont County Planning Commission, 1984). Thus, there appears to be an ample pool of workers available to fill remedial action requirements.

Relocation to Gas Hills

Relocation of the tailings and contaminated materials to Gas Hills would involve an overall average work force of 70 workers over a 31-month period. The 12-month peak period would involve 93 workers including workers involved in the vicinity properties cleanup. Based on the previously stated assumptions concerning local versus in-migrant labor, 83 of these 93 workers would be current county residents (75 for the "general" work force and eight supervisory support persons).

Of the 10 remedial action workers who would in-migrate from outside the county, it was assumed that 49 percent, or five workers, would bring their families with them. This estimate is based on a study of the socioeconomic impacts of large energy projects in the western United States (MWR, 1975). Assuming that the family size of these in-migrants would reflect the average Wyoming family size of 2.89 persons per family as recorded in the 1980 census (DOC, 1982), direct remedial action employment would result in a total of 19 in-migrants.

Direct remedial action employment, however, would also create additional indirect jobs to provide goods and services to the expanded local population. Analyses of the Fremont County economy by the Denver Research Institute indicate an indirect employment multiplier of 1.8 (0.8 new indirect jobs for each direct job created) (NRC, 1980). Thus, the 93 direct remedial action jobs could create up to 74 additional indirect jobs. Because of the relatively short duration of the remedial action (a 12-month peak period and an overall duration of 31 months) and because of the 10.8-percent unemployment rate among current county residents, it is assumed that all of the 74 indirect jobs would be taken by current county residents.

In summary, over the 12-month peak period of relocation to Gas Hills, there would be a total of up to 167 new jobs created (including indirect jobs) and a total population increase of 19 persons. This would represent a negligible increase in the 1983 county population of over 41,000 and an increase in total 1982 county employment of 1.2 percent.

Stabilization in place

Stabilization in place would involve an overall average work force of 68 workers over a 24-month period. The 18-month peak period would involve 78 workers including workers involved in the vicinity properties cleanup. Based on the assumptions described above, all but 12 of these workers would be hired from within Fremont County. Of the 12 remedial action workers who would in-migrate from outside the county, six workers would bring their families with them. Direct remedial action employment would result in a total of 23 in-migrants. A total of up to 62 indirect jobs would be created, and it is assumed that all of the indirect employees would be current county residents.

In summary, over the 18-month peak period of the stabilization in place alternative, there would be a total of up to 140 new jobs created (including indirect jobs) and a total population increase of 23 persons. This would represent a negligible increase in the 1983 county population of over 41,000 and an increase in total 1982 county employment of 1 percent.

Disposal at the Dry Cheyenne site

Disposal of the tailings and contaminated materials at the Dry Cheyenne site would involve an overall average work force of 81 workers over a 30-month period. The 19-month peak period would involve 101 workers including the vicinity properties cleanup work force. Based on he previously stated assumptions, 88 of these workers would be current county residents. Six of the 13 in-migrant workers would bring their families; direct remedial action employment thus would result in a population increase of 24 persons. A total of up to 81 indirect jobs could be created, and it is assumed that all of the indirect employees would be current county residents.

In summary, the Dry Cheyenne alternative could create up to 182 new jobs (including indirect jobs) for a 19-month period and would result in a total population increase of 24 persons. This would represent a negligible increase in the county population and a 1.4-percent increase in county employment over 1982 levels.

E.2.2 HOUSING, SOCIAL STRUCTURE, AND COMMUNITY SERVICES

Housing

Relocation to Gas Hills would bring a total of 10 in-migrant workers into Fremont County. Stabilization in place and disposal at the Dry Cheyenne site would bring a total of 12 and 13 in-migrant workers into the area, respectively. Given the size of the Riverton housing stock (3,653 units in 1980 plus an additional 500 motel-type rooms), negligible impacts on the local housing supply would be expected for any of the action alternatives. The no action alternative would have no impact on local housing.

Social structure

Because of the very low level of population in-migration associated with any of the action alternatives (19 to 24 depending on the alternative), no adverse impacts on the social structures of the city of Riverton or Fremont County would be expected. The no action alternative would have no impacts on local social structures.

Community services

As stated above, population in-migration associated with the three action alternatives would be 19 individuals for relocation to Gas Hills, 23 individuals for stabilization in place, and 24 individuals for the Dry Cheyenne alternative. This in-migrant population would be expected to include four school-aged children for relocation to Gas Hills and five school-aged children for the other two action alternatives. This assumes that the in-migrant population would reflect the demographic characteristics of the state's 1980 population as recorded in the 1980 census (23.0 percent of Wyoming's 1980 population was between 5 and 17 years of age) (WDAFC, 1983). Given that Riverton's elementary, middle, and high schools have a total enrollment of over 3,300 pupils, the addition of four or five pupils would have no adverse impacts on local schools.

Using a per-capita water consumption rate of 100 gallons per day (gpd), remedial action in-migrants would consume 1,900 gpd over a 12-month peak period for relocation to Gas Hills and 2,300 to 2,400 gpd over an 18-month peak period for stabilization in place or a 19-month peak period for the Dry Cheyenne alternative. Total in-migrant water consumption over the entire peak period would approximate 707,000 gallons for the Gas Hills alternative, 1,280,000 gallons for stabilization in place, or 1,410,000 gallons for the Dry Cheyenne alternative. No problems would be expected in supplying these quantities of water from local water supply systems. Direct remedial action uses (mostly nonpotable water for uses such as compaction and dust control) would be approximately 5,580,000 gallons for relocation to Gas Hills, 22,221,000 gallons for stabilization in place, and 35,471,000 gallons for the Dry Cheyenne alternative.

Remedial action in-migrants would impose minor additional demands on local sewer systems. Assuming a per-capita sewage generation factor of 100 gpd, the in-migrant sewage would be 1,900 gpd for relocation to Gas Hills, 2,300 gpd for stabilization in place, or 2,400 gpd for the Dry Cheyenne alternative. The Riverton sewage system now operates at only 50 to 60 percent of its 5 million-gpd capacity (Scott, 1987) and could easily accommodate these increased demands.

Because of the low levels of population in-migration related to remedial action, none of the remedial action alternatives would be expected to have any adverse impacts on local public safety, health care, or recreational systems or facilities. The no action alternative would have no impact on local community services.

E.2.3 ECONOMIC STRUCTURE

The implementation of any of the action alternatives would have a direct impact on the economy of Fremont County through wages and salaries paid to the remedial action work force as well as through local spending for equipment, materials, and supplies needed for the remedial action. There also would be indirect benefits to the local economy as remedial action dollars spent locally are, in turn, respent locally on other goods and services. Remedial action cctivities would also generate sales tax revenues that would be received by state and local governments. The no action alternative would not involve any local expenditures and would therefore have no impact on the local economy.

Relocation to Gas Hills

The cost of relocation to Gas Hills is estimated to be $21,161,000. The cost of the vicinity properties cleanup is estimated to be $1,484,000 so the total direct cost of this remedial action alternative would be approximately $22,645,000.

Including the vicinity properties cleanup, the total wages and salaries paid to remedial action workers (both "general" and "supervisory" personnel) are estimated to be $2,944,000. It is expected that $2,767,000 of this total would be spent locally within Fremont County. The total expenditures for equipment (e.g., equipment lease or rental) and materials (e.g., gravel, fuel, and fence) are estimated to be

$19,701,000, of which $14,579,000 would be spent locally. This estimate is based on the assumptions that all materials would be purchased in Fremont County, 33 percent of the equipment expeditures would occur in Fremont County, and 67 percent of the equipment expenditures would occur elsewhere in Wyoming. Thus, the total direct input to the local economy from remedial action would be approximately $17,346,000.

Direct remedial action expenditures would ripple through the local economy to generate additional expenditures as the remedial action dollars are respent. A 1979 study by the Wyoming Department of Economic Planning and Development indicated that an income multiplier of 1.2238 is appropriate for Fremont County (WDEPAD, 1979). This means that for every remedial action dollar spent locally, an additional $0.2238 would be generated in indirect or secondary spending. Accordingly, the estimated $17,346,000 in direct local expenditures would generate approximately $3,882,000 in indirect local expenditures. The total impact on the Fremont County economy from relocation to Gas Hills would therefore be up to $21,228,000.

Stabilization in place

The cost of stabilization in place is estimated to be $9,874,000. Approximately $1,484,000 would be associated with the vicinity properties cleanup so the total estimated cost of this remedial action alternative would be $11,358,000.

Including the vicinity properties cleanup, the total wages and salaries paid to remedial action workers are estimated to be $2,953,000. It is expected that $2,658,000 of this total would be spent locally within Fremont County. The total expenditures for equipment and materials are estimated to be $8,405,000, of which $6,220,000 would be spent locally. Thus, the total direct input to the local economy from remedial action would be approximately $8,878,000. These direct expenditures would generate $1,987,000 in indirect local expenditure so the total impact on the Fremont County economy from stabilization in place would be up to $10,865,000.

Disposal at the Dry Cheyenne site

The cost of disposal at the Dry Cheyenne site is estimated to be $19,122,000. Including the cost of the vicinity properties cleanup ($1,484,000), the total direct cost of this remedial action alternative would be approximately $20,606,000.

Including the vicinity properties cleanup, the total wages and salaries paid to remedial action workers are estimated to be $4,739,000 and $4,455,000 of this total would be spent locally within Fremont County. The total expenditures for equipment and materials are estimated to be $15,867,000, of which $11,742,000 would be spent locally. The total direct input to the local economy from remedial action would be $16,197,000, and these direct expenditures would generate $3,625,000 in indirect local expenditures. Thus, the total impact on the Fremont County economy from disposal at the Dry Cheyenne site would be up to $19,822,000.

REFERENCES FOR APPENDIX E

DOC (U.S. Department of Commerce), 1982. 1980 Census of Housing, General Housing Characteristics, Wyoming, Washington, D.C.

FBD (Ford, Bacon & Davis, Inc.), 1983. "Environmental Assessment of Remedial Actions on the Uranium Mill Tailings at the Riverton Site, Fremont County, Wyoming," unpublished preliminary draft prepared by FBD, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Fremont County Planning Commission, 1984. "Socioeconomic Profiles and Projections, Fremont County, Wyoming (Progress Draft)," Lander, Wyoming.

MWR (Mountain West Research, Inc.), 1975. Construction Worker Profiles, Billings, Montana.

NRC (U.S. Nuclear Regulatory Commission), 1980. Final Environmental Statement Related to the Operation of Gas Hills Uranium Project, Docket No. 40-299, Union Carbide Corporation, NUREG-0702, Washington, D.C.

Scott, Bernard, 1987. Personal communication with Bernard Scott, City of Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated March 26, 1987.

WDAFC (Wyoming Department of Administration and Fiscal Control), 1983. State of Wyoming Population and Employment Forecast Report, Cheyenne, Wyoming.

WDEPAD (Wyoming Department of Economic Planning and Development), 1979. Perspectives on the Economic Viability of Carbon, Fremont, Goshen and Sheridan Counties, Cheyenne, Wyoming.

WDRT (Wyoming Department of Revenue and Taxation), 1983. State of Wyoming Annual Report, Ad Valorem Tax Division, Cheyenne, Wyoming.

WDRT (Wyoming Department of Revenue and Taxation), 1982a. State of Wyoming Annual Report, Ad Valorem Tax Division, Cheyenne, Wyoming.

WDRT (Wyoming Department of Revenue and Taxation), 1982b. State of Wyoming Tax Revenue Report, Cheyenne, Wyoming.

WDRT (Wyoming Department of Revenue and Taxation), 1981. State of Wyoming Annual Report, Ad Valorem Tax Division, Cheyenne, Wyoming.

WESC (Wyoming Employment Security Commission), 1984. Wyoming Labor Force Trends, Vol. 21, No. 1, Casper, Wyoming.

APPENDIX F

RADIATION

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

F.1 RADIATION

This appendix addresses the increased radiation doses and health impacts to the general public and remedial action workers for the alternatives under consideration for remedial action at the inactive Riverton, Wyoming, tailings site. The slightly increased doses received by these individuals can, in a statistical sense, increase the potential for individual and general public health effects (excess fatal cancers) above those naturally expected. Assumptions made during the calculations of excess health effects for the general public and remedial action workers are realistic but probably conservative in order to derive an estimate of the excess effects that might occur because of exposure to low levels of radiation from the tailings.

F.1.1 BASIC FACTS ABOUT RADIATION AND ITS MEASUREMENT

Atoms that spontaneously transform, or decay, into new atoms are termed radioactive. The decaying atom is called the parent, and the atom produced by the transformation is called the daughter. The rate at which atoms decay is the radioactivity, measured by the unit Curie (Ci). A more convenient unit for measuring the radioactivity of tailings piles is the picoCurie (pCi) which is one-millionth of one-millionth ($1x10^{-12}$) of a Curie. The half-life of a radioactive substance is the time required for it to lose 50 percent of its radioactivity by decay. Each radionuclide has a unique half-life.

When atoms undergo radioactive decay, they emit radiation. The most common types of radiation are alpha particles, beta particles, and gamma rays. Alpha and beta radiation are tiny particles with excess energy, and gamma radiation is pure energy without mass. Radiation transmits energy to matter as it travels through matter. Alpha radiation penetrates only a few millimeters into matter, and beta radiation penetrates a few centimeters, unlike gamma radiation which can travel deeper into matter in the same way as X-rays. Alpha radiation will not penetrate through a layer of skin, whereas gamma radiation can easily penetrate tissue and hence deliver a dose to any internal organ.

The amount of radiation to which an individual is exposed may be expressed in terms of the amount of energy imparted to cells and tissue by the radiation and the degree of biological damage associated with the energy as it is absorbed. This absorbed energy is termed the absorbed dose and is given in units of rads, where one rad equals 100 ergs of energy absorbed per gram of material irradiated. When the irradiated material is living tissue, the damage per rad varies depending on the type of radiation. By applying a "quality factor" to each specific type of radiation, the degree of biological damage can be expressed independently of the type of radiation causing it. The biologically relevant absorbed energy is termed the dose equivalent, and the unit is the rem. One rad is equal to one rem for less damaging radiations where the quality factor is equal to one (e.g., gamma rays). For comparison, one rad of internal alpha-deposited energy is equal to 20 rem because alpha particles are more damaging to tissue and the quality factor for alpha radiation is 20. The millirem (mrem) equals one-thousandth (1×10^{-3}) of a rem and is in more common usage when expressing doses from environmental levels of radiation.

When a succession of radioactive parent atoms decay to radioactive daughter atoms, a radioactive decay series is formed. Uranium-238 (U-238) is such a radioactive parent atom, and the U-238 decay series is shown in Figure F.1.1. The U-238 decay series includes thorium-230 (Th-230), radium-226 (Ra-226), radon-222 (radon or Rn-222), short-lived radon daughters, and other long-lived radioactive atoms. The U-238 decay series ends with lead-206 (Pb-206), an atom that is stable and not radioactive. When the daughter products in a radioactive decay chain have shorter half-lives than the parent, the daughter radioactivities will increase, termed ingrowth, until they equal the radioactivity of the parent.

Radon is the radionuclide of primary importance to the Uranium Mill Tailings Remedial Action (UMTRA) Project because it represents the largest radiation exposure pathway to the general public. The half-life of radon (3.8 days) is short relative to the half-life of Ra-226 (1602 years). As Ra-226 decays, the newly produced radon will begin to decay, and the radon radioactivity will become equal to the Ra-226 radioactivity within 30 days. Similarly, the short-lived radon daughter radioactivities will ingrow within 4 hours to equal the radioactivity of radon and Ra-226. When the radioactivities of the parent and its daughters are equal, the daughters are said to be in 100-percent equilibrium or simply in equilibrium. If the daughters are diluted or carried away in the air as they are formed, they will not reach 100-percent equilibrium.

The only member of the U-238 decay series that is not a solid is radon. Radon is an inert gas and does not react chemically with other elements; it therefore can diffuse out of matter and into the atmosphere. The atmospheric radon concentration is measured in units of picoCurie per liter (pCi/l). In the uranium milling process, Ra-226, the parent of radon, is left in the tailings, which then become a source from which radon diffuses into the atmosphere. Once in the atmosphere, radon is transported downwind and, according to its 3.8-day half-life, decays into the short-lived radon daughters which can attach to particulates in the air. Since radon is an inert gas, it is inhaled and exhaled, contributing very little radiation exposure to the lung. The radon daughters are solids, however, and once inhaled can deposit in or attach to the lung and then decay, transmitting alpha energy in the lung. Because of the short half-life, these daughters will decay before being removed from the lung.

Trace amounts of U-238 and its daughters are found everywhere on the earth; therefore, radon and its short-lived daughters contribute significantly to the natural background radiation exposure of the general public. Human exposure to radiation originates from both natural and man-made sources. The major natural radiations originate from cosmic and terrestrial external sources and from naturally occurring radionuclides which are deposited inside the body via the ingestion and inhalation pathways. Exposure to man-made sources results primarily from medical exposures (e.g., diagnostic X-rays) with minor contributions from other sources such as airline travel, atmospheric weapons tests, the nuclear industry, consumer products, and technologically enhanced natural radiation.

Nuclide	Historical name	Half-life	Major radiation energies (MeV) and intensities†					
			α		β		γ	
$^{238}_{92}U$	Uranium I	4.51×10^{9}y	4.15 4.20	(25%) (75%)	---		---	
$^{234}_{90}Th$	Uranium X_1	24.1d	---		0.103 0.193	(21%) (79%)	0.063c‡ 0.093c	(3.5%) (4%)
$^{234}_{91}Pa^{m}$ (99.87% → $^{234}_{92}U$; 0.13% → $^{234}_{91}Pa$)	Uranium X_2	1.17m	---		2.29	(98%)	0.765 1.001	(0.30%) (0.60%)
$^{234}_{91}Pa$	Uranium Z	6.75h	---		0.53 1.13	(66%) (13%)	0.100 0.70 0.90	(50%) (24%) (70%)
$^{234}_{92}U$	Uranium II	2.47×10^{5}y	4.72 4.77	(28%) (72%)	---		0.053	(0.2%)
$^{230}_{90}Th$	Ionium	8.0×10^{4}y	4.62 4.68	(24%) (76%)	---		0.068 0.142	(0.6%) (0.07%)
$^{226}_{88}Ra$	Radium	1602y	4.60 4.78	(6%) (95%)	---		0.186	(4%)
$^{222}_{86}Rn$	Emanation Radon (Rn)	3.823d	5.49	(100%)	---		0.510	(0.07%)
$^{218}_{84}Po$ (99.98% → $^{214}_{82}Pb$; 0.02% → $^{218}_{85}At$)	Radium A	3.05m	6.00	(~100%)	0.33	(~0.019%)	---	
$^{214}_{82}Pb$	Radium B	26.8m	---		0.65 0.71 0.98	(50%) (40%) (6%)	0.295 0.352	(19%) (36%)
$^{218}_{85}At$	Astatine	~2s	6.65 6.70	(6%) (94%)	?	(~0.1%)	---	
$^{214}_{83}Bi$ (99.98% → $^{214}_{84}Po$; 0.02% → $^{210}_{81}Tl$)	Radium C	19.7m	5.45 5.51	(0.012%) (0.008%)	1.0 1.51 3.26	(23%) (40%) (19%)	0.609 1.120 1.764	(47%) (17%) (17%)
$^{214}_{84}Po$	Radium C'	164μs	7.69	(100%)	---		0.799	(0.014%)
$^{210}_{81}Tl$	Radium C''	1.3m	---		1.3 1.9 2.3	(25%) (56%) (19%)	0.296 0.795 1.31	(80%) (100%) (21%)
$^{210}_{82}Pb$	Radium D	21y	3.72	(.000002%)	0.016 0.061	(85%) (15%)	0.047	(4%)
$^{210}_{83}Bi$ (~100% → $^{210}_{84}Po$; .00013% → $^{206}_{81}Tl$)	Radium E	5.01d	4.65 4.69	(.00007%) (.00005%)	1.161	(~100%)	---	
$^{210}_{84}Po$	Radium F	138.4d	5.305	(100%)	---		0.803	(0.0011%)
$^{206}_{81}Tl$	Radium E''	4.19m	---		1.571	(100%)	---	
$^{206}_{82}Pb$	Radium G	Stable	---		---		---	

REF: BRH, 1970; LEDERER et. al., 1967.

FIGURE F.1.1 URANIUM-238 DECAY SERIES

Medical usage of radiation is responsible for the highest contribution to man's radiation exposure, accounting for 45 percent of man's total radiation exposure. Other man-made contributors, including airline travel, atmospheric weapons tests, the nuclear industry, and consumer and industrial products together account for 4 percent. The remaining 41 percent of man's total radiation exposure results from exposure to natural radiation sources (Shleien and Terpilak, 1984).

F.2 METHOD OF ANALYSIS

Radiation and its associated health effects have been studied more thoroughly than health effects from other carcinogenic agents. The evaluation of health effects caused by low-level radiation is, however, a difficult task, and many uncertainties are associated with the estimation of risks from radiation. The traditional approach for estimating risks from low-level radiation exposures is to extrapolate from effects observed at high radiation exposures using the linear dose response and no threshold assumptions.

There are five principal pathways which could potentially result in exposure of man to radiation from the tailings pile. These are: (1) inhalation of radon daughters; (2) direct exposure to gamma radiation emitted from the contaminated area; (3) inhalation and ingestion of, and submersion in, airborne radioactive particulates; (4) ingestion of ground or surface water contaminated with radioactive materials; and (5) ingestion of contaminated foodstuff produced in areas contaminated by tailings.

For detailed calculations of excess health effects in this appendix, only the most significant radiation exposure pathways are considered; they are inhalation of radon daughters, direct exposure to gamma radiation, and inhalation and ingestion of radioactive particulates. Brief calculations are provided which estimate radiation exposures and excess health effects to the general public from the drinking water ingestion pathway and to the maximally exposed individual from the ingestion of food produced on contaminated land. When excess health effects were estimated for the remedial action alternatives, the following numbers of significant digits were used to facilitate comparison of the alternatives. Estimates that were used in further calculations, such as summations of risk, were rounded to two significant digits. Final estimates, such as total excess health effects, were rounded to one significant digit.

An excess health effects calculation for ingestion of contaminated drinking water was done using the maximum concentrations of radionuclides measured in water samples collected from beneath the tailings pile. The calculation resulted in a conservative individual risk estimate that is 41 percent of the individual risk calculated for inhalation of radon daughters and gamma exposure within 0.1 mile from the pile perimeter. Under existing conditions, no one would be exposed to the radionuclide concentrations used because dilution with distance from the pile was not taken into account.

The ingestion of plant material that has been "dusted" with windblown tailings or the ingestion of animal food products (i.e., meat, milk, and eggs) from animals that have ingested such plant material could potentially result in an excess health risk to a maximally exposed individual during relocation of the tailings to the Dry Cheyenne site that is two times the health risk to a member of the general public living within 0.1 mile of the tailings pile from radon daughters inhalation and gamma exposure. However, the excess health risk to a member of the general public from this pathway is judged to be insignificant because the contaminated agricultural land in the vicinity of the tailings pile does not produce enough food for human consumption to have an appreciable effect on the Riverton population.

The excess health effects estimations made in this appendix are primarily based on data and models presented in the BEIR-III report (NAS, 1980). Quantitative risk estimation of somatic effects (e.g., cancer) for various organs of the body can be obtained using available human radiation exposure data. The manifestation of a cancer caused by radiation exposure would occur after a latent period of up to 25 years or more, depending on the type of cancer and the age of the person exposed. The risks from radiation vary with adult age and sex but are presented here as average values assuming that the variation due to adult age and sex is small. No data are available that indicate whether risk estimates for adults are appropriate for radiation exposure during childhood. Because the BEIR-III report did not always make firm recommendations for application of the data, health risk estimates in this appendix also make use of recommendations published in scientific journals.

F.2.1 HEALTH EFFECTS OF EXPOSURE TO RADON DAUGHTERS

The health effects of radon diffusion from tailings arise from inhalation of the short-lived radon daughters which deposit alpha energy in the lung. For radiation protection purposes, the International Commission on Radiological Protection (ICRP, 1977) proposed an individual lung cancer risk factor of 20×10^{-6} per rem, or 20 excess fatal cancers where one million individuals each receive a one-rem lung dose equivalent commitment from radon daughters.

Health effects from radon daughters inhalation can also be expressed as excess risk of lung cancer based on the lung collective dose equivalent commitment in person-working level-months (person-WLM). The unit of working level (WL) is defined as any combination of short-lived radon daughters in 1 liter of air which, on complete decay, gives a total emission of 1.3×10^{5} million electron volts of alpha radiation. One WL is equivalent to 100 pCi of radon per liter of air with the short-lived radon daughters in 100-percent equilibrium. At equilibrium levels less than 100 percent, the WL corresponding to a given radon concentration is reduced. The working level-month (WLM) is a unit defined as the exposure resulting from the inhalation of air with a concentration of 1 WL of radon daughters for 170 working hours. The total dose of one or more persons is the product of the number of persons and the average dose they receive; the unit for the measurement of such a population dose is the person-WLM.

The following are estimates of excess fatal lung cancers given in terms of person-WLM. The United Nations Scientific Committee on the Effects of Atomic Radiation quoted a range of 200 to 450×10^{-6} fatal cancers per person-WLM (UNSCEAR, 1977), while the U.S. Nuclear Regulatory Commission (NRC) in its environmental impact statement on uranium milling quoted 360×10^{-6} fatal cancers per person-WLM (NRC, 1980a). The BEIR-III report indicated 850×10^{-6} lung cancers per person-WLM (NAS, 1980). The ICRP (1981) has adopted 150 to 450×10^{-6} as the risk of lung cancer per person-WLM. Evans et al. (1981) reviewed the BEIR-III study, lung cancer risk estimates published by other authors, and epidemiological evidence. They concluded that the most defensible upper bound to the lifetime lung cancer risk for the general public is 100×10^{-6} fatal cancers per person-WLM.

The National Council on Radiation Protection (NCRP, 1984) reported a conversion factor of 1 WLM equal to a 12.6- to 25-rem dose equivalent commitment to the lung. Using the previously mentioned ICRP individual lung cancer risk factor of 20 x 10^{-6} per rem, the NCRP dose conversion factors correspond to 250 to 500 x 10^{-6} lung cancers per person-WLM. A risk factor of 300 x 10^{-6} lung cancers per person-WLM was used in this appendix for calculating excess health effects due to exposure to radon daughters. This is equivalent to a conversion factor of 1 WLM equal to a 15-rem dose equivalent commitment to the lung. The risk factor of 300 x 10^{-6} is reasonable relative to the risk factors just mentioned and provides the consistency needed to compare the remedial action alternatives in terms of excess health effects.

F.2.2 HEALTH EFFECTS OF EXPOSURE TO GAMMA RADIATION

Tailings piles emit gamma radiation that delivers an external exposure to the whole body of people near the pile. The BEIR-III report contains several models for estimating cancer risk resulting from exposure to gamma radiation. Health effects estimates in this appendix for excess fatal cancers due to gamma radiation use a risk factor of 120 x 10^{-6} fatal cancers per person-rem (NAS, 1980; Cohen, 1981). This is equivalent to 120 excess fatal cancers in an exposed population for each 1,000,000 person-rems of collective dose equivalent. A personrem is the product of the radiation dose commitment multiplied by the number of people receiving that dose.

Excess health effects estimates for gamma radiation exposure were calculated for remedial action workers and for the general public within 0.3 mile of the tailings site. The contribution from the tailings pile to gamma radiation levels becomes negligible beyond 0.3 mile from the tailings pile perimeter. An excess health effects analysis was done for the general public and remedial action workers to determine gamma radiation effects during transportation of the tailings in the relocation alternatives.

For gamma radiation, 1 rem is equal to 1 roentgen (R) which is the unit for measuring gamma radiation intensity in air. A microroentgen (microR) is 1 x 10^{-6} R, and typical environmental gamma radiation levels are expressed in microR per hour (microR/hr).

The health effects attributed to a gamma radiation dose are categorized into two general types: somatic and genetic. Somatic effects are manifested in the exposed individual (e.g., cancer), and genetic effects are manifested in the descendants of the exposed individual. The ICRP (1977) reported that the average risk estimated for genetic effects, as expressed in the first two generations and considered genetically significant, is 40 x 10^{-6} per rem. For all subsequent generations, the risk is estimated to be equal to that expressed in the first two generations. The total genetic risk (all generations) is, therefore, 80 x 10^{-6} per rem. Measures taken to reduce the somatic effects would also reduce the genetic effects; thus, the calculations in this appendix reflect only the somatic risk.

F.2.3 HEALTH EFFECTS OF EXPOSURE TO AIRBORNE RADIOACTIVE PARTICULATES

Disturbance of the tailings and contaminated materials during remedial action at the Riverton site would create fugitive dust emissions resulting in exposures to airborne radioactive particulates for the general public and remedial action workers. The doses would be to the exposed individual's lung from the inhalation of respirable particulates (less than 10 microns in size) that contain Ra-226, Th-230, U-238, uranium-234 (U-234), and lead-210 (Pb-210). For the general public, the concentration of each radionuclide was calculated as a function of distance from the edge of the tailings pile using a modification of a standard Gaussian diffusion model (Turner, 1969) to account for surface deposition of particulates (AEC, 1968). The resulting dose from each radionuclide was then calculated using a specific dose conversion factor (DOE, 1985) to account for a change in dose relative to the type of radiation emitted by a specific radionuclide (i.e., alpha, beta, or gamma radiation). For the remedial action workers, the dose from each radionuclide was calculated using a method proposed by the NRC (1981) and, again, a specific dose conversion factor; it was conservatively assumed that the workers were on the tailings pile for the entire period of tailings disturbance. For both the general public and remedial action workers, the radionuclide concentrations were multiplied by 2.4 to account for the observed higher radionuclide concentrations associated with suspended particulates (PNL, 1980). The excess health effects were then estimated by applying the cancer risk factor for exposure to gamma radiation (120×20^{-6} fatal cancers per person-rem) to the calculated effective committed whole body dose equivalents.

F.3 CALCULATIONS OF HEALTH EFFECTS

F.3.1 STABILIZATION IN PLACE

General public health effects from radon daughters exposure

The population distribution of Riverton, Wyoming, estimated by Ford, Bacon & Davis Utah Inc. (FBDU) was used as a basis to calculate the excess health effects to the general public during stabilization in place. There are 11,273 people living within a 3.5-mile radius of the tailings pile distributed by sector as shown in Table F.3.1 (FBDU, 1981). In this analysis, additional residents were included at the following locations: (1) 500 residents each at 4.0, 5.0, and 6.0 miles from the tailings pile for conservation at distances beyond the FBDU study, primarily in the urban service area north of Riverton; (2) 17 residents at the St. Stephen's Mission (Johnson, 1984) which is 0.6 mile from the tailings pile; (3) 400 students and staff at the St. Stephen's Mission School for 0.5 year (Doyle, 1984), equivalent to 200 people for a full year; and (4) 11 workers at the active sulfuric acid plant (McFarland, 1984) that is 0.1 mile from the tailings pile. The population distribution in this analysis therefore consists of 13,001 people. It was assumed that people spend 75 percent of their time in the immediate vicinity of their residences (25 percent outdoors and 50 percent indoors) and 25 percent of their time beyond a distance of 0.3 mile from the tailings pile.

To develop the radon source term during stabilization in place, the radon flux was calculated using the RAECOM model (NRC, 1984), assuming that no cover exists. The pile was considered to be one layer, and input parameters for the layer are shown in Table F.3.2. A diffusion coefficient of 0.015 square centimeter per second (cm^2/s) for the tailings was used, and a radon emanating fraction of 0.20 (Nielson, 1984) was used. For this calculation, the average Ra-226 concentration beneath the surface of the tailings pile was based on field data (BFEC, 1983). Samples from 105 drill holes on the tailings pile (including the present cover and 3 feet of material underlying the tailings) were analyzed by gamma spectroscopy, and the sample data were averaged to arrive at the Ra-226 concentration of 342 picoCuries per gram (pCi/g). The radon flux calculation resulted in an annual average flux of 210 picoCuries per square meter per second (pCi/m^2s) from the bare tailings. Using a pile surface area of 70 acres, the radon flux of 210 pCi/m^2s from bare tailings is equivalent to a radon source term of 1,880 Curies per year (Ci/yr).

The remedial action for on-site stabilization of the tailings pile is expected to take 24 months. During that period, disturbance and exposure of the tailings would occur for a maximum of 18 months. Radon releases would be increased somewhat during disturbance of the tailings. It is assumed that 25 percent of the tailings would be handled and moved one time during remedial action and that all radon in the tailings pore spaces would be released instantaneously to the atmosphere when the tailings were moved. Using 342 pCi/g of Ra-226 and a tailings volume of 1.5 x 10^6 cubic yards, the calculation resulted in a release of 22 Ci of radon. Coupled with a bare tailings source term

Table F.3.1 Estimated 1980 population distribution, Riverton, Wyoming

	Distance from pile edge (miles)														
Direction	0.1	0.2	0.3	0.4	0.5	0.75	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	Totals
N	0	0	0	0	0	0	0	0	588	49	60	54	0	0	0	751
NNE	0	7	4	0	0	7	4	28	2,002	2,611	1,523	234	0	0	0	6,420
NE	0	0	0	0	0	14	0	0	658	1,822	838	5	0	0	0	3,337
ENE	0	0	4	0	0	4	0	25	20	25	0	0	0	0	0	78
E	0	0	7	0	4	18	11	7	0	0	0	0	0	0	0	47
ESE	0	7	7	7	0	0	4	0	0	0	0	0	0	0	0	25
SE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSE	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4
S	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
SSW	0	0	0	0	0	52	0	7	0	0	0	0	0	0	0	59
SW	0	0	0	0	0	7	4	7	25	4	7	14	0	0	0	68
WSW	0	0	0	0	0	4	7	7	21	32	35	28	0	0	0	134
W	0	0	0	0	0	4	0	7	11	11	4	39	0	0	0	76
WNW	0	7	0	0	0	0	4	0	0	0	0	18	0	0	0	29
NW	0	11	0	0	0	0	0	11	14	4	14	18	0	0	0	72
NNW	0	0	4	0	0	0	0	7	35	81	35	4	0	0	0	166
Additional residents	11						217						500	500	500	1,728
Totals	18	36	26	7	4	110	251	106	3,374	4,639	2,516	414	500	500	500	13,001

Table F.3.2 RAECOM model radon flux calculation for the tailings pile under no action conditions

Thickness (cm)	Ra-226 (pCi/g)	Radon diffusion coefficient (cm^2/s)	Emanating fraction	Porosity (fraction)	Bulk density (g/cm^3)	Moisture fraction	Exit radon flux (pCi/m^2s)
760	342	0.015	0.20	0.48	1.43	0.10	210

of 1,880 Ci/yr and a maximum tailings disturbance period of 18 months, the total radon source term during tailings disturbance is 2,842 Ci, equivalent to a radon flux of 210 pCi/m^2s.

The radon concentration on the pile during remedial action was determined using the 210-pCi/m^2s radon flux, an average wind speed of 2.0 meters per second (calculated by weighting each wind speed by its frequency of occurrence), and a pile radius of 300 meters. For calculation purposes, a conservative distribution of stability classes was used based upon meteorological data from Lander, Wyoming (NOAA, 1976), and the pile geometry was assumed to be circular. The radon concentration at the center of the circular pile was estimated by calculating the concentration for each of the six standard stability classes, weighting each by the frequency of occurrence, and summing the weighted values. The concentration at the pile center for each stability class was calculated by integrating the functional form of sigma Z as a function of distance from the pile center back to the pile edge, ignoring crosswind spreading. This is similar to assuming that the center of the pile is always at the edge of an infinite strip of area source, with the width equal to the pile radius. The resulting radon concentration on the pile was calculated to average 6.2 pCi/l during remedial action.

To estimate the radon concentrations and working levels downwind from the tailings pile, annual average radon concentrations and working levels as a function of distance from the pile were calculated using a sector average form of the Gaussian diffusion equation (Turner, 1969) and a calculation of the ingrowth of radon daughters as a function of time (Evans, 1980). The area source (tailings pile) was treated as a point source at the pile center with the same source strength as the pile. The calculated radon concentration is a function of wind speed and stability class for each distance downwind. A conservative distribution of wind speed and stability class was assumed that would result in maximized radon and radon daughters concentrations downwind for a sector as summarized in Table F.3.3. This bi-variate joint frequency distribution was then used to time-weight the radon concentration calculated at a given downwind distance according to the percent of the time that each wind speed and stability class pair occurs. Similarly, the percent ingrowth of daughters at a given downwind distance was calculated based on the transit time of the radon from the area source center. The working levels due to the pile at varying distances from the pile are dependent on the percent ingrowth of radon daughters. Between a transit time of 1 minute and 40 minutes, the working level grown into 100 pCi/l of radon can be represented within plus 5 percent by the approximate analytical expression (Evans, 1980):

Equation F.3.1

$$WL = 0.023\ T^{0.85}$$

where:

WL = working level.

T = transit time in minutes.

The working level for each wind speed and stability class was also time-weighted using the assumed joint frequency distribution.

Table F.3.3 Joint frequency distribution between wind speed and stability class for a conservative sector[a]

Stability class	Wind speed (miles per hour)						Totals
	0-3	4-7	8-12	13-18	19-24	>25	
A	0.20	0	0	0	0	0	0.20
B	0.90	0.33	0.14	0	0	0	1.37
C	0.37	1.00	1.09	0.57	0.14	0	3.17
D	1.33	4.09	15.85	18.99	2.71	2.33	45.30
E	0	8.04	22.13	0	0	0	30.17
F	9.23	9.94	0	0	0	0	19.17

[a]The distribution of frequencies in the table refers to the percentage of time that wind blew for each class from the conservative sector.

The use of the sector average model, with the area source replaced by a point source, tends to overestimate the concentrations at distances close to the source. At distances greater than several source diameters from the edge of the source, the model is reasonably accurate; however, overestimation can be up to a factor of 2 at distances less than several source diameters. To estimate radon concentrations within 1 mile of the pile edge, interpolation was done on a log-log basis between the previously calculated on-pile radon concentration and the modeled radon concentrations beyond 1 mile. Similarly, the working level exposures within 1 mile of the pile edge were calculated by extrapolating on a semi-logarithmic basis from the modeled working levels beyond 1 mile.

For the general public excess health effects calculations, assumptions were made which resulted in a conservative estimate of working levels as a function of distance from the pile edge. A wind direction frequency in the conservative sector of 14.4 percent was used. Table F.3.4 presents wind speed and wind direction studies from Lander, Wyoming, which show that the maximum measured wind direction frequency from any direction was 14.3 percent. All of the population was assumed to live in this conservative sector of interest. These assumptions provide a reasonable upper bound for the general public excess health effects estimates.

The radon concentrations and working levels due to the pile at varying distances from the pile edge are presented in Table F.3.5. The percent ingrowth formula used to derive working levels assumes that no daughter products are removed from the air by plate-out on walls or filters. Plate-out occurs when the electrically charged radon daughters attach to walls or other surfaces and are removed from the air,

Table F.3.4 Wind data for Lander, Wyoming (directions of maximum stability class for a conservative sector)[a]

Wind direction	Stability class	Wind speed (miles per hour) 0-3	4-6	7-10	11-16	17-21	>22	Totals
	A	0.0148	0.0137	0	0	0	0	0.0285
	B	0.0807	0.0616	0.0205	0	0	0	0.1628
SW	C	0.0561	0.1233	0.1233	0.0342	0	0	0.3369
	D	0.1361	0.3150	1.2466	1.6987	0.2671	0.0958	3.7593
	E	0	0.6644	1.705	0	0	0	2.3699
	F	0.9509	1.0822	0	0	0	0	2.0331
								8.6905
	A	0.0285	0	0	0	0	0	0.0285
	B	0.1300	0.0479	0.0205	0	0	0	0.1984
WSW	C	0.0526	0.1438	0.1575	0.0822	0.0205	0	0.4566
	D	0.1917	0.5891	2.2808	2.7328	0.3904	0.3356	6.5204
	E	0	1.1575	3.1849	0	0	0	4.3424
	F	1.3284	1.4315	0	0	0	0	2.7599
								14.3062
	A	0.0508	0.0205	0	0	0	0	0.0713
	B	0.1395	0.1096	0.0616	0	0	0	0.3107
W	C	0.0746	0.2671	0.1986	0.1164	0	0	0.6567
	D	0.0973	0.6576	1.1713	1.2397	0.5000	0.2671	3.9330
	E	1.0616	0.7671	0	0	0	0	1.8287
	F	1.5524	1.6164	0	0	0	0	3.1688
								9.9692

[a]Joint frequency distribution from Lander Airport, National Weather Service, Lander, Wyoming.

Table F.3.5 Radon daughters excess health effects to the general public during stabilization in place

Distance from pile edge (miles)	Population (persons)	Modeled outdoor radon concentration (pCi/l)	Modeled outdoor WL(r) x 10^{-4}	Calculated WLM(r) x 10^{-4}	Excess health effects x 10^{-4}
0.1	18	1.6	5.7	3,200	17
0.2	36	0.81	5.2	1,600	17
0.3	26	0.50	4.7	1,000	7.8
0.4	7	0.32	4.5	670	1.5
0.5	4	0.25	4.1	523	0.60
0.75	110	0.15	3.5	320	11
1.0	251	0.10	3.0	220	17
1.5	106	0.06	2.4	140	4.5
2.0	3,374	0.04	2.0	91	92
2.5	4,639	0.02	1.7	65	90
3.0	2,516	0.02	1.5	62	47
3.5	414	0.02	1.2	60	7.5
4.0	500	0.01	1.1	35	5.1
5.0	500	0.01	0.9	17	2.7
6.0	500	0.01	0.7	15	2.1
Totals	13,001				320

thereby reducing the percent equilibrium of radon daughters in the air inhaled. To account for plate-out in health effects calculations for outdoor conditions, the working level in inhaled air was assumed to be one-half of that calculated from the ingrowth formula; that is, 50- percent plate-out was assumed. For indoor working levels, the outdoor radon concentration as a function of distance was multiplied by a 50-percent equilibrium factor for radon daughters. This is applied in Equation F.3.2 to both outdoor and indoor inhalation.

For each distance, the number of working level-months was calculated using the equation:

Equation F.3.2

$$WLM(r) = \left[\left(\frac{R(r)}{100}\right) \times I + (WL(r) \times O)\right]\left[\frac{H}{170\ (hr/WLM)}\right] \times T$$

where

WLM(r) = working level-months at distance r (WLM).

R(r) = radon concentration at distance r (pCi/l).

WL(r) = working level at distance r (WL).

O = fraction of time spent outdoors multiplied by radon daughters equilibrium factor (0.25 x 0.5).

I = fraction of time spent indoors multiplied by radon daughters plate-out factor (0.5 percent x 0.5).

H = hours per year (8,760 hours).

T = duration of exposure (years).

The results of the above calculations are presented in Table F.3.5. The excess health effects were calculated by multiplying the working level-months by the population at each distance and by the conversion factor of 300×10^{-6} effects per person-WLM. Excess health effects were then summed over the distances.

The estimated number of excess health effects due to the 18-month tailings pile disturbance for the general public within 6 miles of the Riverton tailings pile was calculated as 320×10^{-4}, or 0.032 excess health effects for stabilization in place. This is equivalent to an individual risk of contracting a fatal lung cancer of 0.00025 percent (determined by dividing 0.032 by 13,001 people).

General public health effects from gamma exposure

The general public living or working within 0.3 mile of the tailings pile edge will be exposed to gamma radiation from the tailings as well as to radon daughters. The contribution from the tailings pile to gamma radiation levels is negligible beyond approximately 0.3 mile from the tailings pile perimeter. A predictive model (Yuan et al., 1983) which plots the ratio of direct gamma exposure rate divided by tailings Ra-226 concentration (microR/hr per pCi/g) as a function of distance from a tailings pile edge was used to estimate gamma radiation exposure rates contributed by the tailings to the general public. This model assumes that no cover exists on the tailings pile. The measured, average Ra-226 concentration of 342 pCi/g was multiplied by the ratio at each distance to determine the gamma exposure rate. Input parameters and excess health effects results due to the 18-month tailings pile disturbance are shown in Table F.3.6. Since individuals are assumed to spend 75 percent of their time at home, the period of exposure is 0.75 x 18 months, or 9,855 hours. Using the risk factor mentioned in Section F.2.2, the estimated number of excess health effects in the general public living within 0.3 mile of the pile edge due to gamma radiation from the tailings is 2.4×10^{-4}, or 0.00024 excess health effects. The individual risk of fatal cancer due to this exposure would be 0.0003 percent (determined by dividing 0.00024 by 80 people).

Table F.3.6 General public excess health effects from gamma exposure during stabilization in place

Distance from pile edge (miles)	Population (persons)	Individual hours exposed	Excess gamma exposure rate (microR/hr)	Excess health effects $\times 10^{-4}$
0.1	18	9,855	8.6	1.8
0.2	36	9,855	1.2	0.5
0.3	26	9,855	0.2	0.06
Totals	80			2.4

General public health effects from exposure to airborne radioactive particulates

As was done for the relocation to Gas Hills alternative (Section F.3.4), the off-site particulates concentrations as a function of distance from the tailings pile were modeled by use of the sector average model. The excess health effects to the general public and the effected committed whole body dose equivalent per person are shown in Table F.3.7. The resulting total excess health effects for the stabilization in place alternative are 8.6×10^{-4} which is only 2 percent of the total excess health effects from the inhalation of radon daughters.

Table F.3.7 General public excess health effects from exposure to airborne radioactive particulates during stabilization in place

Distance from pile edge (miles)	Population (persons)	Effective committed whole body dose equivalent (mrem per person)						Excess health effects x 10^{-4}
		Ra-226	Th-230	U-238	U-234	Pb-210	Totals	
0.1	18	0.840	34.0	0.888	0.962	0.861	37.6	0.81
0.2	36	0.416	16.8	0.439	0.476	0.426	18.6	0.80
0.3	26	0.244	9.88	0.258	0.279	0.250	10.7	0.33
0.4	7	0.147	5.95	0.155	0.168	0.151	6.57	0.06
0.5	4	0.108	4.37	0.114	0.124	0.110	4.83	0.02
0.75	110	0.058	2.35	0.061	0.067	0.060	2.60	0.34
1.0	251	0.048	1.95	0.051	0.055	0.049	2.15	0.65
1.5	106	0.022	0.897	0.023	0.025	0.023	0.990	0.13
2.0	3,374	0.013	0.514	0.013	0.015	0.013	0.568	2.3
2.5	4,639	0.008	0.335	0.009	0.009	0.008	0.369	2.1
3.0	2,516	0.006	0.237	0.006	0.007	0.006	0.262	0.79
3.5	414	0.004	0.176	0.005	0.005	0.004	0.194	0.10
4.0	500	0.003	0.136	0.004	0.004	0.003	0.150	0.09
5.0	500	0.002	0.089	0.002	0.003	0.002	0.098	0.06
6.0	500	0.002	0.063	0.002	0.002	0.002	0.071	0.04
Totals	13,001							8.6

For a person living within 0.1 mile of the site, the total effective committed whole body dose equivalent is 37.6 mrem, equivalent to a one in 220,000 chance of contracting a fatal cancer.

Health effects during remedial action to the maximally exposed individual from the consumption of contaminated food

In this section, the dose to the hypothetical, maximally exposed adult individual from the ingestion of contaminated food is calculated. It is assumed that a single individual consumes vegetables, meat, and milk produced only on contaminated soil and that washing and cooking vegetables removes half of the radioactive contamination (NRC, 1980a). It is further assumed that the individual lives 50 meters east-northeast of the tailings pile in the predominant wind direction. Only the doses from Ra-226, Th-230, U-238, and U-234 are considered since these nuclides generate the majority of the dose.

The whole body dose equivalent received from ingestion of plant material results from the concentration of radionuclides incorporated in plant tissue through root uptake and from particulate deposition on foliage from airborne dust resulting from remedial action. Radioactive concentrations in plants from root uptake are estimated from soil concentration data measured during the Riverton site radiological characterization and an adapted model from the NRC (NRC, 1980a). The dose equivalent from the dusting effect due to remedial action is established by the model developed for radon concentrations close to the pile and the NRC model.

The remedial action is expected to generate 2.7739×10^5 kilograms per year (kg/yr) of particulates (Section B.3 of Appendix B, Weather and Air Quality). The wind blows predominately from the west-southwest 14.3 percent of the time. Assuming that the particulates have the pile's average concentration of radionuclides, the flux of Ra-226 and Th-230 that is generated on the 2.8338×10^5-square meter (m^2) pile is:

$$2.7739 \times 10^5 \frac{\text{kg}}{\text{yr}} \times \frac{\text{year}}{3.145 \times 10^7 \text{ s}} \times \frac{1000 \text{ g}}{\text{kg}} \times \frac{342 \text{ pCi}}{\text{g}}$$

$$\times \frac{1}{2.8338 \times 10^5 \text{ m}^2} = 1.06 \times 10^{-2} \text{ pCi/m}^2\text{s},$$

and the flux of U-238 and U-234 is:

$$2.7739 \times 10^5 \frac{\text{kg}}{\text{yr}} \times \frac{\text{year}}{3.145 \times 10^7 \text{ s}} \times \frac{1000 \text{ g}}{\text{kg}} \times \frac{24 \text{ pCi}}{\text{g}}$$

$$\times \frac{1}{2.8338 \times 10^5 \text{ m}^2} = 7.75 \times 10^{-4} \text{ pCi/m}^2\text{s}.$$

The flux of radioactive dust generated by the remedial action is conservatively assumed to be transported in a manner similar to gaseous radon. Since the Gaussion sector average model tends to overestimate the concentration of a pollutant at distances close to an area source, the particulates concentration 50 meters from the tailings pile edge was estimated by calculating the concentration for each of the six standard stability classes, weighting each by the frequency of occurrence, and summing the weighted values. The concentration 50 meters from the eastern pile edge for each stability class was calculated by integrating the functional form of sigma Z as a function of distance from 50 meters off of the pile back to the western pile edge, ignoring crosswind spreading. This resulted in particulates concentration values at 50 meters from the tailings pile of 5.98×10^{-2} picoCuries per cubic meter (pCi/m^3) for Ra-226 and Th-230 and 4.37×10^{-3} pCi/m^3 for U-238 and U-234.

The amount of radioactivity that is deposited on plant foliage plus the amount of radioactivity incorporated in plant tissue can be calculated by the following equation (equations 7 and 8 modified from NRC, 1980a):

Equation F.3.3

$$C_{vi} = X_i V_p \, Fr \, Ev \left(\frac{1 - \exp(-\lambda_w t_v)}{Y_v \lambda_w} \right) + C_{si} B_{vi}$$

where

C_{vi} = the resulting concentration of isotope i in and on vegetation v (pCi/g).

Ev = the fraction of the foliar deposition reaching edible portions of vegetation v.

Fr = the fraction of the total deposition retained on plant surfaces (0.2) (NRC, 1980a).

t_v = the assumed duration of exposure while growing for vegetation v (s).

Y_v = the assumed yield density of vegetation v (kg/m^2).

λ_w = the decay constant accounting for weathering losses (6.73×10^{-7}/s) (NRC, 1980a).

V_p = deposition velocity of particle size p (m/s).

C_{si} = average concentration of the radionuclide in soil (pCi/kg).

B_{vi} = soil-to-plant transfer factor.

X_i = air concentration of the ith radionuclide (pCi/m^3).

The value of Ev is assumed to be 1.0 for all above-ground vegetation and 0.1 for all below-ground vegetation. The value t_v is taken to be 60 days except for pasture grass where a value of 30 days is assumed. The yield density, Y_v, is taken to be 2.0 kg/m^2 except for pasture grass where a value of 0.75 kg/m^2 is applied. The deposition velocity, V_p, is conservatively assumed to be 0.0883 m/s for all particles. This corresponds to the settling velocity for particles ranging in size from 10 to 80 microcentimeters which represents the majority of the particles (NRC, 1980a). Soil-to-plant transfer factors, B_{vi}, are listed in Table F.3.8.

The average concentrations of radionuclides in the soil, C_{si}, are estimated from site-specific data. The reported average Ra-226 concentration on the receptor field is 11.4 pCi/g. Since Th-230 is assumed to be in equilibrium, the concentration of Th-230 is 11.4 pCi/g. The U-238 and U-234 concentrations are estimated by multiplying the Ra-226 concentration of 11.4 pCi/g by the U-238 to Ra-226 on-pile ratio of 7.31×10^{-2} which equals 0.833 pCi/g (BFEC, 1983).

Concentrations of the radionuclides in the soil are expected to increase during the remedial action. This increase can be estimated by the following equation (equation 2 modified from NRC, 1980a):

Equation F.3.4

$$C_{si} = \left(\frac{X_i \; V_p}{P}\right)\left(\frac{1 - \exp\left[-(\lambda_i + \lambda_e)t\right]}{\lambda_i + \lambda_e}\right)$$

where

λ_e = assumed rate constant for environmental loss (equal to a 50-year half-life of $4.39 \times 10^{-10}\ s^{-1}$).

t = time interval over which deposition has occurred (s).

Table F.3.8 Environmental transfer coefficients

	Ra-226	Th-230	U-238 and U-234
Soil-to-plant (B_{vi})[a]			
edible above ground	1.4×10^{-2}	4.2×10^{-3}	2.5×10^{-3}
potatoes	3.0×10^{-3}	4.2×10^{-3}	2.5×10^{-3}
other below ground	1.4×10^{-2}	4.2×10^{-3}	2.5×10^{-3}
pasture grass	1.8×10^{-2}	4.2×10^{-3}	2.5×10^{-3}
stored feed (hay)	8.2×10^{-2}	4.2×10^{-3}	2.5×10^{-3}
Feed-to-meat (F_{bi})			
pCi/kg per pCi/day	5.1×10^{-4}	2.0×10^{-4}	3.4×10^{-4}
Feed-to-milk (F_{bi})			
pCi/l per pCi/day	5.9×10^{-4}	5.0×10^{-6}	6.1×10^{-4}

[a]These transfer coefficients are the dimensionless ratios of the concentrations of the ith radionuclides in vegetation (pCi/g) to the concentrations of the ith radionuclides in soils (pCi/g).

Ref. NRC, 1980a.

X_i = radioactive decay constant for isotope i (s^{-1}).

P = the assumed areal soil density for surface mixing (240 kg/m^2) (NRC, 1980a).

By using the previously calculated air concentrations of radionuclides and Equation F.3.4, the total concentrations of Ra-226, Th-230, and U-238 and U-234 in the receptor field are 1.25 x 10^4 pCi/kg, 1.25 x 10^4 pCi/kg, and 9.13 x 10^2 pCi/kg, respectively.

The concentrations on and in vegetation obtained from applying the appropriate parameters in Equation F.3.3 are listed in the first four columns of Table F.3.9. It is assumed that these concentrations in vegetables, hay, and pasture grass are uniform over the field where food for the maximally exposed individual is raised.

The yearly whole body dose equivalent to the maximally exposed adult individual due to consumption of contaminated plant material is calculated by multiplying the radioactive concentrations in Table F.3.8 by the food ingestion rates shown in Table F.3.10 and the dose conversion factors in Table F.3.11. This value is then divided by two since half of the radionuclides are assumed to be removed during food preparation. Table F.3.12 shows the resultant whole body dose equivalents in mrem per year (mrem/yr).

The concentrations of radionuclides in meat and milk can be determined by the following equation (modified from NRC, 1980a):

Equation F.3.5

$$C_{bi} = 0.5 F_{bi} Q (C_{pgi} + C_{hi})$$

where

C_{bi} = resulting average concentration of isotope i in meat or milk (pCi/kg).

C_{pgi} = concentration of isotope i in pasture grass (pCi/kg).

C_{hi} = concentration of isotope i in hay (pCi/kg).

F_{bi} = feed-to-meat or feed-to-milk transfer factor for isotope i (see Table F.3.8).

Q = assumed feed ingestion rate (50 kilograms per day) (NRC, 1980a).

0.5 = the fraction of the annual feed requirement assumed to be satisfied by pasture grass or locally grown and stored feed (NRC, 1980a).

Table F.3.9 Concentrations of radionuclides on and in vegetables, meat, and milk for stabilization in place

	C_{vi} above-ground vegetables (pCi/kg)	C_{vi} below-ground vegetables (pCi/kg)	C_{pgi} pasture grass (pCi/kg)	C_{hi} hay (pCi/kg)	C_{bi} meat (pCi/kg)	C_{bi} milk (pCi/l)
Ra-226	776.0	79.30	1,750	849.0	33.10	38.300
Th-230	765.0	80.60	1,730	765.0	12.50	0.312
U-238	55.8	5.75	126	55.8	1.55	2.780
U-234	55.8	5.75	126	55.8	1.55	2.780

Table F.3.10 Food ingestion rates

	Ingestion rates by age group			
	Infant	Child	Teen	Adult
Vegetables, total (kg/yr)	--	48	76	105
edible above ground	--	17	29	40
potatoes	--	27	42	60
other below ground	--	3.4	5.0	5.0
Meat (beef, fresh pork, and lamb) (kg/yr)	--	28	45	78
Milk (l/yr)	208	208	246	130

Ref. NRC, 1980a.

Table F.3.11 Adult ingestion whole body dose conversion factors

	Internal whole body effective committed dose equivalent conversion factors (mrem per pCi ingested x 10^3)			
	Ra-226	Th-230	U-238	U-234
	1.1×10^{-3}	5.3×10^{-4}	2.5×10^{-5}	2.3×10^{-5}

Ref. DOE, 1985.

Table F.3.12 Whole body dose equivalents in mrem per year for stabilization in place

	Above-ground vegetables	Below-ground vegetables	Meat	Milk
Ra-226	17.1	2.82	2.85	5.48
Th-230	8.11	1.39	0.521	0.019
U-238	0.026	0.004	0.003	0.008
U-234	0.028	0.004	0.003	0.009

The results of applying the appropriate data in Equation F.3.5 are shown in the last two columns of Table F.3.9, and the resulting whole body dose equivalents are listed in the last two columns of Table F.3.12. Dose equivalents are obtained by multiplying the values in Table F.3.9 by the annual adult ingestion rates in Table F.3.10 and the whole body dose conversion factors in Table F.3.11.

The total dose to the hypothetical, maximally exposed adult individual from Ra-226, Th-230, and U-238 and U-234 is 38.4 mrem/yr or 57.5 mrem during the 1.5-year tailings pile disturbance. The excess health risk during the remedial action is 6.9×10^{-6} or a 1 in 140,000 chance of contracting a fatal cancer. This is 0.66 percent of the risk of excess health effects for individuals in the general public within 0.1 mile of the tailings pile from radon daughters inhalation and gamma exposure.

Remedial action worker health effects from radon daughters exposure

An average of 68 workers would be required during the 24-month remedial action for stabilization in place. To estimate an upper bound for excess health effects to remedial action workers, it was assumed that each worker would spend 8 hours per day, 21 days per month, over 24 months (4,032 hours) outside on the pile and be exposed to a radon concentration of 6.2 pCi/l as calculated previously for the 18-month period during tailings pile disturbance. The radon daughters percent equilibrium on the pile was conservatively assumed to be 20 percent based on percent equilibrium measurements made near the Grand Junction, Colorado, uranium tailings pile (Borak and Inkret, 1983). From a calculation similar to Equation F.3.1, the estimated excess health effects to workers due to the 24-month remedial action are (6.2 pCi/l/100 pCi/l-WL) (0.2 equilibrium fraction) (2,016 hours) (1 month/170 hours) (2 yr) (68 persons) (300×10^{-6} health effect/person-WLM), which equals 60×10^{-4}, or 0.0060 excess health effects.

Remedial action worker health effects from gamma exposure

Remedial action workers on the pile would be exposed to gamma radiation from the tailings as well as to radon daughters. The estimated gamma exposure rate on the pile in microR/hr is 2.5 times the Ra-226 concentration in pCi/g (Schiager, 1974), or 855 microR/hr based on the measured, average Ra-226 concentration of 342 pCi/g. It should be noted that this is a highly conservative estimate and represents an upper bound which, in practice, is not expected to be reached. On a partially stabilized portion of the tailings pile, the exposure rate would be reduced by a factor of 10 for each 1 foot of radon barrier. The majority of workers would be enclosed in cabs of earthmoving equipment which would provide shielding from the tailings, where 1 inch of steel reduces gamma ray transmission by a factor of 10. A more realistic average gamma radiation exposure rate to remedial action workers would therefore be a factor of 10 below 855 microR/hr, or 85 microR/hr. Based on 85 microR/hr, the external gamma radiation exposure that a worker could be expected to receive from working 4,032 hours over a 24-month period would be 0.36 rem which is within the standard limit of 5 rem per year for occupational exposure (NRC, 1980b). For 68 remedial action workers, the estimate for excess health effects due to gamma radiation is 28×10^{-4}, or 0.0028 excess health effects.

Remedial action worker health effects from exposure to airborne radioactive particulates

Occupational exposures for remedial action workers breathing dust in the vicinity of earthmoving equipment may be estimated for comparison to the combined radon daughters and gamma radiation exposure. A method proposed by the NRC (1981) was used to estimate doses from the inhalation of particulates. These doses would be to the worker's lung from inhalation of respirable particulates (less than 10 microns in size) that contain trace amounts of Ra-226, Th-230, U-238, U-234, and Pb-210. The equation used is:

Equation F.3.6

$$H = (f_o f_d f_w T_{sa})_{air} \times C_w \times PDCF_{air}$$

where

H = the 50-year dose commitment to the lung in mrem.

f_o = the time delay factor which is equal to 1 for this application.

f_d = the site design factor which is equal to 1 for this application.

f_w = the waste form and package factor which is equal to 1 for this application.

T_{sa} = the soil-to-air transfer factor (in cubic meters of soil per cubic meters of air).

C_w = the radionuclide concentration in the material (pCi/m^3).

$PDCF_{air}$ = the pathway dose conversion factor for air pathways (i.e., inhalation and direct radiation).

The soil-to-air transfer factor, T_{sa}, may be expressed in terms of the geometry of the problem, the suspension flux (E), and the empirical equation (NRC, 1981):

Equation F.3.7

$$T_{sa} = \frac{ExGxfr}{uxd}$$

where

E = the suspension rate of transportable particulates (less than 30 microns in size) (g/m^2s).

G = the geometry factor equal to (area subject to dusting)/(width of area x mixing height).

fr = the fraction of suspended transportable particulates that are respirable (less than 10 microns in size).

d = the density of the soil (assumed to be 1.6 g/cm^3).

u = the wind speed (assumed to be 2.0 m/s).

The following calculates the transfer factor, T_{sa}, for particulates from excavation for the stabilization in place alternative. The total emissions term for construction would be 2.7739×10^5 kg/yr, based on the total fugitive dust emissions of 457.7 tons for stabilization in place as presented in Section B.3 of Appendix B, Weather and Air Quality, divided by 18 months of tailings disturbance. The site consists of 70 acres of contaminated materials or the equivalent of 2.8×10^5 m^2 for the construction.

For the total particulates release rate of 2.7739×10^5 kg/yr, 30 percent by weight would be particles smaller than 30 microns. This assumes that the particle size distribution of initially suspended dust is proportional to the particle size distribution in the tailings and assumes that only a small fraction of the tailings mass is in particles too large to be disturbed by earthmoving equipment. The factor E is thus:

$$E = (0.3) \times (2.7739 \times 10^5 \text{ kg/yr}) \times (1{,}000 \text{ g/kg}) \times (1 \text{ yr}/3.15 \times 10^7 \text{s}) \times 1/(2.8 \times 10^5 \text{ m}^2) = 9.4 \times 10^{-6} \text{ g/m}^2\text{s}.$$

Roughly 30 percent of the particulates release rate for 30 microns and smaller particles would represent particles smaller than 10 microns. Thus the factor fr in this calculation is 0.3.

The geometry factor was calculated by assuming that the area of construction would be 70 acres, or 2.8×10^5 m^2, and that the mixing height would be 3 meters. The width of the area is best represented by the diameter of a circle whose area is 2.8×10^5 m^2. The width of the area is then equal to 600 meters. These assumptions yield G equal to 157. Therefore:

$$T_{sa} = \frac{(9.4 \times 10^{-6}\ g/m^2 s)\ (157)\ (0.3)}{(2\ m/s)\ (1.6 \times 10^6\ g/m^3)} = 1.4 \times 10^{-10}$$

Table F.3.13 lists the pathway dose conversion factors for the air pathways ($PDCF_{air}$) and also tailings concentrations (pCi/m^3) for Ra-226, Th-230, U-238, U-234, and Pb-210 at the Riverton site. The radionuclide concentrations used are conservative because construction work during the 18-month remedial action would not always be on the tailings. The $PDCF_{air}$ factors in Table F.3.13 are based on U.S. Department of Energy (DOE) guidelines (DOE, 1985) and correspond to the committed effective whole body dose equivalent due to the inhalation of radioactive particulates. The $PDCF_{air}$ factors are generically calculated as follows:

$PDCF_{air}$ = (committed effective whole body dose equivalent in rem/pCi) x (10^3 mrem/rem) x (number of hours exposed) x (inhaled air volume/hour)

where the inhaled air volume per hour equals 1.25 cubic meters per hour, or 1250 liters per hour. Furthermore, the bulk tailings concentrations were multiplied by 2.4 to account for the observed higher radionuclide concentrations associated with suspended particulates smaller than 10 microns (PNL, 1980).

Table F.3.13 Occupational dose parameters

Radionuclide	$PDCF_{air}$ (mrem-m^3/pCi)	Concentration in soil[a] (pCi/m^3)
Ra-226	31.3	5.5×10^8
Th-230	1,270	5.5×10^8
U-238	475	4.0×10^7
U-234	515	4.0×10^7
Pb-210	51	5.5×10^8

[a]Assumes a density of 1.6 g/cm^3 and concentrations of 342 pCi/g for Ra-226, Th-230, and Pb-210 and 256 pCi/g for U-238 and U-234.

The calculated 50-year dose commitments to the whole body from Ra-226, Th-230, U-238, U-234, and Pb-210 are shown below. An assumption was made that a remedial action worker would work 8 hours per day, 21 days per month.

- 50-year effective whole body dose equivalent commitment from Ra-226:

  $H = (1.4 \times 10^{-10}) \times (5.5 \times 10^{8}\ pCi/m^{3}) \times (31.3\ mrem\text{-}m^{3}/pCi)$

  $= 2.4$ mrem.

- 50-year effective whole body dose equivalent commitment from Th-230:

  $H = (1.4 \times 10^{-10}) \times (5.5 \times 10^{8}\ pCi/m^{3}) \times (1{,}270\ mrem\text{-}m^{3}/pCi)$

  $= 98$ mrem.

- 50-year effective whole body dose equivalent commitment from U-238:

  $H = (1.4 \times 10^{-10}) \times (4.0 \times 10^{7}\ pCi/m^{3}) \times (475\ mrem\text{-}m^{3}/pCi)$

  $= 2.7$ mrem.

- 50-year effective whole body dose equivalent commitment from U-234:

  $H = (1.4 \times 10^{-10}) \times (4.0 \times 10^{7}\ pCi/m^{3}) \times (515\ mrem\text{-}m^{3}/pCi)$

  $= 2.9$ mrem.

- 50-year effective whole body dose equivalent commitment from Pb-210:

  $H = (1.4 \times 10^{-10}) \times (5.5 \times 10^{8}\ pCi/m^{3}) \times (51\ mrem\text{-}m^{3}/pCi)$

  $= 3.9$ mrem.

- Total 50-year effective whole body dose equivalent commitment:

  $2.4 + 98 + 2.7 + 2.9 + 3.9$

  $= 109.9$ mrem.

Using the cancer risk factor of 120×10^{-6} per rem, the risk from a 50-year dose commitment of 109.9 mrem for the 68 workers is 0.00090 excess health effects.

The total estimated excess health effects to remedial action workers during stabilization in place from radon daughters inhalation, gamma radiation, and airborne radioactive particulates inhalation is 97×10^{-4} excess health effects. This is equivalent to an individual worker risk of contracting a fatal cancer of 0.01 percent.

F.3.2 NO ACTION

General public health effects from radon daughters exposure

For the no action alternative, the radon flux from the bare tailings pile was calculated to be an annual average of 210 pCi/m^2s, assuming no cover exists, or 1,880 Ci/yr from the 70 acres of tailings. A 1.5-foot cover currently exists on the pile; therefore, the excess health effects calculation uses a conservative radon release rate from the tailings. Ignoring the existing cover also compensates for the slight increase in radon flux from contamination in the mill yard and windblown areas which was not considered in this calculation. The downwind radon concentrations were determined using the long-term sector average model as previously applied for the stabilization in place alternative. Table F.3.14 gives the estimated radon concentrations and working levels as a function of distance from the pile edge. The radon concentration on the pile was determined using the same method as in the stabilization in place analysis. The resulting average radon concentration on the pile was calculated to be 6.2 pCi/l.

Equation F.3.1 was applied to determine excess radon daughters health effects to the general public within 6 miles of the tailings due to the no action alternative. Results shown in Table F.3.14 estimate 23×10^{-3} excess health effects for each year of no action, or 0.023 excess radon daughters health effects per year, equivalent to an individual risk of one person out of 570,000 people per year.

General public health effects from gamma exposure

For the no action alternative, a tailings pile average Ra-226 concentration of 342 pCi/g was used. It was assumed that no people enter the tailings site. The predictive model (Yuan et al., 1983) was used to estimate the excess gamma exposure rate caused by the tailings as a function of distance from the pile edge. The model assumes that no cover exists on the tailings pile; therefore, a reduction in gamma exposure rate by the existing 1.5-foot cover on the pile was not accounted for. Table F.3.15 presents the exposure rates as a function of the distance from the pile edge and the general public excess health effects for exposure to gamma rays for the no action alternative. The estimated number of excess health effects due to gamma radiation in the general public living within 0.3 mile of the tailings pile edge is 1.6×10^{-4} per year, or 0.00016 excess health effects per year of no action.

General public health effects from ingestion of contaminated drinking water

The following discussion is an assessment of the radiological risk to individuals living in the vicinity of the Riverton tailings pile who use the confined aquifer as their source for drinking water. Radionuclides from the tailings can seep into the ground water and could migrate downgradient to existing wells in the area.

Table F.3.14 Radon daughters excess health effects to the general public with no remedial action

Distance from pile edge (miles)	Population (persons)	Modeled outdoor radon concentration (pCi/l)	Modeled outdoor WL(r) x 10^{-4}	Calculated WLM(r) x 10^{-4}	Excess health effects x 10^{-4} per year
0.1	18	1.51	5.8	2,020	11
0.2	36	0.79	5.3	1,071	12
0.3	26	0.47	4.7	648	5.1
0.4	7	0.30	4.5	423	9.0
0.5	4	0.22	4.1	315	30
0.75	110	0.14	3.4	210	6.9
1.0	251	0.09	3.0	140	11
1.5	106	0.05	2.4	83	2.7
2.0	3,374	0.04	2.0	63	64
2.5	4,639	0.03	1.8	46	64
3.0	2,516	0.03	1.6	43	32
3.5	414	0.01	1.3	25	3.0
4.0	500	0.01	1.1	24	3.6
5.0	500	0.01	0.9	22	3.3
6.0	500	0.01	0.8	22	3.3
Totals	13,001				230

Table F.3.15 General public excess health effects from gamma exposure with no remedial action

Distance from pile edge (miles)	Population (persons)	Individual hours exposed	Excess gamma exposure rate (microR/hr)	Excess health effects x 10^{-4} per year
0.1	18	6,570	8.6	1.2
0.2	36	6,570	1.2	0.34
0.3	26	6,570	0.2	0.041
Totals	80			1.6

For the no action alternative, the maximum concentrations of radionuclides in samples drawn from test wells in the shallow alluvial aquifer directly beneath the tailings pile were used to calculate health effects. The maximum concentrations were 0.6 pCi/l for Ra-226, 1.2 pCi/l for Th-230, 110 pCi/l for U-238 and U-234, and 140 pCi/l for Pb-210 (see Section C.2.4 of Appendix C, Water). These concentrations are anticipated to be the maximum concentrations found under existing conditions and were used to maximize estimated excess health effects from the ingestion of drinking water under current conditions.

In the calculation, 50-year effective whole body dose equivalent commitments were determined per year of exposure. An F_1 uptake-to-blood factor for U-238 and U-234 of 0.05 (ICRP, 1981) was used. The F_1 factors used for other radionuclides were 0.2 for Ra-226, 0.0002 for Th-230, and 0.2 for Pb-210 (DOE, 1985). The average daily water intake for an individual was assumed to be 1.5 liters per day (Cember, 1983). Dose conversion factors (DCF) in rem per microCi were taken from the DOE guidelines (DOE, 1985) and are summarized in Table F.3.16.

Table F.3.16 Effective committed whole body dose equivalent conversion factors in rem per microCi

Ra-226	Th-230	U-238	U-234	Pb-210
1.1	0.53	0.23	0.26	5.1

Table F.3.17 presents the 50-year dose commitments (DC-50) per year of consumption for each radionuclide as calculated using the following equation:

Equation F.3.8

$$\text{DC-50} = (\text{concentration pCi/l}) \times \frac{1.5 \text{ liters}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}}$$

$$\times \frac{1 \text{ microCi}}{10^6 \text{ pCi}} \times (\text{DCF}) \times \frac{1{,}000 \text{ mrem}}{\text{rem}} = \frac{\text{mrem}}{\text{year}} .$$

Table F.3.17 presents the risk estimates from ingestion of the ground water in terms of whole body effective dose equivalent commitment per year of consumption. The individual risk of excess health effects was determined by multiplying the 50-year dose commitment per year of consumption times the lifetime risk coefficient of 120×10^{-6} health effects per person-rem. The total risk for an exposed individual was 0.51×10^{-4} per year of consumption, or 0.0051 percent. This is 83 percent of the individual risk that was calculated for inhalation of radon daughters by a person within 0.1 mile from the pile under no action conditions.

Table F.3.17 Fifty-year effective committed dose equivalent commitments in mrem per year of consumption of radionuclides in drinking water

Ra-226	Th-230	U-238	U-234	Pb-210	Total
0.361	0.348	13.9	15.7	391	421

It should be noted that conservative assumptions were used in the calculations, and no people would be exposed to the radionuclide concentrations used because dilution with distance from the pile was not taken into account. A more realistic estimate of the excess health effects resulting from the drinking water ingestion pathway could be made by using the concentrations of radionuclides found in downgradient domestic wells.

The maximum concentrations of radionuclides found in downgradient domestic wells in the confined aquifer were 0.7 pCi/l for Ra-226, 1.0 pCi/l for Th-230, 0.001 pCi/l for U-238 and U-234, and 1.8 pCi/l for Pb-210. Using the same procedures as in the previous calculations, the total individual yearly excess health risk from drinking water with these concentrations of radionuclides is 6.9×10^{-7}. This is 1.1 percent of the excess health risk from the inhalation of radon daughters and indicates that the drinking water ingestion pathway has no appreciable impact on the general public.

Remedial action worker health effects from no action

No remedial action workers would be exposed to radon daughters, gamma radiation, or airborne radioactive particulates for the no action alternative.

F.3.3 DISPOSAL AT THE DRY CHEYENNE SITE

General public health effects from radon daughters exposure

Disposal of the tailings and contaminated materials at the Dry Cheyenne site would be expected to take 30 months during which the tailings would be uncovered and disturbed for a maximum of 24 months. All of the radon trapped in the pore spaces of the tailings is assumed to be released when the tailings are handled at the Riverton tailings site. The radon flux of the uncovered tailings at the Dry Cheyenne alternate disposal site, then, is calculated to be 210 pCi/m^2s, using the same methods as in Section F.3.1 for stabilization in place. The application of the radon barrier would occur simultaneously with tailings placement, and the average radon flux at the Dry Cheyenne site during remedial action is therefore assumed to be one-half of the bare tailings flux, or 105 pCi/m^2s.

The average radon flux of 105 pCi/m^2s at the Dry Cheyenne alternate disposal site was used in the long-term sector average model (Turner, 1969) to estimate the maximum downwind radon concentrations and working levels. Table F.3.18 presents radon concentrations and working levels as a function of distance from the pile edge during remedial action. Table F.3.18 also includes the general population distribution and results of the radon daughters excess health effects calculations for the Dry Cheyenne alternative. Since the distance from the Riverton tailings site to the alternate disposal site is only 15 miles, the meteorological data and assumptions for stabilization in place were also used for the Dry Cheyenne alternative.

The population density is significantly lower in the vicinity of the Dry Cheyenne alternate disposal site than the Riverton tailings site. Population data were used within 6 miles of the Dry Cheyenne site for excess health effects calculations. The population as a function of distance from the Dry Cheyenne site is shown in Table F.3.18. Applying Equation F.3.1 and the working level values in Table F.3.18, the excess health effects for the general public within 6 miles of the alternate disposal site during the 24-month tailings disturbance is estimated to be 2.7×10^{-6} which is considered to be negligible.

Table F.3.18 Radon daughters excess health effects to the general public during disposal at the Dry Cheyenne site

Distance from pile edge (miles)	Population (persons)	Modeled outdoor radon concentration (pCi/l)	Modeled outdoor WL(r) x 10^{-4}	Calculated WLM(r) x 10^{-4}	Excess health effects x 10^{-4}
0.1	0	0.68	1.6	1,800	0
0.2	0	0.29	1.5	780	0
0.3	0	0.16	1.4	440	0
0.4	0	0.090	1.3	253	0
0.5	0	0.064	1.2	180	0
0.75	0	0.037	0.99	110	0
1.0	0	0.027	0.79	79	0
1.5	0	0.015	0.64	48	0
2.0	0	0.011	0.55	34	0
2.5	0	0.008	0.48	27	0
3.0	0	0.006	0.41	20	0
4.0	4	0.005	0.30	16	0.018
5.0	0	0.004	0.23	12	0
6.0	4	0.002	0.20	8	0.009
Totals	8				0.027

As with relocation to Gas Hills (Section F.3.4), the general public within 6 miles of the Riverton tailings pile would be exposed to radon daughters during relocation of the tailings. Using the same assumptions as for the Gas Hills alternative and an exposure time of 24 months, the excess health effects for the general public within 6 miles of the tailings pile were estimated to be 210×10^{-4}, or 0.021 excess health effects due to radon daughters inhalation.

General public health effects from gamma exposure

No excess health effects from gamma exposure would occur for the general public in the vicinity of the alternate disposal site because no people live within 0.3 mile of the site. As with the Gas Hills alternative (Section F.3.4), the general public within 0.3 mile of the Riverton tailings pile would be exposed to gamma radiation during relocation of the tailings. Using the same assumptions as for relocation to Gas Hills and an exposure time of 24 months, the excess health effects for the general public within 0.3 mile of the tailings pile were estimated to be 3.2×10^{-4}, or 0.00032 excess health effects due to gamma radiation exposure.

General public health effects from exposure to airborne radioactive particulates

As was done for relocation to Gas Hills (Section F.3.4), the off-site particulates concentrations as a function of distance from the tailings pile were modeled by use of the sector average model. The excess health effects to the general public and the effective committed whole body dose equivalent per person are shown in Table F.3.19. The resulting excess health effects for the Dry Cheyenne alternative would be 16×10^{-4} which is only 10 percent of the total excess health effects from the inhalation of radon daughters. For a person living within 0.1 mile of the site, the total effective committed whole body dose equivalent is 67.7 mrem, equivalent to a one in 120,000 chance of contracting a fatal cancer.

Health effects during remedial action to the maximally exposed individual from the consumption of contaminated food

Disposal of the tailings and contaminated materials at the Dry Cheyenne site would result in a release of 1,700 tons of particulates (Section B.3 of Appendix B, Weather and Air Quality). One-half of these are assumed to be released from the Riverton site. This results in an average on-pile particulates flux during the 2 years of tailings disturbance of 1.48×10^{-2} pCi/m^{2}s for Ra-226 and Th-230 and 1.08×10^{-3} pCi/m^{2}s for U-238.

Health effects to the maximally exposed individual were calculated using the same assumptions and models that were used to estimate food ingestion health effects for the stabilization in place alternative. The resultant concentrations of radionuclides in food are shown in Table F.3.20, and the whole body dose equivalents are shown in Table F.3.21.

Table F.3.19 General public excess health effects from exposure to airborne radioactive particulates during disposal at the Dry Cheyenne site

Distance from pile edge (miles)	Population (persons)	Effective committed whole body dose equivalent (mrem per person)						Excess health effects $\times 10^{-4}$
		Ra-226	Th-230	U-238	U-234	Pb-210	Totals	
0.1	18	1.51	61.2	1.61	1.75	1.55	67.6	1.5
0.2	36	0.757	30.7	0.806	0.874	0.776	33.9	1.5
0.3	26	0.434	17.6	0.463	0.502	0.446	19.5	0.61
0.4	7	0.267	10.8	0.285	0.309	0.274	11.9	0.16
0.5	4	0.192	7.79	0.205	0.222	0.197	8.61	0.04
0.75	110	0.106	4.31	0.113	0.122	0.109	4.76	0.63
1.0	251	0.087	3.53	0.093	0.101	0.089	3.90	1.2
1.5	106	0.040	1.62	0.043	0.046	0.041	1.79	0.23
2.0	3,374	0.023	0.932	0.025	0.027	0.024	1.03	4.2
2.5	4,639	0.015	0.607	0.016	0.017	0.015	0.670	3.7
3.0	2,516	0.011	0.429	0.011	0.012	0.011	0.474	1.4
3.5	414	0.008	0.319	0.008	0.009	0.008	0.352	0.17
4.0	500	0.006	0.247	0.006	0.007	0.006	0.272	0.16
5.0	500	0.004	0.161	0.004	0.004	0.004	0.177	0.11
6.0	500	0.003	0.114	0.003	0.003	0.003	0.126	0.08
Totals	13,001							16

Table F.3.20 Concentrations of radionuclides on and in vegetables, meat, and milk for disposal at the Dry Cheyenne site

	C_{vi} above-ground vegetables (pCi/kg)	C_{vi} below-ground vegetables (pCi/kg)	C_{pgi} grass (pCi/kg)	C_{hvi} hay (pCi/kg)	C_{bi} meat (pCi/kg)	C_{bi} milk (pCi/l)
Ra-226	1076.0	109.0	2420	1140.0	45.50	52.600
Th-230	1060.0	110.0	2410	1060.0	17.40	0.434
U-238	77.7	7.9	176	77.7	2.16	3.870
U-234	77.7	7.9	176	77.7	2.16	3.870

Table F.3.21 Whole body dose equivalents in mrem per year for disposal at the Dry Cheyenne site

	Above-ground vegetables	Below-ground vegetables	Meat	Milk
Ra-226	23.9	3.99	3.90	7.53
Tn-230	11.3	1.96	0.716	0.028
U-238	0.036	0.006	0.004	0.012
U-234	0.041	0.007	0.005	0.014

The increased particulates flux during the Dry Cheyenne alternative yields a total dose equivalent to the maximally exposed individual of 53 mrem per year or 106 mrem during the 2-year pile disturbance. The excess health risk during the remedial action is 1.3×10^{-5} or a one in 77,000 chance of contracting a fatal cancer. This is 25 percent of the risk of excess health effects for individuals in the general public living within 0.1 mile of the tailings pile from radon daughters inhalation and gamma exposure. However, this health risk is judged to be negligible because the acreage of contaminated agricultural land in the vicinity of the tailings pile (29 acres) is not large enough to produce sufficient food for human consumption to have an appreciable effect on the Riverton population.

Remedial action worker health effects from radon daughters exposure

For disposal of the tailings and contaminated materials at the Dry Cheyenne site, remedial action was estimated to take 30 months using an average of 81 remedial action workers for 21 workdays per month. It was assumed that each worker would spend his entire day exposed to a radon concentration of 6.2 pCi/l, as calculated in Section F.3.1, for presence on the existing pile during tailings disturbance. The radon daughters percent equilibrium was conservatively assumed to be 20 percent. Table F.3.22 shows input data and results from a calculation similar to Equation F.3.1 to estimate an upper limit for remedial action worker excess health effects from radon daughters exposure during remedial action for the Dry Cheyenne alternative.

Table F.3.22 Total excess health effects to remedial action workers during disposal at the Dry Cheyenne site

Average number of workers	Hours per worker	Radon daughters health effects $\times 10^{-4}$	Gamma exposure health effects $\times 10^{-4}$	Radioactive particulates health effects $\times 10^{-4}$	Total excess health effects $\times 10^{-4}$
81	5,040	90	42	19	151

Remedial action worker health effects from gamma exposure

Table F.3.22 also shows an estimate for remedial action worker excess health effects from external gamma radiation exposure, based on an average exposure rate of 85 microR/hr as calculated in Section F.3.1. The maximum external gamma radiation exposure during tailings relocation that an individual worker could be expected to receive is 0.43 rem for the Dry Cheyenne alternative.

Remedial action worker health effects from exposure to airborne radioactive particulates

For disposal at the Dry Cheyenne site, 1,700 tons of particulates (Section B.3 of Appendix B, Weather and Air Quality) would be released over the 24 months of tailings disturbance. It was assumed that 850 tons would be released at each site. Health effects to the remedial action workers were calculated using the model (NRC, 1981) as outlined in Section F.3.1. This resulted in a total lung dose from Ra-226, Th-230, U-238 and U-234, and Pb-210 of 199 mrem and an associated risk of 2.4×10^{-5} excess health effects per worker.

Table F.3.22 shows the total estimated excess health effects to remedial action workers caused by radon daughters inhalation, gamma radiation, and airborne radioactive particulates inhalation. The maximum excess health effects for the Dry Cheyenne alternative were calculated to be 151×10^{-4} excess health effects for remedial action workers. This is equivalent to an individual worker maximum risk of contracting a fatal cancer of 0.019 percent, or one person out of 5,400 people.

Health effects from transportation during tailings relocation

During implementation of the Dry Cheyenne alternative, there would be a potential for increased gamma radiation exposure to the general public and to remedial action workers as a result of transportation of the tailings and contaminated materials to the alternate disposal site.

The exposure rate for people living along a transportation route during normal transportation conditions was determined according to the following equation (AEC, 1972; Dames & Moore, 1975; NRC, 1981):

Equation F.3.9

$$D = \frac{2KP_d}{V} \int_d^{\infty} \frac{e^{-\mu r} B(r)dr}{r\sqrt{r^2 - d^2}}$$

where

D = collective dose equivalent (person-microrem per truck-mile).

K = dose rate factor (780 microR/hr).

P_d = population density (people per square mile).

V = truck speed (10 miles per hour).

μ = attenuation coefficient (0.0035 per meter).

r = distance from source.

B(r) = buildup factor.

d = minimum distance from source.

The calculation conservatively assumed a dose rate of 855 microR/hr at 3 feet from the loaded truck as calculated in Section F.3.1. The population density along the transportation route is given in Table F.3.23. Table F.3.23 presents general public collective dose equivalent results in person-microrem per loaded truck-mile and the estimated excess health effects due to gamma radiation. A maximum of 55,900 loaded truck trips was estimated based on an average of 18 cubic yards per trip. Results in Table F.3.23 show that the gamma health effects to the general public during relocation of the tailings are negligible, primarily because few people live along the proposed transportation route.

Table F.3.23 General public excess health effects from gamma exposure during tailings transportation to the Dry Cheyenne site

Population density (people per square mile)	Collective dose (person-microrem per loaded truck-mile)	Equivalent loaded truck-miles	Excess health effects $\times 10^{-4}$
10	0.002	8.4×10^5	0.0002

A transportation accident involving an overturned truck and spillage of tailings onto the roadbed is possible, but the magnitude of the radiation exposure to the general public and subsequent health effects associated with such an accident would be minimal (DOE, 1984). The cleanup of the roadbed would be done promptly, and the exposure of the cleanup crew would be small compared to the estimated 30-month exposure of remedial action workers in the Dry Cheyenne alternative. This exposure pathway is therefore not addressed further in this document.

The only spill that could not be cleaned up would be one that occurs as a truck crosses a river or flowing watercourse. Although the probability of such an accident would be very low, the Dry Cheyenne alternative would have the possibility of this occurring because the transportation route would cross the Little Wind River. Most of the tailings could not be recovered and transport by suspension is assumed to be the mechanism of dispersion because the tailings are largely insoluble.

The main assumption is that the tailings would become part of the wash load of the river. Once in the river, the tailings bolus (a mass of material moving downstream) would be subject to longitudinal dispersion which would reduce the concentration as it moves downstream.

Assuming that the river cross-section and velocity do not change in the distance of interest, the downstream concentrations can be calculated by use of the one-dimensional convective diffusion equation and the proper boundary conditions. The convective diffusion equation used is (Daily and Harleman, 1966):

Equation F.3.10

$$\frac{2c(x,t)}{2t} + u\,\frac{2c(x,t)}{2x} = E_T\,\frac{2^2\,c(x,t)}{2x^2}$$

where

$c(x,t)$ = concentration of Ra-226 in the river (pCi/l) at distance x and time t.

x = distance from the point of the spill (m).

t = time elapsed since the spill (s).

u = mean velocity of the river (m/s).

E_T = longitudinal dispersion coefficient (m^2/s).

The proper boundary conditions for the accident are:

$$c(x, 0) = \frac{M}{A}\ (x), \text{ and}$$

$$C(\pm\infty, t) = 0$$

where

M = total activity of Ra-226 in the spilled material (pCi).

A = cross-sectional area of flow (m^2).

(x) = Dirac delta function.

The solution can be given as:

$$c(x,t) = \frac{M \exp^{-(x-ut)^2/4E_T t}}{A\sqrt{4\pi E_T t}}$$

which represents a Gaussian distribution around the maximum concentration at x = ut. This maximum concentration is given by:

$$c(x,t) = \frac{M}{A\sqrt{4\pi E_T t}}$$

The longitudinal dispersion coefficient may be calculated from the equation (Taylor, 1954):

<u>Equation F.3.11</u>

$$E_T = 10.1\ (aV^*)$$

where

a = the average half-width of the river (m).

V^* = the friction velocity (m/s).

The friction velocity is equal to:

$$V^* = (U_o - u)/f(z)$$

where

U_o = the maximum velocity at the center of the river (m/s).

u = the mean velocity of the river (m/s).

$f(z)$ = a mathematical function which applies to all straight line segments with circular cross-section provided that the flow is fully turbulent.

The mean flow of the Little Wind River (measured over 41 years) is 589 cubic feet per second or 16.7 cubic meters per second (Section C.1.1 of Appendix C, Water). Assuming an average depth of 5 feet and width of 30 feet yields a cross-sectional area of 14.0 square meters. Dividing the mean flow by the cross-sectional area yields a mean velocity of the river of 1 meter per second. The maximum velocity of the river, U_o, is equal to twice the mean velocity, or 2 meters per second.

The friction velocity then becomes:

$$V^* = \frac{1.0}{f(z)}$$

The value for f(z), 1.62, is taken from the tables in Taylor (1954). Substituting this value in the equation above yields a value of 0.62 meter per second for V^*. Substituting V^* and a (15 feet) into the equation for E_T yields a value for the longitudinal dispersion coefficient.

Eighteen-cubic-yard capacity trucks would be used to transport the tailings. Assuming that the Ra-226 concentration in the truck is the same as the tailings pile average concentration, the total activity spilled into the river is 7.5×10^9 pCi.

The parameters yield a maximum Ra-226 concentration of 8.9 pCi/l in the Little Wind River at 10 meters from the spill. At 100 and 1,000 meters, the Ra-226 concentrations would be 2,800 and 890 pCi/l, respectively. From Appendix B, Table B-11 of Title 10, Code of Federal Regulations, Part 20, the maximum permissible concentration (MPC) for Ra-226 in an unrestricted area is 30 pCi/l in a soluble form and 30,000 pCi/l in an insoluble form (NRC, 1980b). As the Ra-226 is in an insoluble form, the concentrations would be well below the MPC and would decrease further downstream. The Th-230 and U-238 concentrations were not calculated for the transportation accident because their MPCs are higher than that for Ra-226.

The maximum dose equivalent for a truck driver would be 8 microrems per loaded truck-mile, based upon 10 miles per hour and 80 microR/hr which accounts for the shielding effect of the truck and the distance from the cab to the enclosed tailings. This exposure is accounted for in the remedial action worker excess health effects calculation. There would be no radon daughters exposures to truck drivers or to the general public along the transportation route since all radon is assumed to be released from the tailings pore spaces during handling at the existing tailings site.

F.3.4 RELOCATION TO GAS HILLS

Gas Hills is an area 45 to 60 road miles east of the Riverton site that contains several active uranium mill tailings sites in the Gas Hils Uranium Mining District. The specific active site for disposal of the inactive Riverton tailings and contaminated materials would be selected by competitive bidding from owners and operators of active tailings sites in the Gas Hills District. In this section, the excess health effects estimates for relocation to Gas Hills are for the the remedial action at the Riverton site and, when appropriate, along the transportation route to Gas Hills (i.e., health effects from transportation during tailings relocation). The remedial action at the selected active tailings site in Gas Hills would be consistent with the U.S. Environmental Protection Agency (EPA) standards for active sites (Title 40, Code of Federal Regulations, Part 192, Subparts D and E) and would be performed in accordance with a remedial action plan prepared by the owner and operator of the selected active site and to be approved by the NRC. The generic impacts of the EPA standards were addressed in an environmental impact statement published by the EPA (EPA, 1983). The health effects at the selected active site would be assessed by the NRC for its compliance with the National Environmental Policy Act, Public Law 91-190 (Pettingill, 1987).

General public health effects from radon daughters exposure

To develop the radon source term for relocation to Gas Hills, the radon flux of 210 pCi/m^2s as calculated for stabilization in place (Section F.3.1) was used. Assuming that the tailings excavation proceeds uniformly, the 70-acre tailings pile would be reduced linearly to zero during the 28 months of relocation. Since the entire 1.5×10^6 cubic yards of tailings would be relocated, 88 Ci of radon would instantaneously be released from the tailings pore spaces.

The total radon released can be described by the following equation:

$$\left[\frac{Ci}{1 \times 10^{12} pCi} \times \frac{210\ pCi}{m^2 s} \times \frac{4{,}048\ m^2}{acre} \times \frac{2.68 \times 10^6\ s}{month} \int_0^{28} \left(70\ acres - \frac{70\ acres}{28\ months}\right) t\ dt\right] + 88\ Ci = 2{,}321\ Ci.$$

This results in a yearly average radon release rate of 995 Ci.

The downwind radon concentrations were determined using the long-term sector average model as previously applied for the stabilization in place alternative. Table F.3.24 gives the estimated radon concentrations and working levels as a function of distance from the pile edge. The radon concentration on the pile was determined using the same method as for stabilization in place. The resulting average radon concentration on the pile was calculated to be 6.2 pCi/l.

Table F.3.24 Radon daughters excess health effects to the general public during relocation to Gas Hills

Distance from pile edge (miles)	Population (persons)	Modeled outdoor radon concentration (pCi/l)	Modeled outdoor WL(r) $\times 10^{-4}$	Calculated WLM(r) $\times 10^{-4}$	Excess health effects $\times 10^{-4}$
0.1	18	0.84	3.0	2,570	14
0.2	36	0.43	2.7	1,320	14
0.3	26	0.26	2.5	826	6.4
0.4	7	0.17	2.4	541	1.1
0.5	4	0.13	2.2	427	0.51
0.75	110	0.08	1.8	264	8.7
1.0	251	0.05	1.6	182	14
1.5	106	0.03	1.3	114	3.6
2.0	3,374	0.02	1.1	79	80
2.5	4,639	0.01	0.89	45	63
3.0	2,516	0.01	0.79	43	33
3.5	415	0.01	0.63	41	5.1
4.0	500	0.005	0.58	24	3.7
5.0	500	0.005	0.47	22	3.4
6.0	500	0.005	0.37	21	3.1
Totals	13,001				250

Equation F.3.1 was applied to determine radon daughters excess health effects to the general public within 6 miles of the tailings pile due to the Gas Hills alternative. The results shown in Table F.3.24 estimate 250 x 10^{-4} excess health effects, equivalent to an individual risk of one person out of 520,000 persons per year.

General public health effects from gamma exposure

For the Gas Hills alternative, a tailings pile average Ra-226 concentration of 342 pCi/g was used. It was assumed that no people enter the tailings site and the predictive model (Yuan et al., 1983) was used to estimate the excess gamma exposure rate caused by the tailings as a function of distance from the pile edge. The model assumes that no cover exists on the tailings pile. Table F.3.25 presents the exposure rates as a function of the distance from the pile edge and the general public excess health effects for exposure to gamma rays for the Gas Hills alternative. The estimated excess health effects due to gamma radiation in the general public living within 0.3 mile of the tailings pile edge is 3.7 x 10^{-4}, or 0.00037 excess health effects for relocation to Gas Hills.

Table F.3.25 General public excess health effects from gamma exposure during relocation to Gas Hills

Distance from pile edge (miles)	Population (persons)	Individual hours exposed	Excess gamma exposure rate (microR/hr)	Excess health effects x 10^{-4}
0.1	18	15,330	8.6	2.8
0.2	36	15,330	1.2	0.79
0.3	26	15,330	0.2	0.096
Totals	80			3.7

General public health effects from exposure to airborne radioactive particulates

To determine the dispersion of airborne radioactive particulates concentrations to off-site locations, the long-term sector average model (Turner, 1969) was modified to include the removal of particulates due to ground deposition with distance. Since the sector average model is valid for gases as well as particulates less than 20 microns in size, the modification consisted of replacing the fixed point source term used for off-site radon dispersion by a distance dependent source term which takes into account surface deposition of particulates (AEC, 1968). The integral equation for the reduction in source term due to particulates deposition for an average deposition velocity V_d (m/s) was incorporated into the dispersion computer code to provide calculated airborne radioactive particulates concentrations for various radionuclides as a function of distance from the source. A representative deposition velocity of 0.01 m/s was used for particulates less than 10 microns in size.

The airborne mass loading due to 28 months of tailings relocation for particulates less than 10 microns in size is determined by multiplying the factor E (suspension rate of transportable particulates less than 30 microns in size) by 0.3, the fraction of particulates less than 10 microns in size, to provide a particulate mass flux term, F_m, of 1.35×10^{-6} g/m^2s.

The average concentration of Ra-226, Th-230, and Pb-210 in the tailings is 342 pCi/g. The average U-238 and U-234 concentrations are 24 pCi/g. Applying a radionuclide concentration factor of 2.4 for suspended airborne particulates (PNL, 1980) yields particulates fluxes, FA, of 1.10×10^{-3} pCi/m^2s for Ra-226, Th-230, and Pb-210 and 7.74×10^{-5} pCi/m^2s for U-238 and U-234.

Calculated results for the modeled dispersion and deposition particulates concentrations for these radionuclides are given in Table F.3.26 as a function of distance (miles) from the source boundary. The 50-year effective committed whole body dose equivalent for a particular radionuclide is generically calculated as follows:

H = (inhaled air volume per hour) x (particulates activity per unit volume) x (number of hours exposed) x (effective committed whole body dose equivalent conversion factor).

For the general public exposed for 28 months in the vicinity of the Riverton tailings site, the input parameters are:

- An inhaled air volume per hour of 625 liters per hour.
- The number of hours exposed equals 9,855 (28 months x 75- percent residency x 730 hours per month).
- Effective committed whole body dose equivalent conversion factors of 7.9, 320, 120, 130, and 8.1 rem per microCi for Ra-226, Th-230, U-238, U-234, and Pb-210, respectively (DOE, 1985).

As an example, an individual residing 1 mile from the source edge during the 28-month tailings relocation period would be exposed to a Th-230 particulates concentration of 5.7×10^{-10} $microCi/m^3$ which would produce a committed dose of 0.5 mrem.

The number of excess health effects for the general public living at a given distance from the source edge is the sum of the individual committed doses multiplied by the whole body risk factor of 120×10^{-6} excess health effects per person-rem. The excess health effects as a function of distance from the source edge are given in Table F.3.26. For the population of 13,001 living within 6 miles of the Riverton site, the estimated number of excess health effects is 0.0063 during the 28 months required to relocate the tailings and contaminated materials to Gas Hills.

Table F.3.26 General public excess health effects from exposure to airborne radioactive particulates during relocation to Gas Hills

Distance from pile edge (miles)	Population (persons)	Effective committed whole body dose equivalent (mrem per person)						Excess health effects x 10^{-4}
		Ra-226	Th-230	U-238	U-234	Pb-210	Totals	
0.1	18	0.622	25.2	0.638	0.663	0.721	27.8	0.60
0.2	36	0.312	12.6	0.320	0.332	0.360	13.9	0.60
0.3	26	0.179	7.25	0.184	0.191	0.207	8.01	0.25
0.4	7	0.110	4.47	0.113	0.117	0.127	4.94	0.04
0.5	4	0.079	3.21	0.081	0.084	0.091	3.55	0.02
0.75	110	0.044	1.77	0.045	0.047	0.050	1.96	0.26
1.0	251	0.036	1.45	0.037	0.038	0.042	1.60	0.48
1.5	106	0.016	0.667	0.017	0.018	0.019	0.737	0.09
2.0	3,374	0.009	0.384	0.010	0.010	0.010	0.423	1.7
2.5	4,639	0.006	0.250	0.006	0.007	0.007	0.276	1.5
3.0	2,516	0.005	0.177	0.005	0.005	0.005	0.197	0.59
3.5	414	0.003	0.131	0.003	0.003	0.004	0.144	0.07
4.0	500	0.002	0.102	0.002	0.002	0.003	0.111	0.07
5.0	500	0.002	0.066	0.002	0.002	0.002	0.074	0.04
6.0	500	0.001	0.047	0.001	0.001	0.001	0.051	0.03
Totals	13,001							6.3

For a person living within 0.1 mile of the Riverton site, the total effective committed whole body dose equivalent is 27.9 mrem, equivalent to a one in 300,000 chance of contracting a fatal cancer.

Health effects during remedial action to the maximally exposed individual from the consumption of contaminated food

Relocation of the tailings and contaminated materials to Gas Hills would result in 44 percent of the particulates released during the Dry Cheyenne alternative. The health effects to the maximally exposed individual would therefore be 44 percent of those estimated for the Dry Cheyenne alternative (23 mrem per year or 54 mrem during the 28-month pile disturbance). The excess health risk during the remedial action is 6.5×10^{-6} or a one in 154,000 chance of contracting a fatal cancer.

Remedial action worker health effects from radon daughters exposure

For relocation to Gas Hills, remedial action was estimated to take a total of 31 months using an average of 49 remedial action workers for 21 workdays per month. It was assumed that each worker would spend his entire day exposed to a radon concentration of 6.2 pCi/l (as calculated in Section F.3.1) for presence on the existing pile during tailings disturbance. The radon daughters percent equilibrium was conservatively assumed to be 20 percent. Table F.3.27 shows input data and results from a calculation similar to Equation F.3.1 to estimate an upper limit for remedial action worker excess health effects during the Gas Hills alternative.

Table F.3.27 Total excess health effects to remedial action workers during relocation to Gas Hills

Average number of workers	Hours per worker	Radon daughters health effects $\times 10^{-4}$	Gamma exposure health effects $\times 10^{-4}$	Radioactive particulates health effects $\times 10^{-4}$	Total excess health effects $\times 10^{-4}$
49	5,208	56	26	4.7	87

Remedial action worker health effects from gamma exposure

Table F.3.27 also shows an estimate for remedial action worker excess health effects from external gamma radiation exposure, based on an average exposure rate of 85 microR/h as calculated in Section F.3.1. The maximum external gamma radiation exposure during tailings relocation that an individual worker could be expected to receive is 0.44 rem for the Gas Hills alternative.

Remedial action worker exposures to airborne radioactive particulates

For relocation of the tailings to Gas Hills, 380 tons of particulates (Section B.3 of Appendix B, Weather and Air Quality) would be released at the Riverton site over the 28 months of tailings disturbance. Excess health effects to the remedial action workers were calculated using the model (NRC, 1981) as outlined in Section F.3.1. This resulted in an effective whole body dose equivalent commitment of 80.3 mrem from Ra-226, Th-230, U-238, U-234, and Pb-210 and an associated risk of 9.6 x 10^{-6} excess health effects per worker.

Table F.3.27 shows the total estimated excess health effects to remedial action workers caused by radon daughters inhalation, gamma radiation, and airborne radioactive particulates inhalation. The maximum excess health effects for the Gas Hills alternative were calculated to be 87 x 10^{-4} excess health effects for remedial action workers. This is equivalent to an individual worker maximum risk of contracting a fatal cancer of 0.018 percent, or one person out of 5,600 people.

Health effects from transportation during tailings relocation

As shown for the Dry Cheyenne alternative, the general public excess health effects from gamma exposure along the transportation route would be negligible. The gamma exposures to truck drivers are accounted for in the remedial action worker excess health effects calculation. The relative excess health effects during remedial action for the action alternatives are presented in Table F.3.28.

F.3.5 EXPOSURES AFTER REMEDIAL ACTION

The only radiation exposure pathway of significance after remedial action would be that due to inhalation of radon daughters from the stabilized tailings pile. Following remedial action, there would be essentially no gamma radiation exposure, and the general public excess gamma health effects are considered to be zero for all of the remedial action alternatives.

Independent of which alternative was chosen, the EPA standard for the final stabilized tailings pile established an upper limit for radon flux of 20 pCi/m^2s or an upper limit for the radon concentration at the pile edge of 0.5 pCi/l above background. Table F.3.29 gives maximum radon and radon daughters concentrations downwind and calculated increases in excess health effects for stabilization in place following remedial action. The values are based upon the radon flux rate of 20 pCi/m^2s and a final pile surface area of 69 acres. Table F.3.30 provides similar data for disposal at the Dry Cheyenne site, assuming a final pile surface area of 40 acres. The excess health effects to the general public within 6 miles of the tailings site following stabilization in place were calculated to be 20 x 10^{-4} per year, which is a factor of 12 lower than the excess health effects estimate for the no action alternative.

Table F.3.28 Summary of excess health effects from each action alternative during remedial action

Remedial action alternative	General public radon daughters health effects x 10^{-4}	General public gamma health effects x 10^{-4}	General public transportation gamma health effects x 10^{-4}	General public radioactive particulates health effects x 10^{-4}	Remedial action worker radon daughters health effects x 10^{-4}	Remedial action worker gamma health effects x 10^{-4}	Remedial action worker radioactive particulates health effects x 10^{-4}	Total excess health effects x 10^{-4}
Stabilization in place	320	2.4	0.00	8.6	56	26.0	7.9	400
Disposal at Dry Cheyenne site	210	3.2	0.0002	16	94	44	19	400
Relocation to Gas Hills	250	3.7	0.0002	6.3	56	26	4.7	300

Table F.3.29 Radon daughters excess health effects to the general public after stabilization in place

Distance from pile edge (miles)	Population (persons)	Modeled outdoor radon concentration (pCi/l)	Modeled outdoor WL(r) x 10^{-4}	Calculated annual WLM(r) x 10^{-4}	Excess health effects x 10^{-4} per year
0.1	18	0.074	0.56	99	0.54
0.2	36	0.048	0.50	65	0.62
0.3	26	0.034	0.45	47	0.36
0.4	7	0.025	0.41	35	0.06
0.5	4	0.020	0.38	28	0.03
0.75	110	0.012	0.31	17	0.54
1.0	251	0.009	0.26	13	0.99
1.5	106	0.005	0.21	8	0.24
2.0	3,374	0.004	0.18	6	6.06
2.5	4,639	0.003	0.16	5	6.96
3.0	2,516	0.002	0.13	3	2.28
3.5	414	0.002	0.11	3	0.36
4.0	500	0.001	0.10	2	0.30
5.0	500	0.001	0.08	2	0.30
6.0	500	0.001	0.06	2	0.30
Totals	13,001				20

Table F.3.30 Radon daughters excess health effects to the general public after disposal at the Dry Cheyenne site

Distance from pile edge (miles)	Population (persons)	Modeled outdoor radon concentration (pCi/l)	Modeled outdoor WL(r) $\times 10^{-4}$	Calculated annual WLM(r) $\times 10^{-4}$	Excess health effects $\times 10^{-4}$ per year
0.1	0	0.044	0.42	59	0
0.2	0	0.028	0.35	38	0
0.3	0	0.020	0.30	28	0
0.4	0	0.015	0.26	21	0
0.5	0	0.012	0.23	17	0
0.75	0	0.008	0.17	11	0
1.0	0	0.005	0.15	7	0
1.5	0	0.003	0.12	5	0
2.0	0	0.002	0.10	3	0
2.5	0	0.002	0.09	3	0
3.0	0	0.001	0.08	1.8	0
3.5	0	0.001	0.07	1.7	0
4.0	4	0.001	0.06	1.7	0.0021
5.0	0	0.001	0.05	1.6	0
6.0	4	0.001	0.04	1.5	0.0018
Totals	8				0.0039

Excess health effects after remedial action were estimated for the Dry Cheyenne alternative in the same way as for stabilization in place, based upon the population in the vicinity of the disposal site. The excess health effects for the general public in the vicinity of the Dry Cheyenne site after remedial action were calculated to be 3.9 x 10^{-7} per year. With the Dry Cheyenne and Gas Hills relocation alternatives, there would be no general public excess health effects near the Riverton site after remedial action.

Table F.3.31 is a summary table presenting comparative estimated excess health effects after remedial action for the action alternatives and for no action in units of excess health effects x 10^{-4} per year, assuming that the population distributions remain constant. Following remedial action, the general public radon daughters excess health effects vary greatly between stabilization in place and the Dry Cheyenne alternative, because the Dry Cheyenne alternate disposal site is far removed from the city of Riverton and is in a sparsely populated area.

Table F.3.31 Summary of excess health effects after each remedial action alternative and for no action[a]

Remedial action alternative	General public radon daughters health effects x 10^{-4} per year	General public gamma health effects x 10^{-4} per year
Stabilization in place	20	0.0
No action	230	1.6
Disposal at Dry Cheyenne site	0.0039	0.0

[a]Relocation to Gas Hills is not included because: (1) there would be no excess health effects to the general public near the Riverton site from exposure to radon daughters and gamma exposure after remedial action, and (2) excess health effects to the general public at Gas Hills after remedial action were not considered in this analysis.

F.3.6 VICINITY PROPERTIES

Remedial action at vicinity properties

The vicinity property cleanup activities would consist of the following:

- o Remove contaminated materials from an estimated 25 properties located in the vicinity of the Riverton tailings site.
- o Transfer the contaminated materials from these vicinity properties to the Riverton site for disposal.
- o Restore the vicinity properties.

Prior to remedial action at each vicinity property, radiological measurements would be necessary to delineate the existing conditions and to make final determinations on each property's status for inclusion in the UMTRA Project.

Radiological impacts for the remedial action

The work called for in the remedial action would be similar to ordinary construction work and would consist of soil removal, decontamination of surfaces, and possibly demolition and replacement of some sidewalks and other structures. These activities might cause a small, temporary increase in radioactivity levels by raising dust and bringing contaminated materials to the surface.

The storage of contaminated materials from the vicinity properties at the Riverton site would not appreciably increase the impacts of radiation already being emitted from the tailings site. The radioactivity per unit volume of the contaminated materials from the vicinity properties would, in most cases, be lower than that of the tailings pile.

Conservative estimates of excess radiation doses and estimated excess health effects per person per year of exposure during remedial action for residents and for cleanup workers are presented in Table F.3.32. In 1 year, each member of the local population living on a vicinity property undergoing cleanup would have received, on the average, a total excess dose equivalent of 0.94 working level-month and 0.45 rem as outlined in Table F.3.32. These dose estimates are conservative because they assume that members of the local public would stay on the property 24 hours per day. This would result in excess health effects of 0.00028 per person per year of exposure due to inhalation of radon daughters and 0.000054 per person per year of exposure to external gamma radiation. If an average of four people reside at each of the 25 properties for 24 hours per day, the estimated total excess health effects for the general public would therefore be 0.033 excess effects per year of exposure. The vicinity property cleanup is estimated to take 24 months, so the total general public excess health effects during remedial action would be 0.066 excess effects. This is based upon the conservative assumption that all residents would be exposed to the estimated excess radiation doses for the entire 24-month cleanup period.

The cleanup workers would be exposed to the same estimated radiation levels as the local public for a working year of 2,000 hours. Thus, in 1 working year, each worker would have experienced a total excess dose equivalent of 0.21 working level-month and 0.10 rem. This

Table F.3.32 Estimated excess radiation doses and excess health effects per person per year of exposure at vicinity properties

	During remedial action	
	Residents	Remedial action workers
Radon daughters product concentration above background (WL)	0.018	0.018
Exposure to radon daughters (hours per year)	8,760	2,000
Exposure to radon daughters (WLM)	0.94	0.21
Chance of an excess case of lung cancer per person per year of exposure to radon daughters	0.00028	0.000063
External gamma dose rate above background (microR/hr)	50	50
Exposure to gamma radiation (hours per year)	8,760	2,000
Exposure to gamma radiation (rem per person per year)	0.45	0.10
Chance of an excess case of cancer per person per year of exposure to gamma radiation	0.000054	0.000012
Total chance of an excess health effect per person per year of exposure	0.00033	0.000075
Total excess health effects per year of exposure	0.033	0.00030

would result in excess health effects of 0.000063 per person per year of exposure to inhalation of radon daughters and 0.000012 per person per year of exposure to external gamma radiation. The vicinity property cleanup is estimated to take 24 months with a work force of four remedial action workers. The estimated number of total excess health effects would therefore be 0.00060 excess effects.

The driver of a truck hauling contaminated materials would receive a much smaller dose than 0.10 rem. Because contaminated materials from vicinity properties consist of tailings interspersed with clean soil, the dose rate 1 meter from a truckload of the materials is less than that for a load of pure tailings, or 0.00002 rem per hour, and the driver would receive less than 3 microrem during a 4-mile trip (DOE, 1982).

The vicinity property cleanup activities would reduce the average radiation exposure at each property to meet the EPA standards (Title 40, Code of Federal Regulations, Part 192, Subparts B and C). The final EPA standards do not allow indoor gamma radiation levels to exceed the background level by more than 20 microR per hour. This would allow gamma radiation doses at each property to be 130 mrem per year, assuming a 75-percent rate of occupancy at the property. The EPA standard for indoor radon decay products is 0.03 WL for radon daughters concentration. To the extent practicable, the limit of radon daughters in a building shall not be allowed to exceed 0.02 WL. The EPA estimated that each increase of 0.02 WL inside a house increases the risk of lung cancer to each of its inhabitants by approximately 0.5 to one in 100 for an assumed lifetime of residency.

REFERENCES FOR APPENDIX F

AEC (U.S. Atomic Energy Commission), 1972. Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants, WASH-1238, Washington, D.C.

AEC (U.S. Atomic Energy Commission), 1968. Meteorology and Atomic Energy, 1968, Silver Springs, Maryland.

BFEC (Bendix Field Engineering Corporation), 1983. "Radium-226 Analysis for Riverton Site Tailings Samples," prepared by BFEC, Grand Junction, Colorado, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

BRH (Bureau of Radiological Health), 1970. Radiological Health Handbook, PHS Publication No. 2016, Department of Health, Education, and Welfare, Washington, D.C.

Borak, T. B., and W. C. Inkret, 1983. "Measurement of Radon Gas Concentrations and Potential Alpha Energy of Radon Daughters near a Uranium Mill Tailings Pile," unpublished data prepared for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Cember, H., 1983. Introduction to Health Physics, Pergamon Press, New York, New York.

Cohen, B. L., 1981. "Proposals on Use of the BEIR-III Report in Environmental Assessments," Health Physics, Vol. 41.

DOE (U.S. Department of Energy), 1985. Committed Dose Equivalent Tables for U.S. Department of Energy Population Dose Calculations, Office of Operational Safety, Washington, D.C.

DOE (U.S. Department of Energy), 1984. Final Environmental Impact Statement, Remedial Actions at the Former Vitro Chemical Company Site, South Salt Lake, Salt Lake County, Utah, DOE/EIS-0099-F, Washington, D.C.

DOE (U.S. Department of Energy), 1982. Environmental Assessment: Preliminary Cleanup Activities at Vicinity Properties Near Canonsburg, Pennsylvania, UMTRA-DOE/ALO-125, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Daily, J.L., and D.R. Harleman, 1966. Fluid Dynamics, Addison-Wesley Publishing Company, Inc., Reading, Massachusetts.

Dames & Moore, 1975. Study of the Shipment of Spent Fuel from the Shoreham Nuclear Power Station to the Reprocessing Plant, prepared for Long Island Lighting Co., Inc., New York, New York.

Doyle, Jim, 1984. Personal communication with Jim Doyle, St. Stephen's Mission School, St. Stephen's, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated June 5, 1984.

EPA (U.S. Environmental Protection Agency), 1983. Final Environmental Impact Statement for Standards for the Control of Byproduct Materials from Uranium Ore Processing (40 CFR 192), EPA 520/1-83-008-1 and -2, Washington, D.C.

Evans et al. (R.D. Evans, J. H. Harley, W. Jacobi, A. S. McLean, W. A. Mills, and C. G. Stewart), 1981. "Estimate of Risk from Environmental Exposure to Radon-222 and Its Decay Products", Nature, Volume 290, No. 5802.

Evans, R. D., 1980. "Engineers' Guide to the Elementary Behavior of Radon Daughters," Health Physics, Vol. 38, No. 6.

FBDU (Ford, Bacon & Davis Utah Inc.), 1981. Engineering Assessment of Inactive Uranium Mill Tailings, Riverton Site, Riverton, Wyoming, DOE/UMT-0106, FBDU-360-19, UC 70, prepared by FBDU, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

ICRP (International Commission of Radiological Protection), 1981. Limits for Intake of Radionuclides for Workers, ICRP Publication 30, Pergamon Press, London, England.

ICRP (International Commission on Radiological Protection), 1977. Recommendations of the International Commission on Radiological Protection, ICRP Publication 26, Pergamon Press, Elmsford, New York.

Johnson, Don, 1984. Personal communication with Don Johnson, St. Stephen's Mission, St. Stephen's, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated June 5, 1984.

Lederer et al. (C.M. Lederer, J. M. Hollander, and I. Perlman), 1967. Table of Isotopes, 6th Edition, John Wiley and Sons, Inc., New York, New York.

McFarland, W.L., 1984. Personal communication with W.L. McFarland, Western Nuclear, Inc., Riverton, Wyoming, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated May 22, 1984.

NAS (National Academy of Sciences), 1980. BEIR-III Report, The Effects on Population of Exposure to Low Levels of Ionizing Radiation, Advisory Committee on Biological Effects of Ionizing Radiation, National Research Council, Washington, D.C.

NCRP (National Council on Radiation Protection), 1984. Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States, NCRP Publication 78, Washington, D.C.

NOAA (National Oceanic and Atmospheric Administration), 1976. Annual (Day/Night) Wind Direction by Pasquill Stability Classes (Star Program), National Climatic Center, Asheville, North Carolina.

NRC (U.S. Nuclear Regulatory Commission), 1984. Radon Attenuation Handbook for Uranium Mill Tailings Cover Design, NUREG/CR-3533, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission), 1981. Data Base for Radioactive Waste Management - Impacts Analyses Methodology Report, NUREG/CR-1759, Volume 3, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission), 1980a. Final Generic Environmental Impact Statement on Uranium Milling, NUREG-0706, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission), 1980b. "Standards for Protection Against Radiation," Title 10, Code of Federal Regulations, Part 20.

Nielson, K. K., 1984. Letter report on Riverton Radon Emanation Tests dated March 27, 1984; prepared for the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico.

PNL (Pacific Northwest Laboratory), 1980. A Field and Modeling Study of Windblown Particulates From a Uranium Mill Tailings Pile, NUREG/CR-1407, PNL-3345, prepared by PNL, Richland, Washington, for the U.S. Nuclear Regulatory Commission, Washington, D.C.

Pettingill, Harry, 1987. Personal communication with Harry Pettingill, U.S. Nuclear Regulatory Commission, Uranium Recovery Field Office, Denver, Colorado, to the Technical Assistance Contractor (Jacobs-Weston Team), UMTRA Project Office, Albuquerque, New Mexico, dated April 30, 1987.

Schiager, K. J., 1974. "Analysis of Radiation Exposure On or Near Uranium Mill Tailings Piles," Radiation and Data Reports, 14:411.

Shleien, B., and M. S. Terpilak, 1984. The Health Physics and Radiological Health Handbook, Nuclear Lectern Associates, Inc., Olney, Maryland.

Taylor, G.I., 1954. "The Dispersion of Matter in Turbulent Flow Through a Pipe," in Proceedings of the Royal Society (London) (A), Vol. 223.

Turner, B. D., 1969. Workbook of Atmospheric Dispersion Estimates, PHS Publication No. 999-AP-26, Department of Health, Education, and Welfare, Washington, D.C.

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), 1977. Sources and Effects of Ionizing Radiation, United Nations Publication No. E.77.IX.I, Report to the General Assembly, Washington, D.C.

Yuan et al. (Y.C. Yuan, C. J. Roberts, P. C. Chee, S. Y. Chen, S. L. Giardini, and J. M. Peterson), 1983. "Methodology for Assessing Radiological Impact from UMTRA-Related Activities, Draft Report," Argonne National Laboratory, Argonne, Illinois.

APPENDIX G

PERMITS, LICENSES, AND APPROVALS

TABLE OF CONTENTS

LIST OF TABLES

G.1 INTRODUCTION

This appendix contains a listing of the permits, licenses, and approvals (Table G.1.1) that would be required for various aspects of the remedial action alternatives for the Riverton, Wyoming, tailings site. The regulatory permits, licenses, and approvals would be obtained by the Remedial Action Contractor or the U.S. Department of Energy, whichever is appropriate.

Table G.1.1 Permits, licenses, and approvals for remedial action at the Riverton, Wyoming, tailings site

Permit, license, or approval	Granting or approving agency	Statute or regulation	Activity
U.S. Nuclear Regulatory Commission License	U.S. Nuclear Regulatory Commission	Public Law 95-604, Section 104(f)	Surveillance and maintenance at the disposal facility after completion of the remedial action.
Free Use Permit	Bureau of Land Management	Material Sales Act of 1947; Title 43, Code of Federal Regulations, Part 3611	Extraction of common minerals (e.g., clay, and rock) on lands administered by the Bureau of Land Management.
Sand and Gravel Permit	Bureau of Indian Affairs, Shoshone and Arapahoe Indian Tribes	Title 25, Code of Federal Regulations, Part 216	Extraction of common minerals (e.g., earth, gravel, and rock) on Indian lands.
Revokable Use Permit	Bureau of Indian Affairs, Shoshone and Arapahoe Indian Tribes	Title 25, Code of Federal Regulations, Part 169	Decontamination of Indian lands.
Cultural Resource Clearance	Bureau of Land Management, Wyoming Recreation Commission, Bureau of Indian Affairs	National Historic Preservation Act; Archaeological Resources Protection Act	Any action that might impact archaeological or historic resources.
Threatened and Endangered Species Consultation	U.S. Fish and Wildlife Service	Endangered Species Act of 1973, Section 7; 16 United States Code 1531, et seq.	Any action that might affect threatened or endangered species.

Table G.1.1 Permits, licenses, and approvals for remedial action at the Riverton, Wyoming, tailings site (Continued)

Permit, license, or approval	Granting or approving agency	Statute or regulation	Activity
Air Quality Construction Permit	Wyoming Department of Environmental Quality, Air Quality Division	Wyoming Air Quality Standards and Regulations	Construction or modification of a new source of air pollution.
Approval of Borrow Site Soil Sampling Pits	Wyoming Department of Environmental Quality, Land Quality Division	Land Quality Division Regulations	Backhoe excavation of soil sampling pits.
Exemption from Permit to Mine	Wyoming Department of Environmental Quality, Land Quality Division	Wyoming Statutes 35-11-401-(e)(II); Land Quality Division Regulations, Chapter 1, Section 3, B(II)(b)	Extraction of rock, clay, or earthen borrow materials.
Permit to Appropriate Ground Water	Wyoming State Engineer's Office	State Engineer's Office Rules and Regulations, Part II, Ground Water	Drilling water wells and dewatering of tailings.
Monitor Well Abandonment	Wyoming Department of Environmental Quality, Water Quality Division and Land Quality Division, and Wyoming State Engineer's Office	Water Quality Division Rules and Regulations; State Engineer's Office Rules and Regulations, Part II, Ground Water	Sealing of wells and drill holes.

Table G.1.1 Permits, licenses, and approvals for remedial action at the Riverton, Wyoming, tailings site (Concluded)

Permit, license, or approval	Granting or approving agency	Statute or regulation	Activity
Drill Hole Abandonment	Wyoming Department of Environmental Quality, Land Quality Division	Land Quality Division Rules and Regulations	Sealing of drill holes.
Waste-Water Discharge Permit	Wyoming Department of Environmental Quality, Water Quality Division	Water Quality Rules and Regulations	Controlled surface discharge of waste water.
Permit to Construct a Waste-Water Treatment Facility	Wyoming Department of Environmental Quality, Water Quality Division	Water Quality Rules and Regulations	Construction of sedimentation ponds or evaporation reservoirs.
Permit to Construct a Reservoir	Wyoming State Engineer's Office	Wyoming State Engineer's Office Rules and Regulations, Part I, Surface Water	Construction of reservoirs or ponds for the retention of surface runoff water and use of water.
License to Encroach on Highway Right-of-Way	Wyoming Highway Department	Wyoming Statutes 24 through 64	Decontamination of highway right-of-way.