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P–GJPO–109
Revision 2

MRAP OU111 AR 561 3-26 ENVIRO MONITOR
GRAND JUNCTION PROJECTS OFFICE FACILITY.
ENVIRONMENTAL MONITORING PLAN 11/95

Grand Junction Projects Office Facility
Grand Junction Projects Office Remedial Action Project
Monticello Mill Tailings Site

Environmental Monitoring Plan

November 1995

U.S. Department of Energy
Grand Junction Projects Office

Approved for public release; distribution is unlimited.

Work Performed Under DOE Contracts No. DE-AC04-86ID12584 and DE-AC04-94AL96907
for the U.S. Department of Energy

P–GJPO–109
Revision 2

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Grand Junction Projects Office Facility
Grand Junction Projects Office
Remedial Action Project
Monticello Mill Tailings Site

Environmental Monitoring Plan

November 1995

Prepared for
U.S. Department of Energy
Albuquerque Operations Office
Grand Junction Projects Office

Prepared by
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Grand Junction, Colorado

Work Performed Under DOE Contracts No. DE–AC07–86ID12584 and DE–AC04–94AL96907

05161

GJPO/GJPORAP/MMTS Environmental Monitoring Plan Annual Review

November 1996

Revisions

Section 1.0 Introduction

Section 1.1, 1st ¶, page 1-1. The second sentence will be revised as follows: "Monitoring activities for the DOE Grand Junction Projects Office (GJPO) facility, the DOE Grand Junction Projects Office Remedial Action Project (GJPORAP), and the DOE Monticello Mill Tailings Site (MMTS) are addressed."

Section 1.1, 2nd ¶, page 1-1. The first sentence will be revised as follows: "Contained within this EMP are..."

Section 1.1, 3rd ¶, page 1-1. The first sentence will be revised as follows: "Soils and pond or river sediments are not discussed in this EMP because they are not regularly monitored at GJPO or MMTS." The fifth sentence will be revised as follows: "...exceeding UMTRCA standards were identified within the Montezuma Creek valley."

Section 1.1, 4th ¶, page 1-1. The first sentence will be revised as follows: "Data collected through the environmental monitoring programs are..."

Section 1.1, 5th ¶, page 1-2. The first sentence will be revised as follows: "Selected data from the environmental monitoring programs are..." The second sentence will be revised as follows: "These various reports are..."

Section 1.1, 7th ¶, page 1-2. The second sentence will be revised as follows: "Revisions and updates will be issued by the contractors' environmental sections through the records management sections..."

Section 1.1, 9th ¶, page 1-2. The first sentence will be revised as follows: "...sampling the laboratory exhaust stack, ground and surface water, sewer effluent, and storm water at the GJPO facility."

Section 1.3.1, 1st ¶, page 1-3. The third sentence will be deleted and replaced with: "The number of buildings on the facility has been decreased to 37 by removing several trailer structures in an effort to decrease the footprint of the facility." The fourth sentence will be revised as follows: "...more than 425 employees of DOE, Oak Ridge National Laboratories (ORNL), DOE's contractors, and the General Services Administration."

Section 1.3.1, 2nd ¶, page 1-5. The third sentence will be revised as follows: "...fully equipped laboratory that is uniquely suited to the support and management of environmental restoration activities."

Section 1.3.1, 3rd ¶, page 1-5. The fourth sentence will be revised as follows: "...operations is in the *Environmental Assessment of Facility Operations at the U.S. Department of Energy Grand Junction Projects Office, Grand Junction, Colorado* (DOE 1996a)."

Section 1.3.3, 1st ¶, page 1-7. The third sentence will be replaced with: "The 1995 modeling resulted in a calculated dose to the maximally exposed individual of 5.9×10^{-5}" millirems per year (mrem/yr) effective dose equivalent, which is well below the DOE/EPA standard of 10 mrem/yr."

Section 1.3.4, 9th ¶, page 1-11. The second sentence will be revised as follows: "This repository has been designed..."

Section 2.0 Meteorology

Section 2.2.1, 1st ¶, page 2-1. The second sentence will be modified as follows: "An on-site meteorological monitoring station (Figure 2-1) provides site-specific data that are used to support the off-site dose modeling effort."

Section 2.2.2.2, 1st ¶, page 2-4. The first sentence will be modified as follows: "Meteorological data will continue to be collected at GJPO with the Campbell Scientific CR-10 logger at a measurement frequency of 15 seconds and averaged at 1-hour and 24-hour intervals."

Section 2.2.2.2, 2nd ¶, page 2-4. The last word in the third sentence will be changed from "quarterly" to "monthly."

Section 3.0 Liquid Effluent

Section 3.2 GJPO, page 3-1. The second sentence will be revised as follows: "The sewer effluent consists of domestic sewage and typical industrial-type discharges from the Analytical Laboratory, Environmental Sciences laboratory, maintenance shop, and cafeteria."

Section 3.2.1, page 3-1, will be revised as follows: "Initially, all on-site sanitary wastewater was passed through septic tanks and then discharged into the South Pond on the GJPO Facility. The facility was connected to the city of Grand Junction sewer system in 1981, eliminating the need for septic systems. In 1987, the GJPO applied for an Industrial Pretreatment Permit (permit) and developed a profile of its effluent. Permit No. 0023, issued to the GJPO by the city of Grand Junction in March 1989, required biannual sampling for several heavy metals, polychlorinated biphenyls, and other common effluent analytes.

The city of Grand Junction issued the GJPO a revised permit (No. 0023REV) on March 1, 1993, which required quarterly sampling for a reduced number of analytes and the submission of quarterly analysis reports to the city. The revised permit also required the GJPO to submit measurements of the average daily effluent flow from the GJPO.

Prior to permit No. 0023REV expiring on May 30, 1996, the GJPO recharacterized its effluent in order to obtain a new permit. The new permit was issued to the GJPO on June 1, 1996, and will expire on May 31, 1999. The permit requires effluent sampling and reporting on a quarterly basis for the same analytes as required in permit No. 0023REV, but with fewer established daily maximum limits.

Table 3-2 identifies the pretreatment standard for the GJPO and lists the analytes required to be sampled and the daily maximum limits established by the permit. Sampling occurs at a location marked as Outfall 001 in Figure 3-1. In addition to the permit requirements, analyses for gross alpha and gross beta are performed to provide evidence of compliance with DOE Order 5400.5 regarding the discharge of radioactive materials to the sewer system."

Table 3-1, page 3-4. The last block of the table that deals with ARARs specific to GJPO, under the table heading of Standard, Requirement, Criterion, or Limitation, will be revised as follows: "City of Grand Junction Industrial Pretreatment Permit."

Table 3-2, page 3-5. The title will be revised as follows: "Pretreatment Standards for the GJPO Facility[a]."

Table 3-2, page 3-5. Table 3-2 will be revised as follows:

Pollutant	Daily Maximum Limit	Type of Sample
Biochemical Oxygen Demand (BOD)	Report Only	Composite
Total Suspended Solids (TSS)	Report Only	Composite
Total Dissolved Solids (TDS)	Report Only	Composite
Ammonia (NH_3)	Report Only	Composite
Temperature, not to exceed	40°C or 104°F	Instantaneous
pH, Standard Units	≥5.5	Instantaneous
Oil and Grease	Report Only	Grab
Silver - Total	0.43 mg/L	Composite
Polychlorinated Biphenyls	0.002 mg/L	Grab
Gross Alpha and Beta[b]	150 pCi/L	Composite

[a]mg/L = milligram per liter; C = Celsius; F - Fahrenheit; pCi/L = picocurie per liter.
[b]Not required by permit.

Section 3.2.2.2, 1st ¶ page 3-7. The third sentence will be deleted.

Table 3-4, page 3-10. The following will be added to Table 3-4:

Analyte	Effluent Concentration Limits (30-day average)	Maximum Effluent Concentration in Any Sample
Total Aluminum	0.25 mg/L	0.75 mg/L

Section 3.3.2.2, 1st ¶, page 3-10. The first sentence will be modified as follows: "During operations, the..."

Section 4.0 Surface Water

Section 4.2.1, 3rd ¶, page 4-6. At the end of the first sentence, "1994" will be changed to "1995." At the end of the of the references in parentheses, "1996b" will be added.

Table 4-2, page 4-6. Dissolved Oxygen, pH, and Specific Conductance will be deleted from the table. Nitrate, Nitrite, Silicon, and Thorium will be added to the table. "Fecal Coliform" will be changed to read "Coliform."

Section 4.2.2.1, 4th ¶, page 4-8. The fifth sentence will be changed to read: "Field measurements of alkalinity, pH, and specific conductance will be taken to detect gross changes in water quality."

Table 4-4, page 4-8. Total Organic Carbon, Radium-228, Thorium-230, Thorium-232, Uranium-234, and Uranium-238 will be deleted. Uranium will be added under the Nonradiological Constituents at a Reporting Limit of 0.001 mg/L.

Section 4.2.3, page 4-10. The second sentence will be revised as follows: "Responsibility for planning and budgeting surface water monitoring, sampling surface water, conducting data evaluation, and preparing reports resides with the FOS contractor's environmental section."

Figure 4-4, page 4-13. Figure 4-4 will be replaced.

Section 4.3, 3rd ¶, page 4-14. The ninth sentence will be revised as follows: "Seeps outside the millsite that have been sampled previously include Upper North Drainage, Pehrson 1, Pehrson 2, and Cabin Spring (Figures 4-3 and 4-4). The last sentence of this paragraph will be deleted.

Section 4.3.1, 3rd ¶, page 4-14. The third sentence will be revised as follows: "Contamination potentially attributable to the uranium mill tailings..."

Section 4.3.2.2, 1st ¶, page 4-16. The first paragraph will be deleted and replaced with: "Continued surface water chemistry monitoring is scheduled to occur on a semi-annual basis during the months of April and October. During the October sampling event, surface-water samples will be collected from three locations upstream of the millsite (SW92-01, SW92-02, and SW92-03), six locations on the millsite (Slade Spring, North Drainage, Carbonate Seep, W-2, SW92-04, and SW92-05), and nine locations downstream of the millsite (W-4, SW92-06, Sorenson Site, SW92-07, SW92-08, SW92-09, SW94-01, SW95-01, and Montezuma Canyon), as shown in Figures 4-3 and 4-4. During the April sampling event, surface-water samples will be collected from SW94-01, SW92-07, Sorenson Site, and SW92-05. Surface-water samples will be analyzed for the constituents listed in Table 4-6.

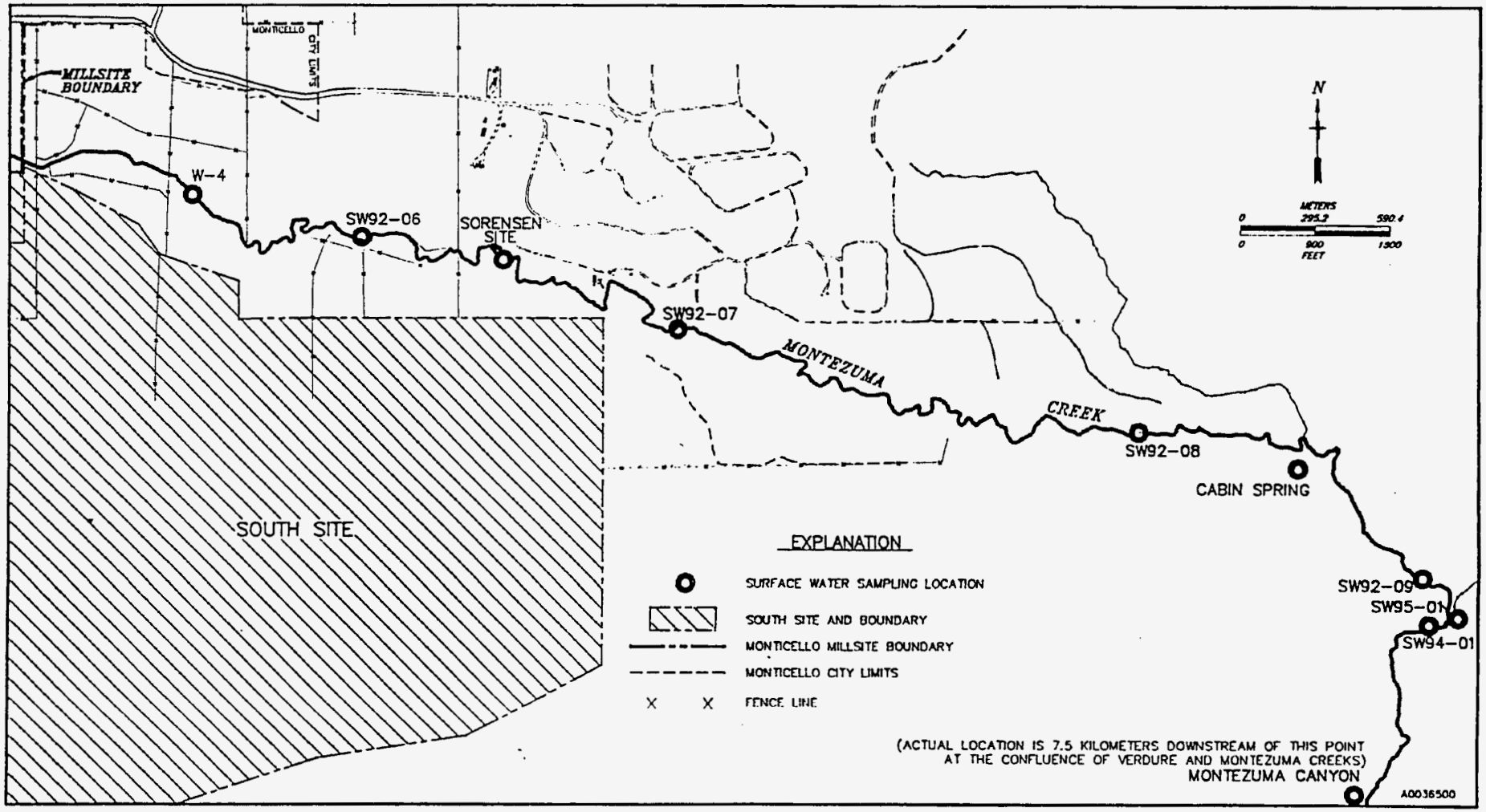

Figure 4-4. Surface-Water Sampling Locations Downstream of Monticello Millsite

Section 4.3.3, Responsible Organizations, page 4-16, will be changed to read: "It is the responsibility of the DOE-GJPO Manager to direct the surface-water monitoring effort. Responsibility for planning and budgeting surface-water monitoring, sampling, conducting data evaluation, and preparing reports resides with the TAR contractor's environmental section.

Table 4-6, page 4-17. Footnote "a" will be added to Metals. Footnote "a" is: "Filtered and unfiltered aliquots."

Section 5.0 Groundwater

Section 5.2.1, 1st ¶, page 5-1. In the first sentence, "1979" will be changed to "1980."

Table 5-2, page 5-7. In the figure title, change "1979 " will be changed to "1980." Alkalinity, Dissolved Oxygen, Oxidation-Reduction Potential, pH, Silica, Specific Conductance, and Sulphate will be deleted. Cyanide, Nitrate, Nitrite, Silicon, Sulfate, and Thorium will be added. "Fecal Coliform" will be changed to "Coliform."

Table 5-5, page 5-11. Total Organic Carbon, Radium-228, Uranium-234, Uranium-238, Thorium-230, and Thorium-232 will be deleted. Uranium will be added under the Nonradiological Constituents at a Reporting Limit of 0.001 mg/L.

Section 5.2.2.2, 1st ¶, page 5-11. The fourth sentence will be revised as follows: "One of the wells (GJ84-09) is located upgradient from the mill tailings contaminant plume and will provide background water quality data." In the fifth sentence, "10 " will be changed to "11."

Figure 5-1, page 5-12. Figure 5-1 will be replaced.

Table 5-6, page 5-13. Wells GJ84-10 and 1-9SA will be deleted. The following new wells will be added:

Well No.	Location	Total Depth (feet)
10-2NA	On Site	22
6-2N	On Site	35

Section 5.2.3, page 5-14. The second sentence will be revised as follows: "Responsibility for planning and budgeting groundwater monitoring, sampling groundwater, conducting data evaluation, and preparing reports resides with the FOS contractor's environmental section."

Section 5.3.1, 1st ¶, page 5-14. The fifth and sixth sentences will be combined and revised as follows: "The new wells allowed assessments to be made of water quality on site and downgradient; samples from these wells were shown to be contaminated by uranium, molybdenum, radium, vanadium, and selenium."

Section 5.3.1, 3rd ¶, page 5-15. The last sentence will be deleted and replaced with the following: "Approximately 26 wells were sampled on a semiannual frequency from October 1993 until February 1995 as the remedial investigation continued. In the winter of 1996, seven new wells were installed downgradient and crossgradient of the millsite. These wells were sampled four times during 1996 to better define the extent of contamination in the alluvial aquifer and to determine if water quality in the Burro Canyon aquifer was being degraded by contaminated alluvial groundwater."

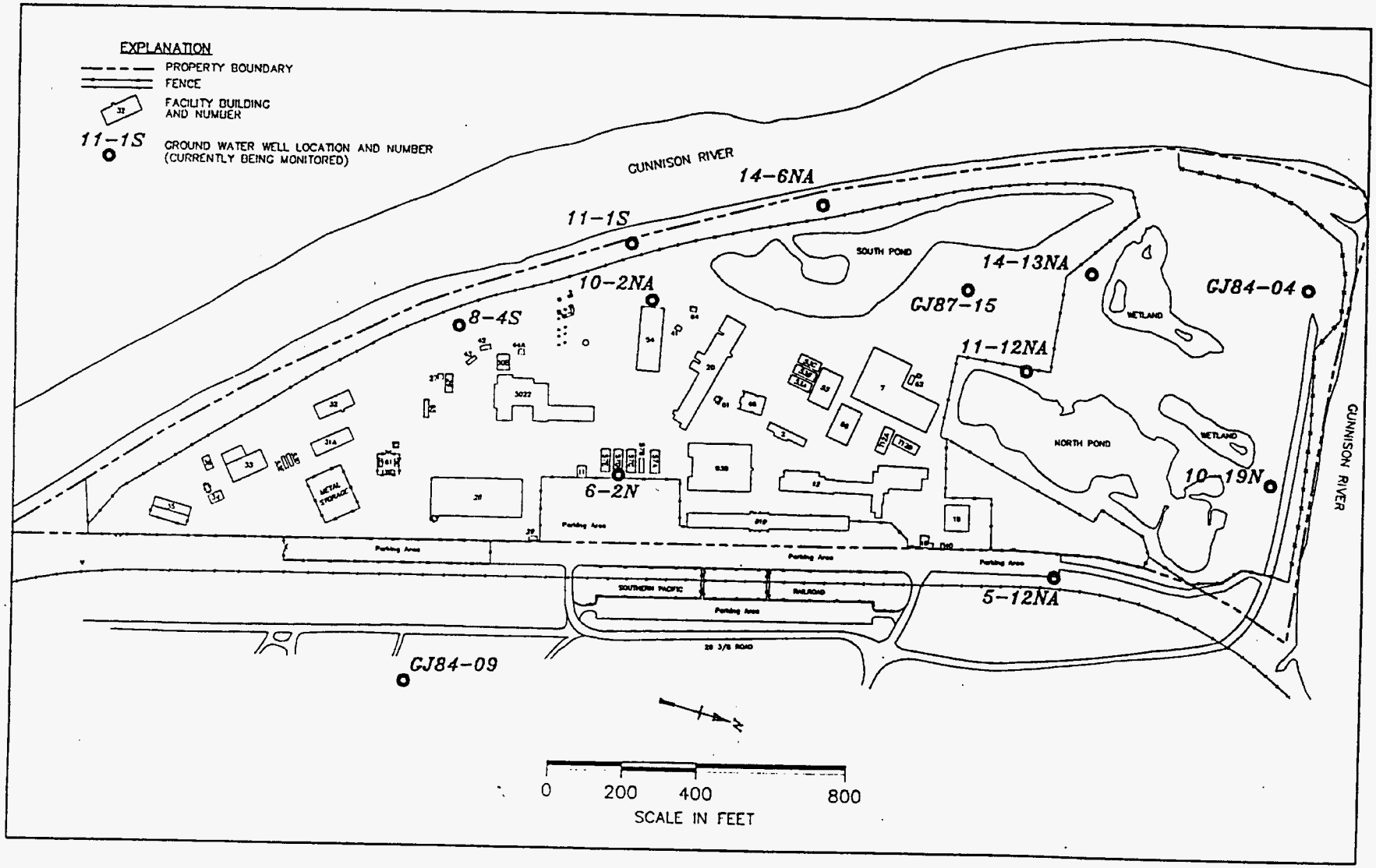

Figure 5-1. Ground Water Sampling Locations at the GJPO Facility

Section 5.3.2.2, 1st ¶, page 5-15. The first paragraph will be deleted and replaced with the following: "Sampling will occur semiannually, in April and October. The number of wells sampled will vary from 13 during a limited April sampling event to 28 during a comprehensive October sampling event. Table 5-8 lists the wells to be sampled, and Figures 5-2 and 5-3 show the locations of the wells. Water levels will be measured quarterly.

Section 5.3.2.2, 2nd ¶, page 5-15. The first and second sentences will be deleted. The third sentence will be revised as follows: "The rationale for the groundwater..."

Table 5-7, page 5-16. Alkalinity, Dissolved Oxygen, Eh, Tritium, and Turbidity will be deleted. Gross Alpha and Gross Beta will be deleted from the Nonradiological column.

Table 5-8, page 5-17. Wells 82-30B, 82-40A, 82-42, 82-31B-E, 31SW91-03, 31SW91-14, 31SW91-23, and 36SE93-201-2 will be deleted. The following seven wells will be added:

Well No.	Aquifer	Location
95-01	Alluvium	Downgradient
95-02	Burro Canyon	Downgradient
95-03	Alluvium	Downgradient
95-04	Burro Canyon	Downgradient
95-06	Burro Canyon	Downgradient
95-07	Dakota Sandstone	Crossgradient
95-08	Burro Canyon	Downgradient

A footnote will be added to this table stating "October sampling event only" and reference made behind Well Nos. 92-01, 92-02, 92-03, 92-04, 92-05, 92-06, 92-13, 82-07, 83-70, 88-85, 92-07, 09-08, 31NE93-205, P92-02, and P92-09.

Figure 5-2, page 5-18. Figure 5-2 will be replaced.

Figure 5-3, page 5-19. Figure 5-3 will be replaced.

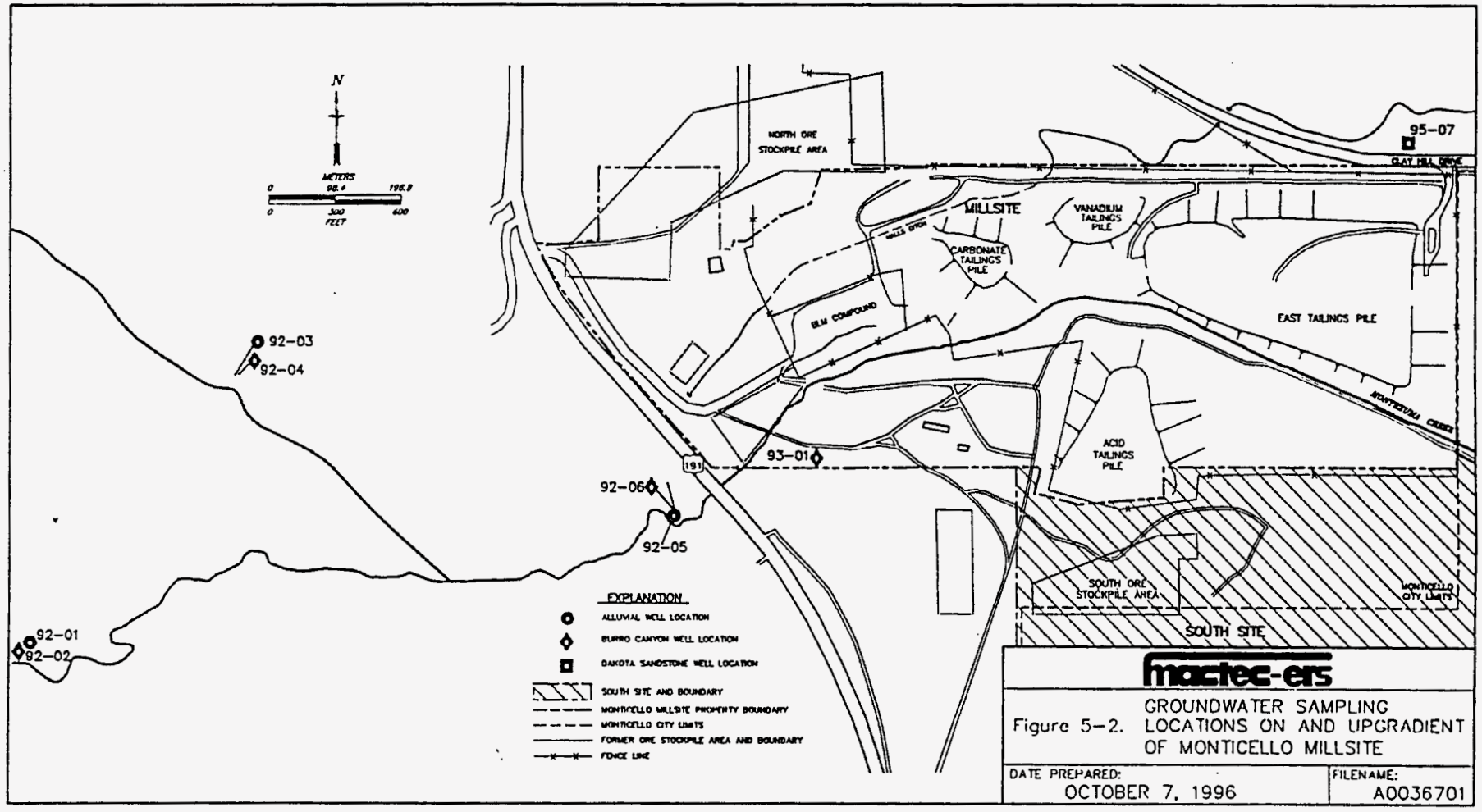

Figure 5-2. Groundwater Sampling Locations On Site and Upgradient of Monticello Millsite

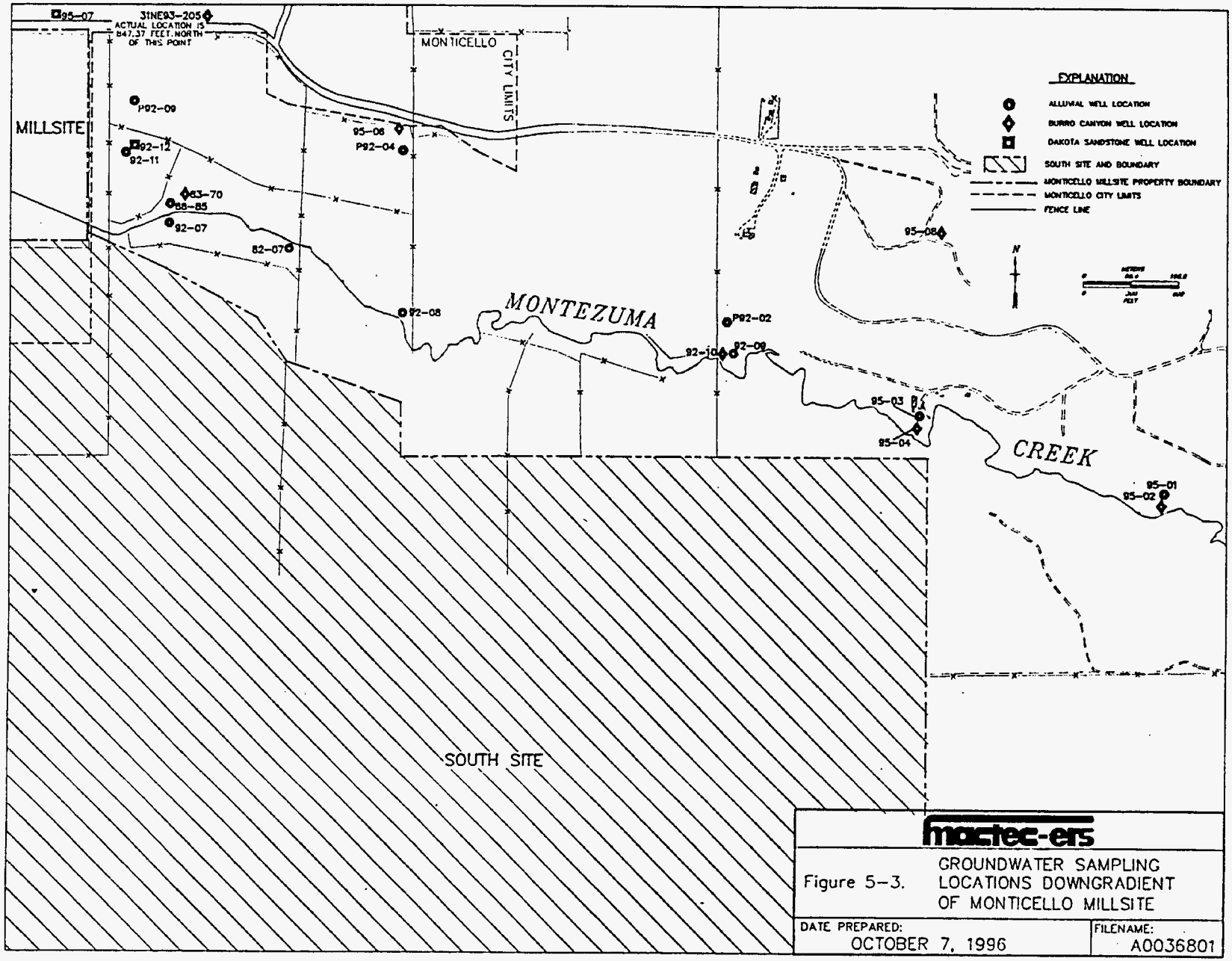

Figure 5-3. Groundwater Sampling Locations Downgradient of Monticello Millsite

Table 5-9, pages 5-20 and 5-21. Volatile Organic Compounds, Semivolatile Organic Compounds, Pesticides/PCBs, and Herbicides will be deleted from the table. Nitrite and tin will be deleted from the Major Anions and Metals lists, respectively. Lead will be added to the Metals list.

Section 5.3.3, Responsible Organizations, page 5-22, will be changed to read: "It is the responsibility of the DOE-GJPO Manager to direct the ground-water monitoring effort. Responsibility for planning and budgeting ground-water monitoring, sampling, conducting data evaluation, and preparing reports resides with the TAR contractor's environmental section."

Section 6.0 Air Effluent

Section 6.2, 1st ¶, page 6-1. The words "and Radon Laboratory" will be stricken from the first sentence. The second sentence will be modified as follows: "Emissions from the Baghouse stack (Figure 6-1) are sampled, whereas emissions from the Analytical Laboratory and calibration test pits are estimated."

Section 6.3.1, 3rd ¶, page 6-7. A new sentence will be added to the end of this paragraph that reads: "In 1995, sampler R-M-4-Air was removed at the request of the property owner."

Section 6.3.1, 4th ¶, page 6-7. A new sentence will be added after the third sentence that reads: "In 1996, in preparation for mill tailings disposal at the South Site Repository, 21 locations were added along the South Site perimeter."

Section 6.3.1. 4th ¶, page 6-7. In the fourth sentence, "13" will be changed to "34."

Figure 6-3, page 6-9. Figure 6-3 will be replaced.

6.3.2.2, 1st ¶, page 6-10. In the first sentence, "seven" will be changed to "six."

6.3.2.2, 1st ¶, page 6-10. In the fourth sentence, "15" will be changed to "36."

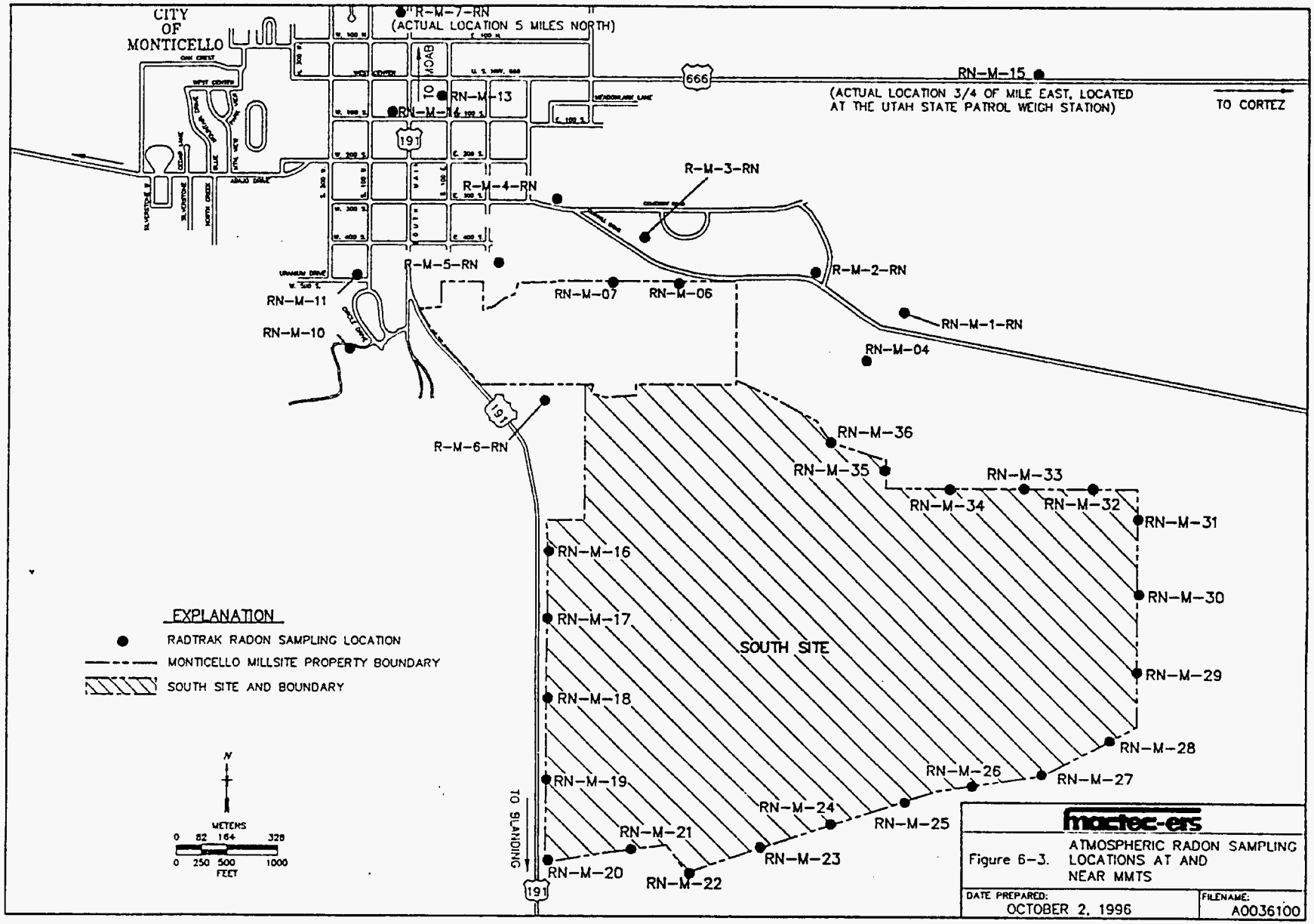

Figure 6-3. Atmospheric Radon Sampling Locations At and Near MMTS

Section 7.0 Direct Gamma Radiation

Section 7.3.1, 1st ¶, page 7-1. From the third sentence "...in Figure 7-1..." will be deleted. A sentence will be added after the third sentence that reads: "In 1996, in preparation for mill tailings disposal at the South Site Repository, 21 locations were added along the South Site perimeter (Figure 7-1)."

Figure 7-1, page 7-3. Figure 7-1 will be replaced.

Section 7.3.2.2, 1st ¶, page 7-4. In the first sentence, "19" will be changed to "40."

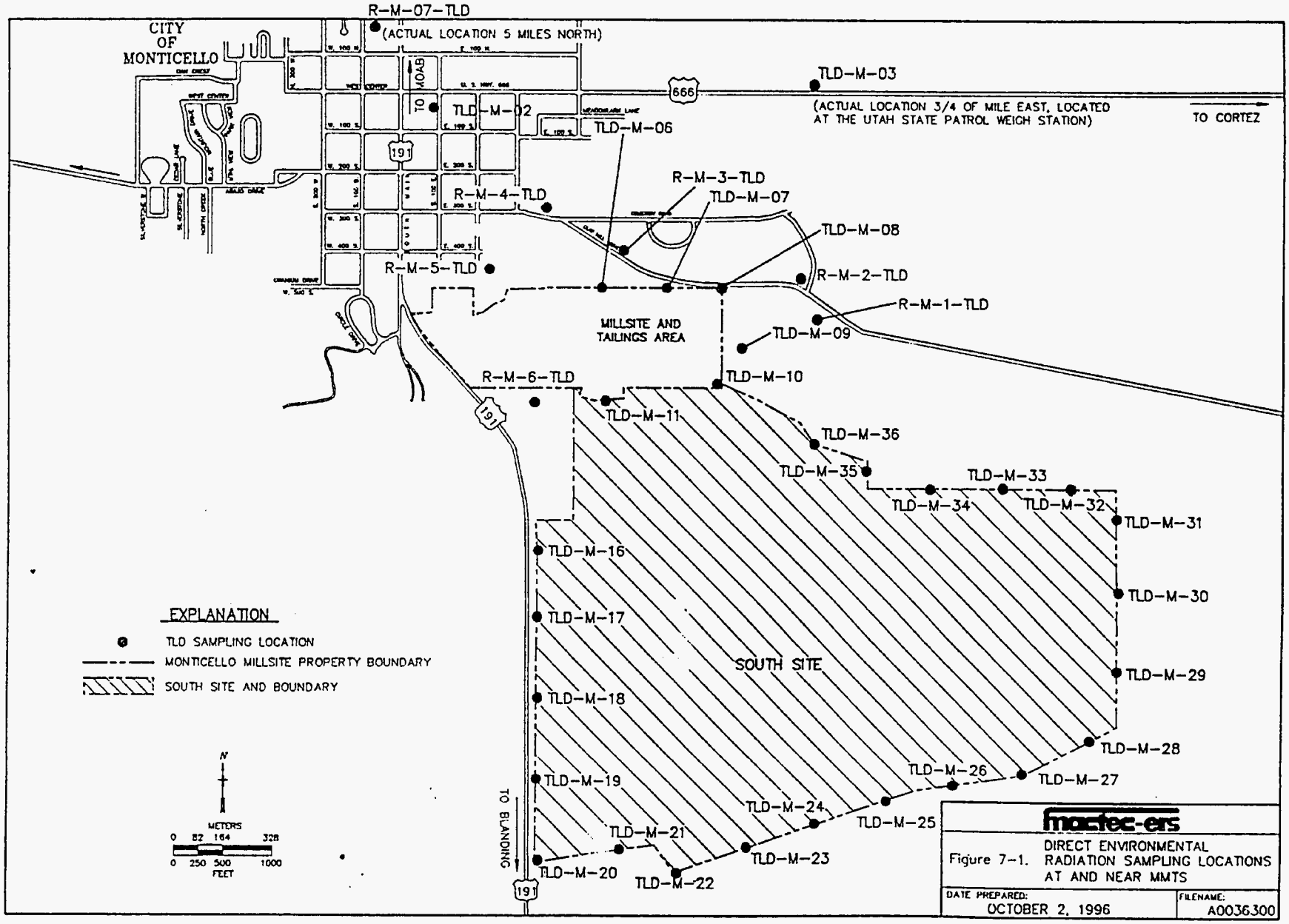

Figure 7-1. Direct Environmental Radiation Sampling Locations At and Near MMTS

Section 8.0 Biota.

Section 8.3.2.1, 1st ¶, page 8-3. The first sentence will be revised as follows: "The objectives of the 1995 and 1996 MMTS biota monitoring efforts were....:"

Section 8.3.2.2, 1st ¶, Page 8-3. The first sentence will be revised as follows: "Biota sampling was..." The second sentence will be modified as follows: "The study design for biota sampling is presented in the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/ Feasibility Study Work Plan, Draft Final* (DOE 1995f), in the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Field Sampling Plan and Quality Assurance Project Plan, Draft Final* (DOE 1995e), and in the *Monticello Mill Tailings, Operable Unit III Sampling and Analysis Plan for Additional Characterization of Middle and Lower Montezuma Creek* (DOE 1996c)."

Section 8.3.2.4, 1st ¶, page 8-3. The first sentence will be revised as follows: "...completed in 1997."

Section 8.3.3, 1st ¶, page 8-3. The second sentence will be revised as follows: "...the TAR contractor's environmental section."

Section 9.0 Wetland Restoration

Section 9.1, page 9-1. The second sentence will be modified as follows "...for the GJPO facility and by DOE's *Monticello Wetlands Master Plan* (DOE 1996d)."

Section 9.2.2.3, page 9-1. This paragraph will be modified as follows: "... FOS contractor's environmental and records management sections."

Section 9.2.3, page 9-2. This paragraph will be modified as follows: "... FOS contractor's environmental section."

Section 9.3, page 9-2. The third sentence will be modified as follows: "The *Monticello Wetlands Master Plan* (DOE 1996d)..."

Section 9.3.1, page 9-2. This sentence will be deleted and replaced with: "Monitoring of restored wetland areas began in August 1996 and consisted of measuring (1) herbaceous and woody species composition, (2) combined cover of grasses and desirable herbaceous species, as a percentage of total cover, (3) density of viable transplanted woody plants, and (4) average height and canopy dripline of transplanted woody species. At the same time, baseline data were collected for these parameters from existing, established wetland areas. Baseline data were then compared to data collected from restored wetland areas."

Section 9.3.2.1, page 9-2. The first sentence will be modified as follows: "...criteria established in the *Monticello Wetlands Master Plan* (DOE 1996d)."

Section 9.3.2.2, page 9-2. The first sentence will be modified as follows: "...discussed in the *Monticello Wetlands Master Plan* (DOE 1996d)." The second sentence will be deleted.

Section 9.3.3, Responsible Organizations, page 9-3, will be changed to read: "It is the responsibility of the DOE-GJPO Manager to direct the wetland restoration monitoring effort. Responsibility for planning and budgeting wetland monitoring, sampling, conducting data evaluation, and preparing reports resides with the TAR contractor's environmental section. EPA Region VIII is the regulatory oversight for wetlands at MMTS.

Section 10.0 Quality Assurance

Section 10.0, 1st ¶, page 10-1. The second sentence will be modified as follows: "The contractor's QA program is supplemented with the ANSI/ASQC E-4 1994, *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs* (American Society for Quality Control 1994)."

Table 10-1, page 10-5. The block of the table that deals with ARARs specific to MMTS will be deleted.

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Abbreviations and Acronyms

ALARA	as low as reasonably achievable
ARAR	applicable or relevant and appropriate requirement
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BAT	best available technology
C	Celsius
CAR	corrective action request
$CaSO_4$:Dy	calcium sulfate:dysprosium
CCR	Code of Colorado Regulations
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*U.S. Code of Federal Regulations*
DCG	Derived Concentration Guides
D&D	decontamination and decommissioning
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DQO	data quality objective
EA	environmental assessment
EH–1	Assistant Secretary for Environment, Safety and Health, DOE Headquarters
EMP	Environmental Monitoring Plan
EPA	U.S. Environmental Protection Agency
ft/day	feet per day
GJPO	Grand Junction Projects Office
GJPORAP	Grand Junction Projects Office Remedial Action Project
HEPA	high-efficiency particulate air (filter)
km	kilometer
L	liter
m	meter
mb	millibar
mg	milligram
min	minute
mL	milliliter
MMTS	Monticello Mill Tailings Site
mph	miles per hour
MRAP	Monticello Remedial Action Project
mrem	millirem
mR/hr	milliroentgens per hour
MSGRAP	Monticello Surface and Ground-Water Remedial Action Project
NA	not applicable
NEPA	National Environmental Policy Act
NESHAPs	National Emission Standards for Hazardous Air Pollutants
NIST	National Institute of Standards and Technology
NPDES	National Pollutant Discharge Elimination System
NQA–1	Nuclear Quality Assurance
ORNL	Oak Ridge National Laboratory
PCB	polychlorinated biphenyl

Abbreviations and Acronyms (continued)

pCi	picocurie
pH	negative log of the hydrogen ion concentration
PM_{10}	particulate matter less than 10 micrometers in diameter
QA	quality assurance
QAPP	Quality Assurance Program Plan
QC	quality control
rad	radian
RCRA	Resource Conservation and Recovery Act
rem	roentgen equivalent man
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SDMH	storm-drain manhole
SFMP	Surplus Facilities Management Program
TCL	target compound list
TLD	thermoluminescent dosimeter
UAC	Utah Administrative Code
μCi	microcurie
μg	microgram
μm	micrometer
UMTRCA	Uranium Mill Tailings Radiation Control Act
UPDES	Utah Pollutant Discharge Elimination System
WET	whole effluent toxicity
yr	year

Definitions

Criterion as a capitalized term (when used in the Quality Assurance Program) is a statement of the application of one of the 18 Nuclear Quality Assurance (NQA–1) Basic Requirements to the kind of work performed or directed by the U.S. Department of Energy (DOE) or its contractors.

Data Quality Objectives describe the uncertainty that a decision maker is willing to accept in results derived from environmental data. This uncertainty is used to specify the quality of the measurement data required, usually in terms of accuracy, precision, completeness, representativeness, and comparability.

> **Accuracy**—The degree of agreement of a measurement with an accepted reference or true value, usually expressed as the difference between or ratio of the two values. Accuracy is a measure of the bias in a system.
>
> **Precision**—A measure of mutual agreement among individual measurements of the same property, usually under prescribed similar conditions. Precision is most desirably expressed in terms of the standard deviation.
>
> **Completeness**—A measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under correct normal conditions.
>
> **Representativeness**—The degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, or an environmental condition.
>
> **Comparability**—A measure of the confidence with which one data set can be compared to another.

Environmental Monitoring is the collection and analysis of samples or direct measurements of environmental media. Environmental monitoring consists of two major activities: effluent monitoring and environmental surveillance.

> **Effluent Monitoring**—The collection and analysis of samples, or measurements of liquid and gaseous effluents, for the purposes of characterizing and quantifying contaminants, assessing radiation exposures to members of the public, providing a means to control effluents at or near the point of discharge, and demonstrating compliance with applicable standards and permit requirements.
>
> **Environmental Surveillance**—The collection and analysis of samples, or direct measurements of air, water, soil, foodstuff, biota, and other media, for the purposes of determining compliance with applicable standards and permit requirements, assessing radiation exposures of members of the public, and assessing the effects (if any) on the local environment.

Nonconformance is a deficiency in a characteristic, procedure, or documentation that renders the quality of an item unacceptable or indeterminate. Examples of nonconformances include, but are not limited to, physical defects; test failures; incorrect or inadequate documentation; deviations from prescribed processing, inspection, and test procedures; and deviations from other technical requirements.

Quality Assurance (QA) includes all planned and systematic actions necessary to provide adequate confidence that a facility, structure, system, or component will perform satisfactorily. The goal of QA is to ensure (1) that research, development, demonstration, and production activities are performed in a controlled manner; (2) that components, systems, and processes are designed, developed, constructed, tested, operated, maintained, and decommissioned according to sound engineering standards, quality practices, and technical specifications; and (3) that the resulting technical data are valid and retrievable. QA includes quality control (QC).

> **QA Program Standard (S) Level**—A base QA program that applies to all DOE activities. Required reviews, inspections, assessments, verifications, and audits are applied to ensure that practices and procedures are adequate to provide quality.
>
> **QA Program Quality (Q) Level**—The application of a higher level of QA requirements than those for the S Level. Q Level applies to all items and activities that will be used in regulatory licensing actions or that have a reasonable potential for becoming critical to the attainment of DOE programmatic objectives.

Quality Assurance Program Plan (QAPP) is a document identifying the requirements that the program manager and the QA coordinator have judiciously selected from the overall QA Program, along with DOE's QA requirements, that are to be imposed on a particular program. The QAPP provides an index or a description of the procedures that implement these QA requirements and other supplementary requirements. The QAPP also includes specific responsibilities and authorities for implementing applicable QA requirements.

Quality Control (QC) are those quality actions necessary to control and verify the features and characteristics of an item, material, process, facility, or service to specified requirements.

Section 1.0
Introduction

1.0 Introduction

1.1 Overview

This Environmental Monitoring Plan (EMP) has been prepared in compliance with U.S. Department of Energy (DOE) Order 5400.1, *General Environmental Protection Program*, which requires an EMP to be prepared for each site, facility, or process that uses, generates, releases, or manages significant pollutants or hazardous materials. This EMP addresses monitoring activities for the DOE Grand Junction Projects Office (GJPO) facility, the DOE Grand Junction Projects Office Remedial Action Project (GJPORAP), and the DOE Monticello Mill Tailings Site (MMTS). Associated with the MMTS are two remedial action projects: the Monticello Remedial Action Project (MRAP) and the Monticello Surface and Ground-Water Remedial Action Project (MSGRAP). All sites and projects are managed by DOE–GJPO.

Many elements are contained within this EMP, including the rationale and design criteria for the monitoring programs, extent and frequency of monitoring and measurements, laboratory analysis procedures, quality assurance (QA) requirements, program implementation procedures, and direction for the preparation and disposition of reports. Section 1.0, Introduction, describes the purpose of the EMP and the location of and general environmental conditions at each of the sites. Sections 2.0 through 9.0 present the individual environmental monitoring programs for meteorology, liquid effluent, surface water, groundwater, air effluent, direct gamma radiation, biota, and wetland restoration, respectively. Within each section, the monitoring objectives, sampling plans, data management responsibilities, data analysis techniques, and data reporting formats are presented. The organizations responsible for implementing the programs also are identified. Each monitoring program is carefully designed to comply with the requirements of local, State, and Federal laws and regulations, and DOE orders. The *Quality Assurance Program Plan*, which is applicable to all the monitoring programs, is described in Section 10.0 and is attached as Appendix A. Section 11.0 contains a description of the records management policy for EMP activities.

Soils and pond or river sediments are not discussed in this EMP because they are not regularly monitored for at GJPO or MMTS. In 1984, 1985, 1987, 1989, 1994, and 1995, radiological characterization surveys were conducted at GJPO and MMTS (Abramiuk et al. 1984, Marutsky et al. 1985, Henwood and Ridolfi 1986, DOE 1990e, DOE 1991d, DOE 1995f). Soils were sampled and analyzed for radium-226, potassium-40, thorium-232, and delta-gamma exposure rates. From these analyses, contour maps were generated to delineate areas containing radium-226 concentrations exceeding Uranium Mill Tailings Radiation Control Act (UMTRCA) standards (40 *U.S. Code of Federal Regulations* [CFR] 192.12). At GJPO, all known areas of exterior contaminated soils were remediated and verified to be clean by July 1, 1994. At MMTS, contaminated sediments with radiologic concentrations exceeding UMTRCA standards were found within Montezuma Creek valley. MRAP and MSGRAP were initiated, and are currently ongoing, to assess the risk-based impacts of these and other contaminated materials.

Data collected through the environmental monitoring programs will be tabulated and summarized in the GJPO and MMTS Annual Site Environmental Reports, which are submitted to the DOE Albuquerque Operations Office by June 1 of each year. In addition to the summary of environmental data, the annual reports include: (1) a characterization of the site's environmental management performance; (2) a comparison of the monitoring data with established standards and regulations; and (3) a description of the significant programs and efforts being implemented at DOE facilities, such as those pertaining to site management inspections, waste management programs, Superfund Amendments and Reauthorization Act (SARA) Title III reporting, and pollution abatement projects. The reports are available to members

of the public and are distributed to local, State, and Federal officials and agencies who have an interest in the sites' activities.

Selected data from the environmental monitoring programs will be used to update other reports generated by DOE–GJPO, including the *Groundwater Protection Management Program Plan, Air Emissions Annual Report, Radioactive Effluent and On-Site Discharge Data Report*, and the *Industrial Pretreatment Report* to the city of Grand Junction. These various reports will be prepared by the DOE contractor and will be submitted to DOE–GJPO for approval and off-site distribution.

Data gathered through the environmental monitoring programs will support the ALARA (As Low As Reasonably Achievable) Programs established for GJPO and MMTS. These programs were established to ensure that radiation doses to individuals are maintained as far below the prescribed limits as is reasonable. Environmental monitoring of radiological sources will help determine if ALARA goals are met.

Changes in monitoring strategies may occur in response to regulatory changes or to increases or decreases in ongoing remedial activities at GJPO and MMTS. At a minimum, the EMP will be reviewed annually and updated every 3 years. Revisions and updates will be issued by the contractor's Environmental Services section through the records management section.

Closely tied to this EMP are supporting documents titled, *Sampling and Analysis Plan for Environmental Monitoring* (DOE 1994e), the *Monticello Mill Tailings Site, Monitoring of Air Particulate, Radon, and Gamma Radiation Emissions Work Plan* (DOE 1994c), and the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Field Sampling Plan and Quality Assurance Project Plan* (DOE 1995e). Whereas the EMP establishes the rationale and basic framework for environmental monitoring at GJPO and MMTS, the latter documents identify field and laboratory procedures for collecting and analyzing samples of environmental media. They provide details of the procedures that are introduced, but not fully discussed, in the EMP. Because the latter documents will be updated each time a change in field or laboratory procedures occurs, they will likely contain more current information than the EMP; the date of revision will indicate which document contains the most up-to-date information.

The *Sampling and Analysis Plan for Environmental Monitoring* (DOE 1994e) contains procedures for sampling the Sample Preparation Facility exhaust stack, groundwater, surface water, sewer effluent, and storm water at the GJPO facility. The plan also contains procedures for operating and calibrating meteorological stations at the GJPO facility and MMTS. Procedures for sampling environmental media (radon, direct gamma radiation, air particulates, groundwater, and surface water) at MMTS are discussed in separate, controlled documents: the *Monticello Mill Tailings Site, Monitoring of Air Particulate, Radon, and Gamma Radiation Emissions Work Plan* (DOE 1994c) and the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Field Sampling Plan and Quality Assurance Project Plan* (DOE 1995e).

1.2 Data Quality Objectives

Data quality objectives (DQOs) have been defined by both the American Society for Testing and Materials (ASTM) and the U.S. Environmental Protection Agency (EPA). The ASTM Standard ES 16–90 defines DQOs as "statements about the level of uncertainty that a decision maker is willing to accept in results derived from environmental data." According to EPA (1987a), DQOs are "qualitative

and quantitative statements that specify the quality of the data required to support the Agency's decisions during remedial response activities." The DQO development process involves the identification of decision types, data uses, data quality and quantity needs, and data users; and the design of a data-collection program that will satisfy the requirements of these elements. For environmental monitoring purposes, DQOs are primarily defined by the applicable or relevant and appropriate requirements (ARARs) specific to the environmental media being monitored. ARARs for the monitoring of meteorology, liquid effluents, surface water, groundwater, air effluent, direct gamma radiation, biota, and wetland restoration are listed at the beginning of individual sections in this EMP.

NOTE: Although ARARs are commonly associated with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites, ARARs are used in this document in association with both the GJPO and MMTS locations. While MMTS is a National Priorities List CERCLA site, GJPO is ***not***.

Historical documentation of monitoring data has been fairly extensive at both the GJPO and MMTS sites and has provided useful information regarding the direction of future monitoring for regulatory compliance. Current and future sampling plans for the various environmental media are established on the basis of assessments of historical monitoring data. Primary users of the collected data include decision makers from DOE, EPA, and the States of Colorado and Utah. Secondary data users include contractor personnel.

The quality of data collected for the GJPO, GJPORAP, and MMTS environmental monitoring programs is ensured by numerous quality control (QC) measures implemented during collection of the data. These measures are described in individual sampling and analysis plans for specific environmental media. QC measures allow for the assessment of data precision, accuracy, representativeness, completeness, and comparability (see "Definitions" section).

1.3 Facility Descriptions and Health Effects

1.3.1 Grand Junction Projects Office

The GJPO facility is located in Mesa County, Colorado, immediately south and west of the Grand Junction city limits (Figure 1–1) in Sections 26 and 27 of Township 1 South, Range 2 West, Ute Principal Meridian. Lying within an accretionary bend of the Gunnison River, the facility occupies an elongated north-south-trending tract of 22.8 hectares (56.4 acres) that is bounded on the north and west by the river and on the south and east by county, city, and private property. Approximately 45 structures are located on the facility. Most of these structures are occupied during normal working hours by the more than 650 employees of DOE, Oak Ridge National Laboratories (ORNL), DOE's contractor, and the General Services Administration. Technical, administrative, and support services are provided to various DOE, U.S. Department of Defense (DOD), and U.S. Nuclear Regulatory Commission programs by these personnel. Analytical laboratory and construction-related services support a variety of remedial action programs, including the Grand Junction Vicinity Properties Project, GJPORAP, MRAP, MSGRAP, work associated with the DOE Defense Decontamination and Decommissioning (D&D) Program, and projects funded by DOD.

Historically, programs conducted at GJPO were directed primarily toward uranium procurement, domestic uranium resource evaluation, and the advancement of geologic and geophysical techniques. The technology, equipment, procedures, and personnel base developed through these programs have

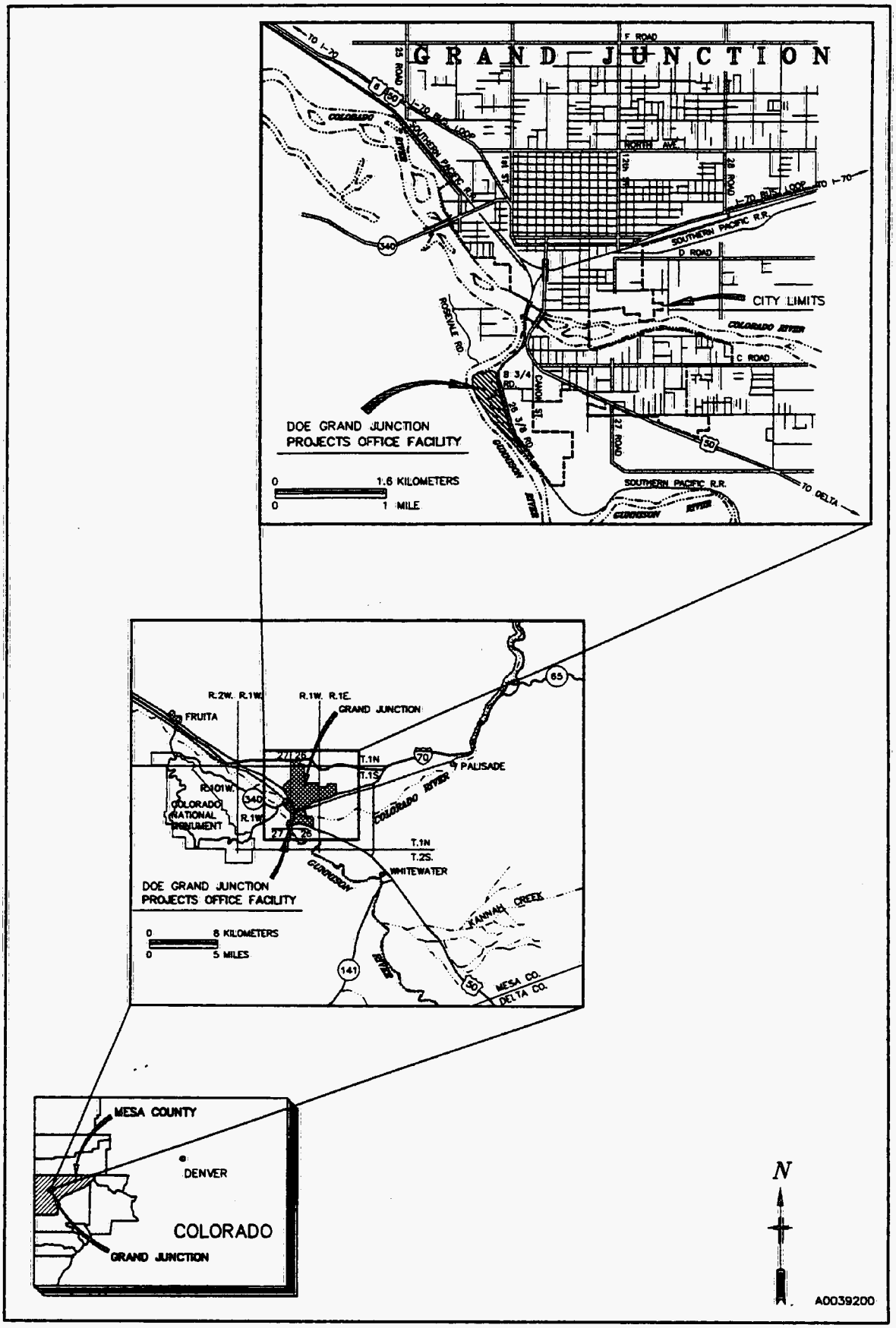

Figure 1–1. Location Map for GJPO Facility

proven invaluable to other DOE programs. Today, DOE–GJPO maintains a personnel base and fully equipped laboratories that are uniquely suited to the support and management of environmental restoration activities.

Facility operations are conducted in an environmentally safe and responsible manner. Waste disposal operations are conducted in compliance with all applicable policies and regulations. Currently, the GJPO facility is a conditionally exempt small quantity generator of hazardous and mixed wastes. Sanitary wastewater is discharged to the local publicly owned treatment works in accordance with the conditions established in an Industrial Pretreatment Permit issued by the city of Grand Junction. Solid, nonhazardous waste is routed to the local Mesa County landfill. A detailed description of facility operations is in the *Draft Environmental Assessment of Facility Operations at the U.S. Department of Energy Grand Junction Projects Office, Grand Junction, Colorado* (DOE 1995c).

1.3.2 Grand Junction Projects Office Remedial Action Project

GJPORAP encompasses activities associated with the removal of uranium mill tailings and mill-related contamination from early operations at GJPO. The GJPO facility lands were first acquired by the U.S. War Department in August 1943 for the Manhattan Engineer District. From 1943 through 1945, the U.S. Vanadium Corporation constructed and operated a central refinery for the Federal government to roast and further concentrate green sludges of uranium oxide that were obtained as by-products of vanadium production from vanadium plants in Uravan and Durango, Colorado. The resultant 20-percent uranium oxide sludge was shipped to Tonawanda, New York, for further refining to black oxide.

In December 1947, the U.S. Atomic Energy Commission established the Colorado Raw Materials Office at the site to manage the domestic uranium procurement program. This office was responsible for the receipt, sampling, and analysis of uranium and vanadium concentrates purchased from ore-processing operations in the western United States. A total of 173,650 tons of uranium oxide and 14,300 tons of vanadium oxide was received and stockpiled in steel drums at the facility from 1948 to 1971.

A pilot-plant program was initiated in 1953 with the construction of a small plant intended for research and development of a resin-in-pulp milling process. After 1954, the pilot-plant program was dedicated to amenability testing of uranium ores and to the development and testing of new uranium milling processes. A new larger pilot plant consisting of two large mill buildings, a crushing and sampling plant, office, laboratory, warehouse, and maintenance shop was constructed in the south portion of the site. From 1954 until closure in 1958, the pilot plant operated three circuits on a 24-hour-a-day, 7-day-a-week basis. Tailings from this plant were initially allowed to pond just west of what is now Building 33 (Figure 1–2). A slurry line was later constructed to carry the tailings to the old gravel pit south and west of Building 7. All tailings, both solids and liquids, were subsequently disposed of in this gravel pit.

Remedial action site investigations formally began for GJPORAP in 1984 when the facility was accepted into the DOE Surplus Facilities Management Program (SFMP). In 1988, the GJPO facility was transferred from SFMP to the DOE Defense D&D Program. DOE Headquarters was restructured in November 1990, and facility cleanup is now overseen by the Southwestern Area Programs Division's D&D Branch in the Office of Environmental Restoration. Under the guidelines set forth in UMTRCA, site characterization and remedial action studies were initiated to asses the radiological environmental hazards at GJPO. DOE–GJPO's initial goal was to prepare an environmental assessment (EA) as required by the National Environmental Policy Act (NEPA). Federal facilities were originally exempt from the requirements of CERCLA. However, with the passage of SARA by Congress in October 1986,

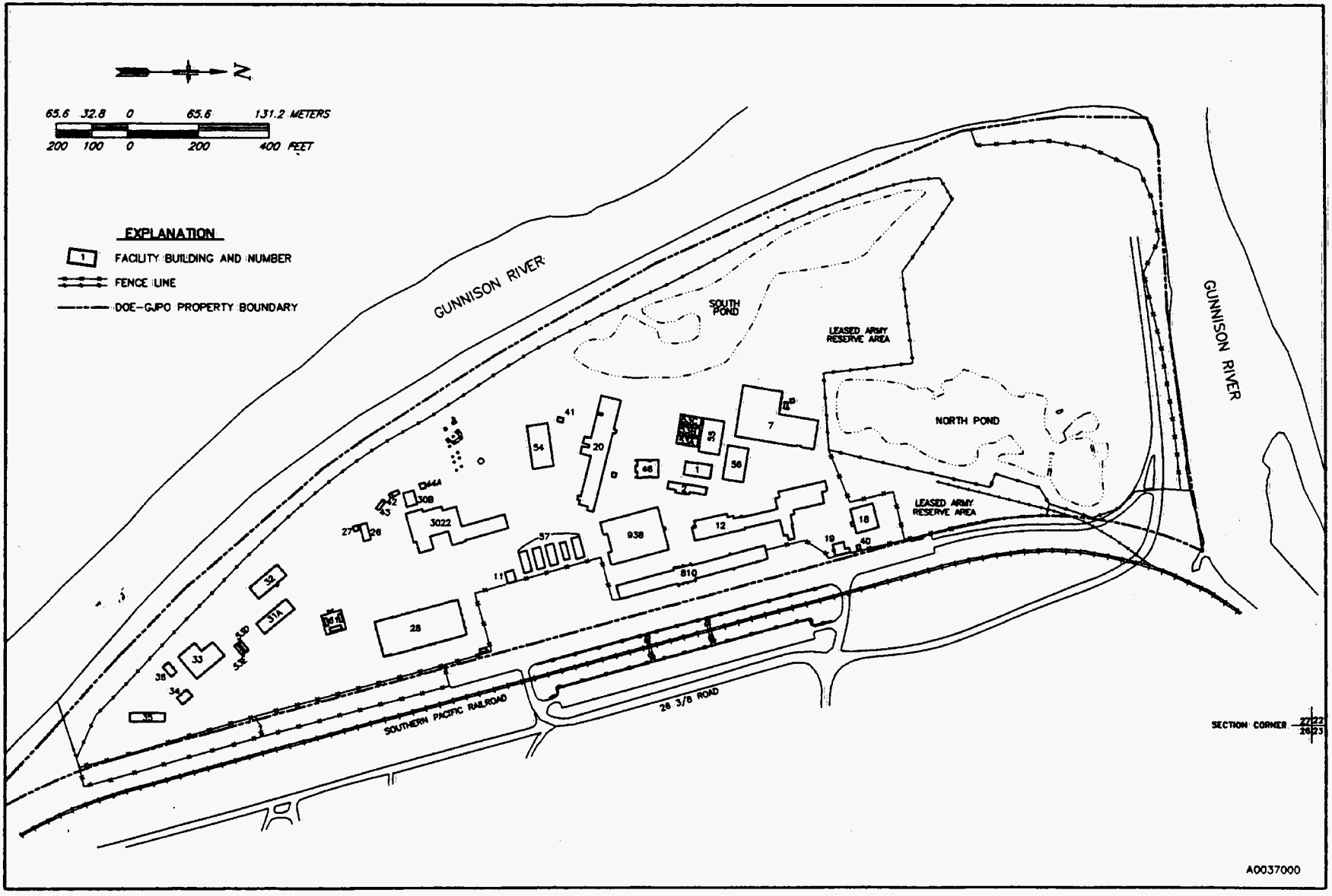

Figure 1–2. Layout of GJPO Facility

DOE–GJPO elected to reevaluate the facility in accordance with CERCLA. A Remedial Investigation/ Feasibility Study–Environmental Assessment (RI/FS–EA) was thus prepared to satisfy both the NEPA and SARA processes (DOE 1989c).

The GJPORAP Record of Decision (ROD) was finalized and approved by the DOE Idaho Field Office in April of 1990 (DOE 1990a). Remedial action activities began at GJPO in 1989 and are expected to continue through 1998. By July 1, 1994, all known exterior residual radioactive material had been removed from the facility. Activities remaining under GJPORAP include the D&D of about 12 on-site buildings.

1.3.3 GJPO Health Effects

Calculations have been performed by DOE to model the dispersion and radiological dose to the maximally exposed off-site individual and the collective population dose within 80 kilometers (km) (50 miles) of the GJPO facility. This dispersion and radiological dose modeling is undertaken each year to demonstrate compliance with 40 CFR Part 61, Subpart H (NESHAPs), and DOE Order 5400.5, *Radiation Protection of the Public and the Environment*. Results of the 1994 modeling indicated that the calculated dose to the maximally exposed individual (1.92×10^{-2} millirems per year [mrem/yr] effective dose equivalent) was well below the regulatory limit of 10 mrem/yr (DOE 1995h).

When uranium mill tailings were present on the facility, a number of toxic elements contained in the tailings leached into the shallow, alluvial groundwater and surface ponds on the site. Today, the groundwater and ponded surface water exhibit elevated concentrations of uranium, molybdenum, selenium, and arsenic that make these waters unfit for human and livestock consumption. However, the health risk to humans and livestock is considered slight because these waters are not used for any purpose, and the elevated contaminant levels drop below the Colorado Water Quality Standards once the groundwater leaves the facility and enters the Gunnison River.

1.3.4 Monticello Mill Tailings Site

DOE–GJPO also oversees MMTS, which encompasses the activities associated with the removal of uranium mill tailings and other mill-related contamination from the inactive Monticello millsite and peripheral properties (together known as MRAP) and the activities associated with remediation of surface water and groundwater on and below the millsite (MSGRAP). The millsite is a 31.6-hectare (78-acre) tract of land located in San Juan County, Utah, in Section 36 of Township 33 South, Range 23 East, and Section 31 of Township 33 South, Range 24 East, Salt Lake Meridian, and is within the city limits of Monticello (Figure 1–3). Included in the millsite acreage is the former mill area, which covers approximately 4 hectares (10 acres), and the tailings impoundment area, which covers the remaining 27.6 hectares (68 acres) (Figure 1–4). None of the original mill-process buildings remain, but contaminated foundations and scrap materials are buried on site. The tailings impoundment area contains approximately 1,680,000 cubic meters (m^3) (2.2 million cubic yards [yd^3]) of tailings and contaminated soil in four discrete piles. An additional 230,000 m^3 (300,000 yd^3) of contaminated material is present on adjacent open lands (DOE 1995f).

MMTS also encompasses activities associated with the disposal of uranium mill tailings and associated contaminated materials at a permanent repository on the South Site. The South Site is a 347-hectare (858.5-acre) tract of land south of the Monticello millsite (Figure 1–3).

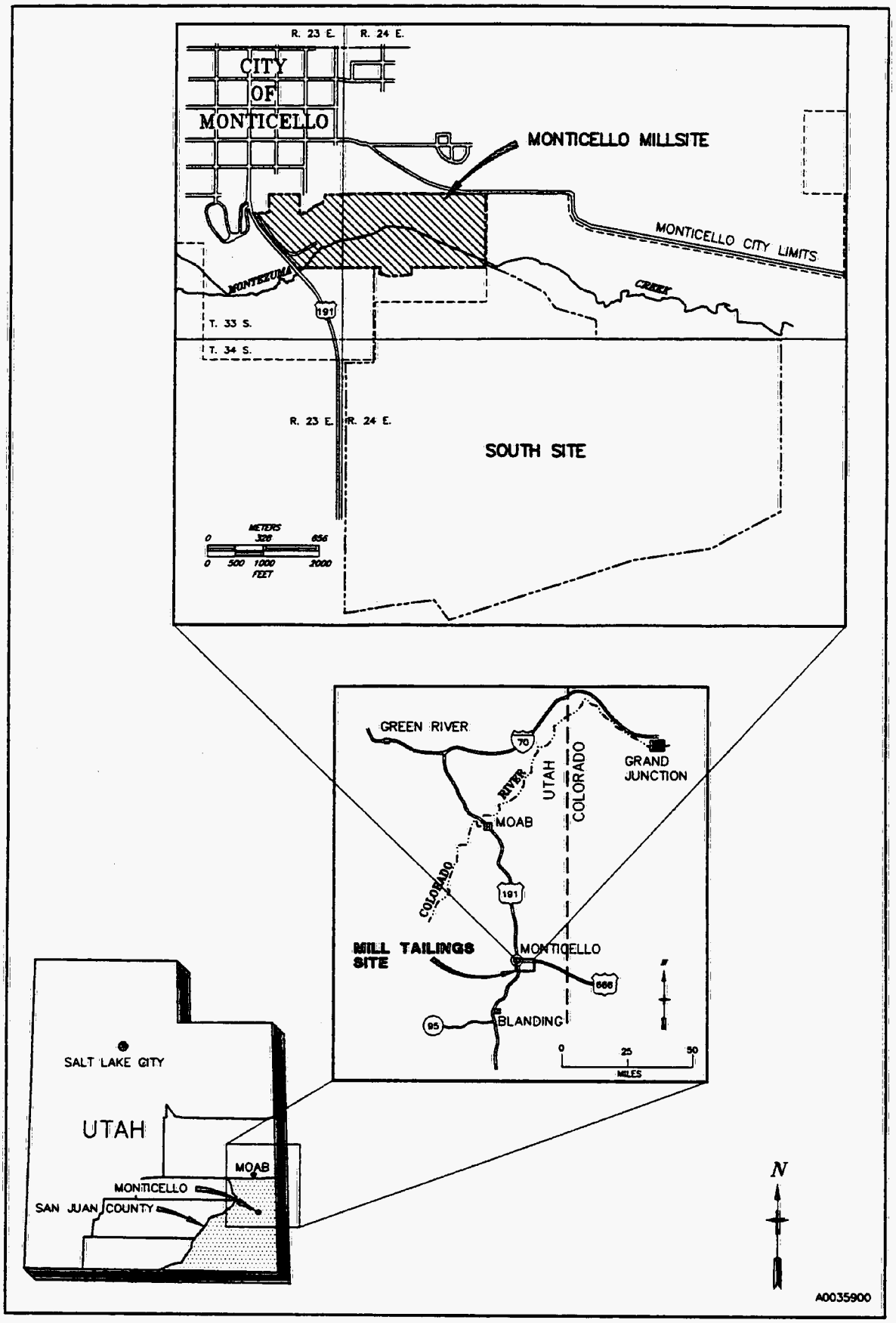

Figure 1–3. Location of Monticello Mill Tailings Site

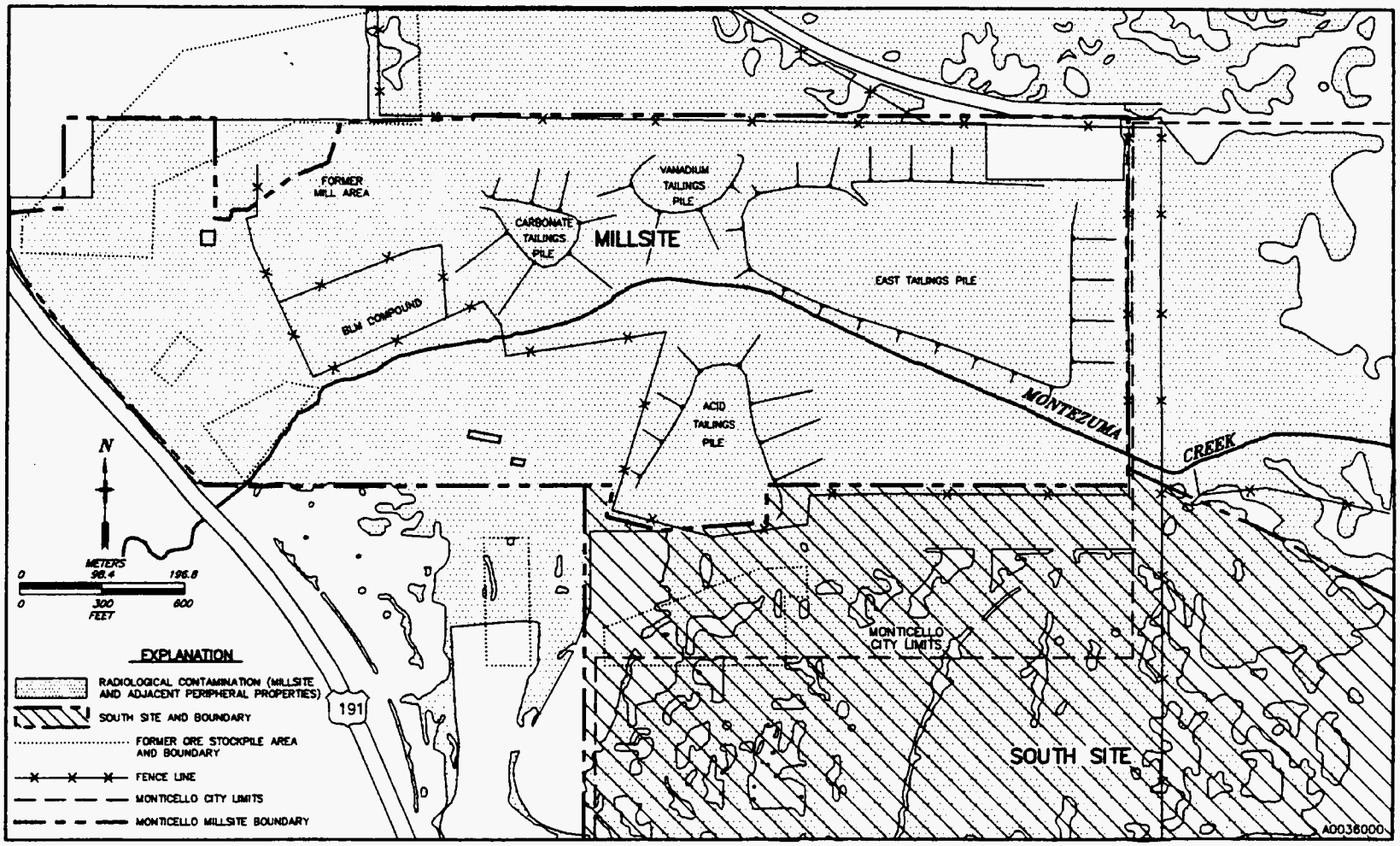

Figure 1–4. Radiological Contamination Map of Monticello Millsite

The Monticello mill was constructed in 1942 and was operated by various companies through 1960. Before 1955, the environmental problems receiving attention at the Monticello mill arose from the salt roast method used to enhance vanadium recovery. An average of nearly 1,182 kilograms (2,600 pounds) of dust containing 0.363-percent uranium oxide and 1.52-percent vanadium pentoxide escaped daily through the roaster stack (Allen and Klemenic 1954). Corrosion of wire fences, clotheslines, and galvanized roofs was verified by the mill operator in response to complaints from nearby residents.

Liquid effluent from the salt roast/carbonate leach plant, which contained higher-than-background concentrations of chloride, sulfate, carbonate, bicarbonate, sodium, and other dissolved species, was released into Montezuma Creek during early operations. Releases of radium-226 were of special concern; soluble radium activity in Montezuma Creek was found to be 160 picocuries per liter (pCi/L). Additionally, suspended solids were found to contain considerable radium activity, and it was discovered that dry tailings were eroding into the creek (Whitman and Beverly 1958).

Cleanup activities conducted since the time of mill closure reduced the release of radium-226 and stabilized the tailings piles, but water contamination from leaching of the mill tailings remains a problem. Extensive hydrologic monitoring conducted at the millsite has demonstrated that all four tailings piles contribute to the contamination of groundwater and surface water, both on and off of the site (Bendix 1980; Korte and Thul 1981, 1982, 1983, 1984; Korte and Wagner 1985, 1986; Sewell and Spencer 1987; DOE 1988b, 1989b, 1990c, 1991c, 1992b, 1993b, 1994b, and 1995d).

Other environmental monitoring has included meteorological and atmospheric radon measurements and air particulate sampling. Radon emissions at all four tailings piles historically have exceeded EPA standards; however, air particulate concentrations have been below regulatory limits.

DOE–GJPO and DOE Headquarters are responsible for the administration, maintenance, and environmental monitoring of MMTS. The millsite was accepted into the SFMP in 1980 and, in November 1989, was transferred to the DOE Office of Environmental Restoration and Waste Management, Eastern Area Programs Division, D&D Branch. In May 1991, program oversight responsibility for the Monticello projects was transferred to the Southwestern Area Programs Division, D&D Branch. The goals of MRAP and MSGRAP are to minimize potential health hazards that are associated with the millsite tailings and to clean up contaminated surface water and groundwater on and below the millsite.

With the passage of SARA, the activities at the Monticello millsite also came under the regulatory framework of CERCLA. During 1987, existing environmental site characterization and engineering documents were revised into the format of a CERCLA RI/FS. DOE, EPA, and the State of Utah entered into a *Federal Facility Agreement* (EPA et. al 1988), pursuant to CERCLA Section 120, in December 1988. This agreement stipulated the procedural framework for developing and implementing response actions under CERCLA. On November 16, 1989, the Monticello millsite was listed on the National Priorities List. The RI/FS was modified in 1989 to include the requirements for an EA under NEPA and was finalized in March 1990 as the *Final Remedial Investigation/Feasibility Study–Environmental Assessment for the Monticello, Utah, Uranium Mill Tailings Site* (DOE 1990d). The MMTS ROD, which describes remedial actions for MRAP, was signed on September 20, 1990 (DOE 1990f). Remedial action started on August 19, 1991, with the abandonment of the older U.S. Atomic Energy Commission wells. DOE currently is conducting an RI/FS for surface water and groundwater.

The permanent repository that will contain tailings removed from the millsite and the Monticello area will be constructed on the South Site (Figure 1–3). This repository will be designed to protect groundwater in accordance with applicable regulations. After construction is completed, the Long-Term Surveillance and Maintenance Program will assess compliance with groundwater protection standards. Surface water, air quality, and meteorological data will be collected, as required, to assess emissions during repository construction and at closure.

1.3.5 Monticello Millsite Health Effects

A quantitative assessment of the potential health effects associated with tailings-related contamination is presented in the Final RI/FS–EA (DOE 1990d). This assessment is based on site-specific data collected from 1981 through 1986. Additional data of a more limited scope were collected during 1988, 1989, and 1990 and indicate that the groundwater and atmospheric radon concentrations are consistent with previous years' values. Because these data were consistent and because there were no operational activities at the site during this period that would be expected to cause a significant increase in the source terms, a risk assessment based on the 1988–1990 monitoring data was not undertaken. The risk estimates presented in Table 1–1, summarized from the Final RI/FS–EA, are representative of the radiological risk at the site.

Table 1–1. Population Dose Commitments to Monticello Residents From Natural Background and Present Enhanced Conditions

Source	Dose Commitment (person-rem per year)[a] Whole Body	Lung
Natural Background		
Direct External Exposure	316	NA[b]
Radon Daughters (Inhalation)	NA	1,265
Enhanced Conditions (excluding background)		
Direct External Exposure	165	NA
Radon Daughters	NA	188

[a]Dose estimates are based on a population of 2,469.
[b]NA = not applicable. The dose from external exposure is not applicable to the lung because it is an internal organ; the dose from radon daughters is not applicable to the whole body because alpha particles do not penetrate the skin.

Although contaminant levels are low, a potential exists for adverse health effects from chance exposure to nonradiological contaminants found in the waters of Montezuma Creek, associated floodplain soils, and uranium tailings piles. Toxicity potentials were derived from a comparison of contaminant levels with acceptable intakes for chronic exposure. Tables showing these toxicity potentials are in the Final RI/FS–EA. When average concentrations in the tailings were used, none of the dose levels were exceeded. When maximum concentrations in the tailings were used, copper, uranium, and zinc exceeded the recommended exposure limits for children. However, because of the low population densities along the Montezuma Creek drainage and because of the land-use patterns in the area, it is unlikely that individuals would receive chronic exposures to these maximum concentrations.

Some constituents found in Montezuma Creek such as arsenic, gross alpha, gross beta, pH, selenium, and total dissolved solids regularly exceed State of Utah water quality standards. DOE is conducting a risk assessment to determine if these constituents pose an unacceptable risk to ecological and human receptors.

Section 2.0
Meteorology

2.0 Meteorology

2.1 Regulatory Requirements

Meteorological monitoring for GJPO and MMTS is conducted to comply with the ARARs listed in Table 2–1.

2.2 GJPO

2.2.1 Historical and Present Meteorological Monitoring

Meteorological monitoring for GJPO involves collection of on-site and, at times, off-site meteorological monitoring data. An on-site meteorological monitoring station (Figure 2–1) provides site-specific data that are used to compile baseline meteorological data. Off-site meteorological data are available from the National Weather Service office, located approximately 8 km (5 miles) northeast of the GJPO facility at Walker Field Airport.

The current meteorological monitoring program began at GJPO in fall 1993. Before that date, data were obtained from the National Weather Service office. Meteorological parameters measured at the GJPO station include temperature, relative humidity, barometric pressure, precipitation, wind speed, and wind direction. The standard deviation of wind direction, which is used to estimate atmospheric stability, is calculated and stored hourly. Monitoring sensors are mounted on a 10-meter tower and are connected to a Campbell Scientific CR–10 data logger. Measurements are taken every 15 seconds and are averaged at 1-hour and 24-hour intervals by the data logger and associated software. Specifications for the on-site monitoring station's instrumentation, including the instrument type, manufacturer, accuracy, range, and starting threshold values, are listed in Table 2–2.

2.2.2 Planned Meteorological Monitoring

2.2.2.1 Monitoring Objectives

The objectives of the GJPO meteorological monitoring program are

1. To maintain and expand a meteorological database.

2. To provide data to characterize atmospheric transport and diffusion conditions in the vicinity of the GJPO facility for assessing impacts of airborne releases on public health and safety.

Current and future monitoring will accomplish these objectives.

DOE Order 5400.5 and 40 CFR Part 61, Subpart H, both require that meteorological data be used with an EPA-approved computer model to determine the potential impacts to members of the public from DOE activities. To comply with these requirements, meteorological data will be used with the CAP88–PC computer model.

Table 2–1. ARARs for Meteorological Monitoring

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO and MMTS		
General Environmental Protection Program	DOE Order 5400.1, Chapter IV, Part 6	Representative meteorological data are required at U.S. Department of Energy (DOE) facilities to support environmental monitoring requirements. Meteorological information must be available at or in the vicinity of DOE facilities to characterize atmospheric transport and diffusion conditions, to characterize conditions important to environmental surveillance activities, and to confirm compliance with and implementation of regulations and DOE orders.
Radiation Protection of the Public and the Environment	DOE Order 5400.5, Chapter I, Part 8a, Chapter II, Part 6b(1)	Demonstrations of compliance with this order generally will be based on calculations that make use of information obtained from environmental monitoring and surveillance programs. Compliance with the dose limits of this order is demonstrated by the use of a dose model. The dose model requires the input of meteorological data that characterize the atmospheric transport and diffusion conditions in the vicinity of the site.
Radiological Effluent Monitoring and Environmental Surveillance	DOE Environmental Regulatory Guide Chapter 4	Each DOE facility must establish a meteorological monitoring program that is appropriate to the activities at the site. Characterization of meteorological conditions is an integral part of the dose-assessment capabilities for both planned and unplanned releases. DOE sites are required to have on-site measurement capabilities of wind direction, wind speed, and atmospheric stability available to evaluate atmospheric dispersion in the vicinity of facilities and to perform the required dose calculations specified in this document and 40 *U.S. Code of Federal Regulations* (CFR) Part 61. However, some sites may choose to establish a meteorological program that makes use of meteorological measurements from off-site sources. If data from an off-site source are used, they must be representative of conditions at the DOE facility, statistically valid, and consistent with on-site monitoring data requirements. Specific meteorological information requirements for each facility must be based on the magnitude of potential source terms, nature of potential releases from the facility, possible pathways to the atmosphere, distances from release points to critical receptors, and proximity of other DOE facilities. Meteorological information requirements for facilities must also be sufficient to support environmental monitoring and surveillance programs.
ARAR Specific to GJPO		
Clean Air Act	40 CFR 61 Subpart H (NESHAPs)	Meteorological information is required for input in a dose model that is used to calculate the highest effective dose equivalent to any member of the public.

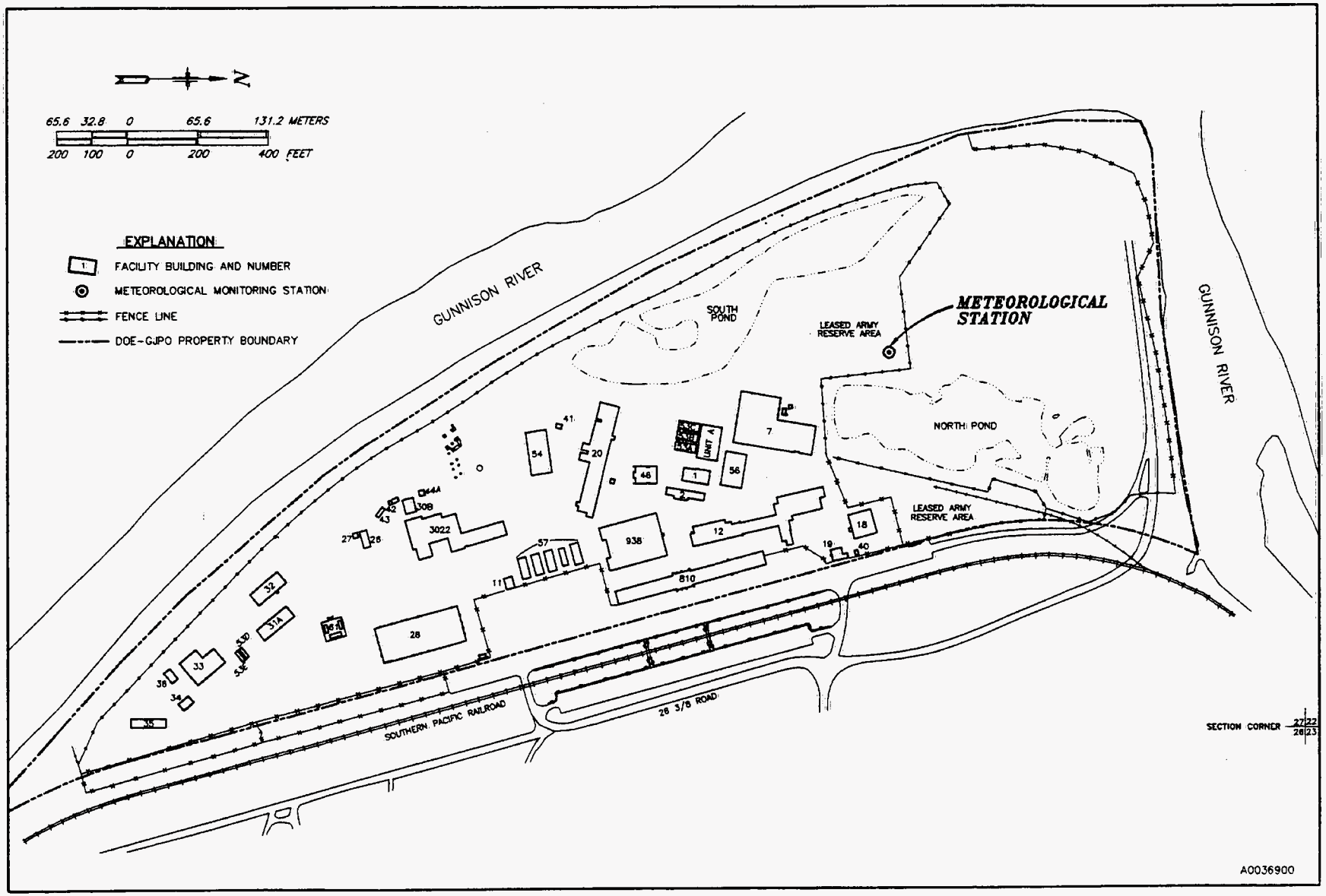

Figure 2–1. Location of Meteorological Monitoring Station at GJPO Facility

Table 2–2. GJPO Meteorological Equipment Specifications[a]

Instrument Type	Manufacturer	Accuracy	Range	Starting Threshold
Wind Speed	R.M. Young	± 0.2 m/s	0–90 m/s	0.4 m/s
Wind Direction	R.M. Young	± 1.5°	0–360°	0.5 m/s
Relative Humidity	Nova Lynx	± 2%	0–100 %	NA
Barometric Press.	Vaisala	± 0.4 mb	600–1045 mb	NA
Temperature	Nova Lynx	± 0.4 °C	-40 to +60 °C	NA
Precipitation	Met One	± 1 mm	Infinite	NA

[a]m/s = meter per second; NA = not applicable; mb = millibars; C = Celsius; mm = millimeter

2.2.2.2 Sampling Plan

Meteorological data will continue to be collected at GJPO with the Campbell Scientific CR–10 logger at a measurement frequency of 15 seconds and a data-averaging frequency of 1 hour. Data will be downloaded weekly from the data logger to a database and will be evaluated for completeness and quality.

Contractor Environmental Services personnel will perform field checks on instrumentation weekly. Field checks will involve a visual inspection to ensure that all sensors are clean and undamaged. Additionally, field calibration checks of the sensors will be performed quarterly. Equipment used for calibration checks will be calibrated by the contractor's Electronics Laboratory personnel (or subcontracted to an off-site laboratory) in accordance with the lab's QA-approved procedures. Procedures for operating, maintaining, and performing calibration checks are described in detail in the *Sampling and Analysis Plan for Environmental Monitoring* (DOE 1994e).

2.2.2.3 Data Management

The contractor's data manager will maintain a database for all meteorological monitoring data. Data management will include downloading meteorological data into an ORACLE database and formatting the data for report preparation and computer input. Data will be stored in the ORACLE database on a multi-user computer system and will be backed up weekly.

2.2.2.4 Data Analysis and Reporting Format

Before collected data are downloaded to the ORACLE database, they will be visually inspected to ensure that data values are within the expected range and that the data set is complete. Monitoring data will be converted to a yearly average file that is compatible with the CAP88–PC computer model. In addition, meteorological monitoring data will be made available to users upon request.

2.2.3 Responsible Organizations

Meteorological monitoring at GJPO is the responsibility of the DOE–GJPO Manager. Responsibility for implementing the monitoring program resides with the contractor's Environmental Services section.

2.3 MMTS

2.3.1 Historical and Present Meteorological Monitoring

The current meteorological monitoring program began at MMTS in fall 1993. Before that date, data were obtained from several sources, including a former MMTS monitoring station. Meteorological parameters measured at MMTS include temperature, relative humidity, barometric pressure, precipitation, solar radiation, wind speed, and wind direction. The standard deviation of wind direction, which is used to estimate atmospheric stability, is calculated and stored hourly. Monitoring sensors are mounted on a 10-meter tower and are connected to a Campbell Scientific CR–10 data logger. Measurements are taken every 15 seconds and are averaged at 1-hour and 24-hour intervals by the data logger and associated software. Specifications for the station's instrumentation, including the instrument type, manufacturer, accuracy, range, and starting threshold values, are listed in Table 2–3. Location of the station is shown in Figure 2–2.

Table 2–3. MMTS Meteorological Equipment Specifications[a]

Instrument Type	Manufacturer	Accuracy	Range	Starting Threshold
Wind Speed	R.M. Young	± 0.2 m/s	0–90 m/s	0.4 m/s
Wind Direction	R.M. Young	± 1.5°	0–360°	0.5 m/s
Relative Humidity	Nova Lynx	± 2 %	0–100 %	NA
Barometric Press.	Vaisala	± 0.4 mb	600–1045 mb	NA
Temperature	Nova Lynx	± 0.4 °C	-40 to +60 °C	NA
Precipitation	ETI	± 1 mm	Infinite	NA
Solar Radiation	Nova Lynx	± 5 %	0.35–1.15 μm	NA

[a]m/s = meter per second; NA = not applicable; mb = millibars; C = Celsius; mm = millimeter; μm = micrometers.

2.3.2 Planned Meteorological Monitoring

2.3.2.1 Monitoring Objectives

The objectives of the MMTS meteorological monitoring program are

1. To establish a meteorological database, and

2. To provide data to characterize atmospheric transport and diffusion conditions in the vicinity of MMTS for assessing impacts of airborne releases on public health and safety.

Current and future monitoring will accomplish these objectives.

DOE Order 5400.5 requires that meteorological data be used with an EPA-approved computer model to determine the potential impacts to members of the public from DOE activities. To comply with this requirement, meteorological data will be used with the CAP88–PC computer model.

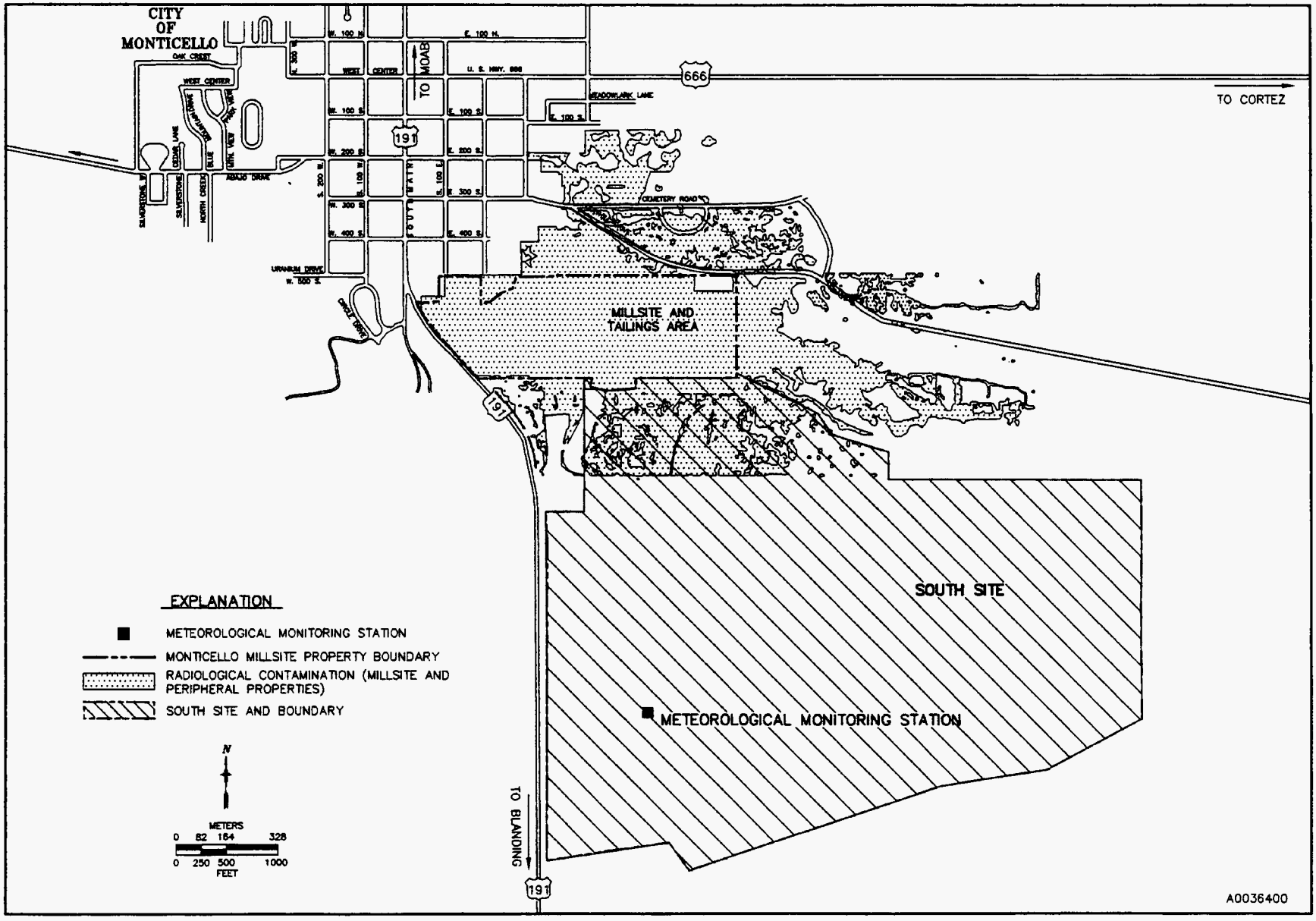

Figure 2–2. Location of Meteorological Monitoring Station at MMTS

2.3.2.2 Sampling Plan

Sampling of meteorological data will be the same as that described for GJPO in Section 2.2.2.2.

2.3.2.3 Data Management

Data management will be the same as that described for GJPO in Section 2.2.2.3.

2.3.2.4 Data Analysis and Reporting Format

The data analysis and reporting format will be the same as that described for GJPO in Section 2.2.2.4.

2.3.3 Responsible Organizations

Responsible organizations will be the same as those described for GJPO in Section 2.2.3.

3.0 Liquid Effluent

3.1 Regulatory Requirements

Radiological and nonradiological liquid effluent monitoring for GJPO and MMTS are conducted to comply with the ARARs outlined in Table 3–1.

3.2 GJPO

Two types of liquid effluent are generated on the GJPO facility: (1) waste effluent discharged into an underground sewer system that is routed to the city of Grand Junction's publicly owned treatment works and (2) storm water runoff that is collected in a series of drain pipes and discharged into the South Pond (located on the facility). The sewer effluent consists of domestic sewage and typical industrial-type discharges from the Analytical Laboratory, cafeteria, and wash bay of the maintenance shop. Storm water effluent consists of runoff from the facility parking lots, office buildings, and paved areas. According to Federal regulations outlined in 40 CFR 122, National Pollutant Discharge Elimination System (NPDES) permits are not required for either type of discharge.

3.2.1 Historical Liquid Effluent Monitoring

Initially, all on-site sanitary wastewater was passed through septic tanks and then discharged into the South Pond on the GJPO facility. The facility was connected to the city of Grand Junction sewer system in 1981, eliminating the need for septic systems. In 1987, GJPO applied for an Industrial Pretreatment Permit and developed an effluent profile to characterize the discharge. The effluent included approximately 23 kilograms (50 pounds) per year of laboratory acids—primarily nitric and hydrochloric—in dilute concentrations. Less than 1 gram per year of organics such as aldrin, lindane, endrin, and toxaphene was present. Several inorganics also were discharged to the sewer system in low concentrations. During the permit application period, several pretreatment measures, such as installing grease traps in the cafeteria and maintenance shop, were implemented.

An Industrial Pretreatment Permit (No. 0023) was issued to GJPO by the city of Grand Junction in March 1989. On March 1, 1993, conditions of a revised permit (No. 23REV) became effective. The issuance of the original and revised permits was in accordance with provisions of the Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977; and in accordance with Article 10 of Chapter 25, Code of Ordinance, for the city of Grand Junction. The revised permit requires GJPO to sample the sewer effluent quarterly and to submit quarterly analysis reports to the city. Table 3–2 lists the analytes required to be sampled and the threshold limits established by the permit. The permit also requires GJPO to submit measurements of the average and maximum daily flows. Sampling occurs from a location marked as Outfall 001 in Figure 3–1.

In addition to the permit requirements, analyses for gross alpha and gross beta are performed to provide evidence of compliance with DOE Order 5400.5 regarding discharge of radioactive materials to the sewer system.

Table 3–1. ARARs for Liquid Effluent Monitoring

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO and MMTS		
General Environmental Protection Program	DOE Order 5400.1, Chapter II, Part 5	A Radioactive Effluent and On-Site Discharge Data Report is required annually and must include unplanned releases of radioactive materials in effluents.
	DOE Order 5400.1 Chapter IV, Part 5a	Effluent monitoring shall be conducted at all U.S. Department of Energy (DOE) sites to satisfy the following program objectives: • Evaluate the effectiveness of effluent treatment and control. • Identify potential environmental problems and evaluate the need for remedial actions or mitigation measures. • Support permit revision and/or reissuance. • Detect, characterize, and report unplanned releases.
Radiation Protection of the Public and the Environment	DOE Order 5400.5, Chapter I, Parts 3 and 7	The best available technology (BAT) selection process shall be implemented through a BAT Analysis Implementation Plan if radionuclides are detected greater than 5 times the derived concentration guide (DCG).
	DOE Order 5400.5, Chapter III, Part 3d	The exposure of members of the public to radiation sources as a consequence of all routine DOE activities shall not cause an annual effective dose equivalent of greater than 100 mrems.
Radiological Effluent Monitoring and Environmental Surveillance	DOE Environmental Regulatory Guide, Chapter 2	All effluent streams from DOE facilities shall be evaluated and their potential for release of radionuclides shall be assessed. This evaluation is required to adequately control such releases. The results of assessments provide the basis for each facility's effluent monitoring program that shall be documented in the Environmental Monitoring Plan to show: • Effluent extraction locations used for providing quantitative effluent-release data for each outfall. • Procedures and equipment used to perform effluent extraction and measurement. • Minimum detection level and accuracy. • Frequency and analysis required for each extraction location. • Quality assurance components.

Table 3–1 (continued). ARARs for Liquid Effluent Monitoring

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO and MMTS (continued)		
Radiological Effluent Monitoring and Environmental Surveillance (continued)	DOE Environmental Regulatory Guide, Chapter 2	Liquid effluents that have the potential for radioactive contamination shall be monitored in accordance with the requirements of DOE Order 5400.1, *General Environmental Protection Program*; and DOE Order 5400.5, *Radiation Protection of the Public and the Environment*. Facility operators shall provide monitoring of liquid waste streams • To quantify radionuclides released from each discharge point. • To alert affected process supervisors of disturbances in process and emissions controls. Continuous radionuclide monitoring should be provided on those release points that could • Exceed 1 DCG equivalent at the point of release averaged over 1 year and that are detectable with state-of-the-art continuous monitoring devices, or • Result in unanticipated releases to the environment that could exceed 1 DCG averaged over 1 year.
ARARs Specific to GJPO		
National Pretreatment Standards (40 CFR Part 403)	Federal Water Pollution Control Act, as amended by Clean Water Act of 1977 (Public Law 95–217)	Standards specify quantities or concentrations of pollutants or pollutant properties that may be discharged to a publicly owned treatment works and specify prohibited discharges.
National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges	40 CFR Parts 122, 123, and 124 (Federal Register November 16, 1990)	This rule implements Section 402(p) of the Clean Water Act, which requires the U.S. Environmental Protection Agency to establish regulations setting forth National Pollutant Discharge Elimination System permit application requirements for storm water discharges associated with industrial activity.

Table 3–1 (continued). ARARs for Liquid Effluent Monitoring

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Specific to GJPO (continued)		
Guidelines Establishing Test Procedures for the Analysis of Pollutants	40 CFR Part 136	This rule lists the analytical procedures that are approved for the testing of storm water discharge.
Radiation Control	Colorado Department of Public Health and Environment (CDPHE), Rules and Regulations, Section 4.18, Part IV	The discharge limit for releases into the sanitary sewer system is 400 picocuries per liter. This limit is based on the conservative assumption that neither the identity nor the concentration of any radionuclide is known.
City of Grand Junction/Mesa County Industrial Pretreatment Permit	Article 10, Chapter 25, Code of Ordinance of the City of Grand Junction	Industrial discharge into the sanitary sewer and subsequently to the city of Grand Junction's publicly owned treatment works requires an Industrial Pretreatment Permit to comply with the provisions of the Clean Water Act of 1977. The Industrial Pretreatment Permit specifies concentration limits for a list of analytes. Quarterly monitoring and reporting is required to comply with an Industrial Pretreatment Permit.
ARAR Specific to MMTS		
Utah Pollutant Discharge Elimination System (UPDES) Rules	Utah Administration Code (UAC) R317-8. Environmental Quality, Water Quality Control	UPDES criteria have been established for the discharge of pollutants from the wastewater treatment plant at MMTS.

Table 3–2. Sewer Effluent Pollutants, Discharge Limits, and Reporting Limits for GJPO Facility[a]

Pollutant	Daily Maximum Limit	Type of Sample	Reporting Limit	
Biochemical Oxygen Demand	No limit	Composite	10	mg/L
Total Suspended Solids	No limit	Composite	5	mg/L
Total Dissolved Solids	No limit	Composite	10	mg/L
Ammonia	No limit	Composite	0.02	mg/L
Temperature	40 °C or 104 °F	Grab	0.5	°C
pH	5.5–9.5 units	Grab	0.01	units
Oil and Grease	50 mg/L	Grab	5	mg/L
Silver	0.43 mg/L	Composite	0.010	mg/L
Polychlorinated Biphenyls	0.002 mg/L	Composite	0.0002	mg/L
Gross Alpha and Beta[b]	150 pCi/L	Composite	1.0	pCi/L[c]

[a]mg/L = milligram per liter; C = Celsius; F = Fahrenheit; pCi/L = picocurie per liter.
[b]Not required by permit.
[c]Value expressed is the typical reporting limit. The actual reporting limit varies with the concentration of total dissolved solids in the effluent.

The storm-water drain system was installed at GJPO during the 1950s and was renovated during GJPORAP remedial activities in 1992. Storm water runoff from administrative office buildings and employee parking lots is collected and discharged into the South Pond. Because this type of runoff does not meet the regulatory definition of "being associated with industrial activity," the GJPO facility is exempt from the requirements of the NPDES Storm Water Program.

The first storm water sample was collected in September 1994 from storm drain manhole No. 3 (SDMH–3 in Figure 3–1). This location was selected because it receives storm water from areas of the facility that have the highest potential for contamination: employee parking lots, the main entrance to the facility, storage areas, and site maintenance workshops. The sample was analyzed for the constituents recommended by EPA (1991) and listed in Table 3–3. Maximum contaminant levels for these constituents have not been established for the GJPO facility.

3.2.2 Planned Liquid Effluent Monitoring

3.2.2.1 Monitoring Objectives

The objectives of the GJPO liquid-effluent monitoring program are

1. To verify compliance with the Industrial Pretreatment Permit (No. 23REV) issued by the city of Grand Junction.

2. To provide evidence of compliance with DOE Order 5400.5 regarding the discharge of radioactive materials to the sanitary sewer system.

3. To characterize the quality of storm water runoff discharged from the storm-water collection system.

Table 3–3. Storm-Water Effluent Analytes and Respective Reporting Limits for GJPO Facility[a]

Analyte	Reporting Limit
pH	0.01 unit
Biochemical Oxygen Demand	10.0 mg/L
Chemical Oxygen Demand	1 mg/L
Total Suspended Solids	5 mg/L
Total Phosphorus	0.5 mg/L
(Nitrate + Nitrite) as Nitrogen	0.02 mg/L
Total Kjeldahl Nitrogen	1 mg/L
Radium-226	0.5 pCi/L
Total Uranium	1.0 pCi/L

[a]mg/L = milligram per liter; pCi/L = picocurie per liter.

3.2.2.2 Sampling Plan

The liquid effluent discharged into the sanitary sewer system will be sampled quarterly at Outfall 001 (Figure 3–1). Samples collected from the sewer effluent will be analyzed for the constituents listed in Table 3–2. Reporting limits for each of the analytes also are listed in Table 3–2. The list of constituents was chosen on the basis of the Industrial Pretreatment Permit requirements and DOE Order 5400.5 requirements for radiological-effluent rate characterization.

Although sampling and monitoring of storm water runoff is not required by Federal or State regulations, characterization of the effluent is a best management practice. Storm water effluent will be sampled manually from SDMH–3 near the outfall to the South Pond (Figure 3–1) and will be analyzed for the constituents listed in Table 3–3. At a minimum, effluent will be sampled once a year during a representative storm event.

Procedures, methods, and equipment used for sewer effluent and storm water sampling are described in the *Sampling and Analysis Plan for Environmental Monitoring* (DOE 1994e). Effluent samples will be analyzed by the Analytical Laboratory following procedures outlined in the *Analytical Chemistry Laboratory Handbook of Analytical and Sample-Preparation Methods* (DOE 1995b). This handbook prescribes the precision of each of the analytical techniques and the methodology and reporting limits used by the laboratory.

QA and QC measures will be implemented during all sampling and analysis activities. The precision and accuracy of the sample results will be determined by the use of field and laboratory QC measures. Field QC will be accomplished by the collection and analysis of field duplicates. Laboratory QC will be accomplished by the analysis of blind duplicates, spikes, spike duplicates, method blanks, and calibration standards, when applicable to the analytical method being performed at a frequency in accordance with the *Analytical Chemistry Laboratory Administrative Plan and Quality Control Procedures* (DOE 1995a). Details of the QA program are in Section 10.0 and Appendix A of this EMP.

3.2.2.3 Data Management

The contractor's data manager will maintain a database for the liquid-effluent monitoring program. All documentation, such as laboratory reports and Industrial Pretreatment Permit reports, will be centralized in a permanent project file by the contractor's Environmental Services section. In addition, all reports and data will be stored in a permanent project file in the contractor's records management section.

3.2.2.4 Data Analysis and Reporting Format

Data will be analyzed to determine if monitoring objectives have been met. Only data of known quality will be compared to threshold limits. Compliance with the threshold limits established for sewer effluent will be achieved if every measured value falls below or within the limits of the threshold value(s). Sewer effluent data will be internally reviewed by the contractor's Waste Management subsection and subsequently submitted to the city of Grand Junction on a quarterly basis. Results of the sewer effluent and storm water monitoring will be summarized in the Annual Site Environmental Report.

3.2.3 Responsible Organizations

The DOE–GJPO Manager is responsible for ensuring compliance with the Industrial Pretreatment Permit. Routine sample collection and data evaluation are delegated to the contractor's Environmental Services section.

3.3 MMTS

Two types of contaminated liquid effluent are generated on the Monticello millsite: (1) liquid from dewatering of the shallow alluvial aquifer during remediation activities and (2) storm water runoff. Both types of effluent are routed to Holding Pond No. 3 (Figure 3–2). The collected water is then pumped to the wastewater treatment plant for treatment and eventual discharge to Montezuma Creek.

The Utah Pollutant Discharge Elimination System (UPDES) permit rules establish an analyte list, 30-day average effluent limits, and maximum discharge levels for discharges to waters of the State. Although MMTS is a CERCLA site and, therefore, exempt from obtaining a discharge permit, compliance with substantive UPDES requirements is required.

3.3.1 Historical Liquid Effluent Monitoring

Monitoring of pretreated storm water runoff and the wastewater-treatment-plant effluent (i.e., treated storm water runoff) began in 1995. The sampling goal was to characterize storm water runoff and treated effluent waters. Sampling of the pretreated and treated effluent was conducted weekly for the analytes listed in Table 3–4. In addition, one acute static-replacement whole-effluent-toxicity (WET) sample was collected from Montezuma Creek downstream of the effluent discharge point.

In July 1995, groundwater was extracted from monitoring well 88–89 (completed in the shallow alluvial aquifer), diverted into Holding Pond No. 3, and eventually treated and discharged to Montezuma Creek. This pump-and-treat exercise, in anticipation of aquifer dewatering during remediation, was conducted to determine the treatment-plant capability for treating contaminated groundwater. Sampling results indicated that, regardless of the type of water treated, the wastewater-treatment-plant effluent was in compliance with UPDES limits.

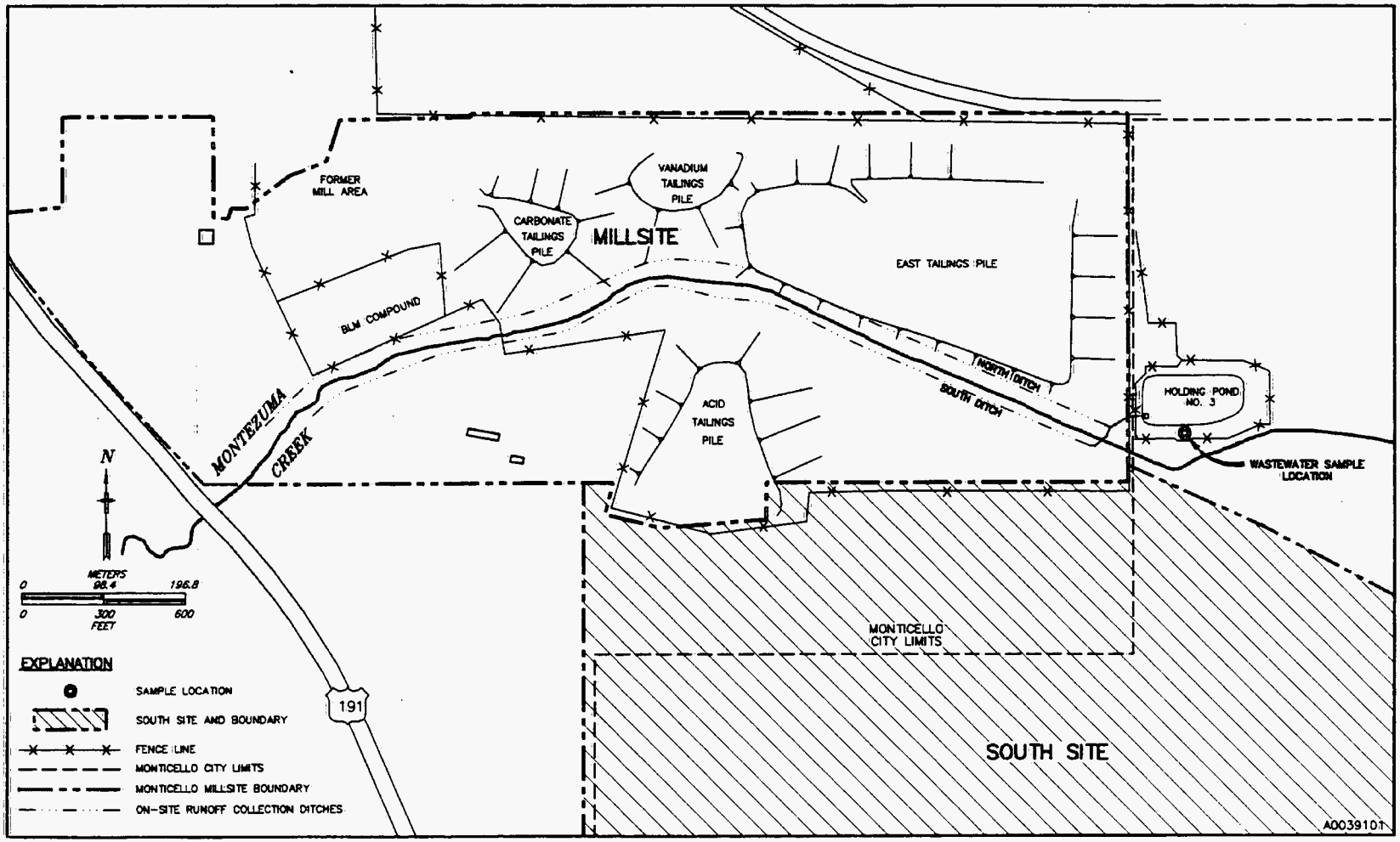

Figure 3–2. Liquid-Effluent Sampling Locations at MMTS

Table 3–4 Liquid Effluent Analytes and Discharge Limits for MMTS[a]

Analyte	Effluent Concentration Limits (30-day average)		Maximum Effluent Concentration in Any Sample	
Total Suspended Solids	20	mg/L	30	mg/L
Biochemical Oxygen Demand	25	mg/L	35	mg/L
Chemical Oxygen Demand	100	mg/L	200	mg/L
Total Radium-226	---		5	pCi/L
Dissolved Radium-226	3	pCi/L	---	
Uranium	2	mg/L	4	mg/L
Total Zinc	0.31	mg/L	0.34	mg/L
Ammonia as Nitrogen	3.9	mg/L	5.6	mg/L
Total Alpha (includes uranium)	50	pCi/L	50	pCi/L
Total Arsenic	0.01	mg/L	0.05	mg/L
Total Mercury	0.00002	mg/L	0.0024	mg/L
Iron	---		1	mg/L
Total Lead	0.016	mg/L	0.05	mg/L
Total Selenium	0.012	mg/L	0.02	mg/L
Total Silver	0.00012	mg/L	0.035	mg/L
Oil and Grease	---		10	mg/L
pH	6.5–9.0	units	---	
Nitrate as Nitrogen	5	mg/L	10	mg/L
Total Dissolved Solids	1500	mg/L	3000	mg/L

[a]mg/L = milligram per liter; pCi/L = picocurie per liter.

3.3.2 Planned Liquid Effluent Monitoring

3.3.2.1 Monitoring Objective

The objective of the MMTS liquid-effluent monitoring program is to verify compliance with the UPDES water-quality discharge limits.

3.3.2.2 Sampling Plan

The wastewater-treatment-plant effluent will be sampled at least twice a month for the analytes listed in Table 3–4. In addition, an acute static-replacement WET test will be collected quarterly. The WET test will be conducted with *Ceriodaphnia* species (water flea) and *Pimaphales promelas* (fathead minnow). Accelerated testing and pattern of toxicity will be performed if the WET test results in 50-percent or greater mortality.

A sampling and analysis plan will be developed before the plant begins operating in 1996. This plan will identify the following sampling criteria:

- Sampling location.
- Number and purpose of samples to be taken.
- Chain-of-custody procedures.

- Analytical methods, including detection and reporting levels.
- DQOs for each analyte.
- Specific information to be reported.
- Number and type of QC samples.
- Sample analysis reporting format, report content, and measurement units.

3.3.2.3 Data Management

The contractor's data manager will maintain a database for the liquid-effluent monitoring program. In addition, all reports and data will be stored in a permanent project file in the contractor's records management section.

3.3.2.4 Data Analysis and Reporting Format

Semimonthly analytical data will be averaged and compared to the allowable monthly average values and to the maximum values given in Table 3–4. Only data of known quality will be used to assess compliance with the discharge limits. Analytical data reports will be submitted to the State on a quarterly basis.

3.3.3 Responsible Organizations

The DOE–GJPO Manager is responsible for ensuring compliance with the UPDES discharge limits. Routine sample collection and data evaluation responsibilities are delegated to the contractor operating the wastewater treatment plant.

4.0 Surface Water

4.1 Regulatory Requirements

Surface-water environmental surveillance programs for GJPO, GJPORAP, and MMTS are conducted to comply with the ARARs outlined in Table 4–1.

4.2 GJPO/GJPORAP

Surface waters at or near the GJPO facility include the Gunnison River, North and South Ponds, and Wetland Area (Figure 4–1). The Gunnison River is immediately adjacent to the facility and flows along the north and west boundaries of the property; the North and South Ponds are located on the GJPO facility and contain water year-round; the Wetland Area was formed in spring 1994 from the excavation of contaminated soils during GJPORAP operations. Although the majority of the Wetland Area is dry during low groundwater periods (September through February), a portion of the area was designed to contain water year-round for monitoring purposes.

The North and South Ponds and Wetland Area are recharged by the shallow alluvial aquifer underlying the facility and exhibit some of the same characteristics as the groundwater. Like the groundwater, these surface waters are contaminated by the leached by-products of uranium mill tailings (e.g., arsenic, manganese, molybdenum, selenium, sulfate, uranium, and vanadium). The Gunnison River also receives discharges from the shallow alluvial aquifer. The only known constituent that might affect Gunnison River water quality is uranium. However, water quality has never been affected to the extent that the State standard for uranium was exceeded. A complete description of surface water sources is available in the GJPO RI/FS–EA (DOE 1989c).

4.2.1 Historical Surface Water Monitoring

Monitoring of surface water quality at GJPO began in 1979 and is ongoing. Originally, the main goal of the monitoring was to characterize the type and extent of contamination within the North and South Ponds, Dike Ditch, Wetland Area, and Gunnison River. The Dike Ditch was a depression next to the Gunnison River dike that was recharged by groundwater during high groundwater periods. This feature was removed during remedial action at the GJPO facility. Generally, the surface water sources were "grab sampled" at the shorelines semiannually or quarterly. The Gunnison River was sampled upstream of the facility for background concentrations, and the results were compared with those of samples taken adjacent to and downstream of the facility. Constituents that were measured in surface waters during this period are listed in Table 4–2.

Since 1987, measured values within the Gunnison River have been compared to the surface-water quality standards established for the stream segment by the Colorado Department of Public Health and Environment (CDPHE). Only manganese, sulfate, and pH have consistently exceeded State standards. These sample constituents were occasionally measured at higher-than-standard levels at all river sampling locations and were not necessarily an indication of the facility's influence on the river. The Gunnison River may have been affected by discharges of uranium-contaminated alluvial groundwater but not to the extent that the State standard was exceeded. Generally, concentrations of uranium are higher in samples collected from the downstream location than at either the upstream or middle locations.

Table 4–1. ARARs for Surface-Water Environmental Surveillance

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO, GJPORAP, and MMTS		
General Environmental Protection Program	DOE Order 5400.1, Chapter IV, Part 8d	Ambient water quality monitoring should be conducted through a network of fixed stations from which data will establish well-defined histories of the physical and chemical conditions of local bodies of water. The data obtained from this network should be coordinated with other monitoring activities. Analysis from a fixed-station monitoring network should support • Characterizing and defining trends in the physical and chemical condition of surface waters. • Establishing baselines of water quality. • A continuing assessment of water pollution control programs. • Identifying new water quality problems. • Detecting, characterizing, and reporting unplanned releases and their effects on the environment. Monitoring stations should be operated and maintained through established procedures. Types of sampling performed should depend on local conditions and the variability of stream characteristics and water quality. The monitoring frequency at a fixed network will be a function of the variability of the chemical, physical, and biological conditions of the water body. Ambient water quality monitoring will serve to confirm compliance with the Clean Water Act.
Radiation Protection of the Public and the Environment	DOE Order 5400.5, Chapter I, Part 8a	Demonstrations of compliance with the requirements of this order generally will be based on calculations that use information obtained from monitoring and surveillance programs.

Table 4–1 (continued). ARARs for Surface-Water Environmental Surveillance

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO, GJPORAP, and MMTS (continued)		
Radiological Effluent Monitoring and Environmental Surveillance	DOE Environmental Regulatory Guide, Chapter 5	An evaluation will be conducted and used as the basis for establishing an environmental surveillance program. The scope of the environmental surveillance program will be based on applicable regulations, hazard potential of the effluents, quantities and concentrations of effluents, specific public interest, and the nature of potential or actual impacts on air, land, biota, and water. The results of the evaluation shall be documented in the Environmental Monitoring Plan to show • Environmental measurement and sampling locations used to determine ambient environmental levels resulting from facility operations. • Procedures and equipment needed to perform the measurement and sampling. • Frequency and analyses required for each measurement and sampling location. • Minimum detection level and accuracy. • Quality assurance components. Provisions shall be made for the detection and quantification of unplanned releases of radionuclides to the environment. U.S. Department of Energy (DOE) field office and contractor personnel shall ensure that groundwater monitoring plans are consistent with State and regional U.S. Environmental Protection Agency groundwater monitoring requirements under the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability Act to avoid unnecessary duplication.

Table 4-1 (continued). ARARs for Surface-Water Environmental Surveillance

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO, GJPORAP, and MMTS (continued)		
Data Analysis and Statistical Treatment	DOE Environmental Regulatory Guide, Chapter 7	The statistical techniques used to support the concentration estimates, to determine their corresponding measures of reliability, and to compare radionuclide data between sampling and/or measurement points and times shall be designed with consideration of the characteristics of environmental data. Documented and approved sampling, sample-handling, analysis, and data management techniques shall be used to reduce the variability of results. The level of confidence in radiological data shall be estimated by analyzing blanks and spiked pseudo-samples and by comparing the resulting concentration estimates with the known concentrations in those samples. The precision of radionuclide analytical results shall be reported as a range, variance, standard deviation, standard error, and/or a confidence interval. Outliers shall be excluded from the data only after investigation confirms that an error has been made in the sample collection, measurement, or data analysis process.
ARAR Specific to GJPO/GJPORAP		
The Basic Standards and Methodologies for Surface Water, and the Classifications and Numeric Standards for Gunnison and Lower Delores River Basins.	Colorado Department of Public Health and Environment (CDPHE), Water Quality Control Commission (5 CCR 1002-8)	Establishes basic standards, an antidegration rule and a system for State of Colorado surface waters. Also establishes State water quality standards for specific stream segments.
ARARs Specific to MMTS		
Definitions for Water Pollution Rules and General Requirements	Title 19, Chapter 5 Utah Code Annotated (R317-1, UAC)	The statute and rules set forth the definitions and general requirements for the Utah Water Quality Standards.
State of Utah Water Quality Standards	Title 19, Chapter 5 Utah Code Annotated R317-2, UAC)	Establishes a classification system for surface waters within the State of Utah and standards for specific stream segments.

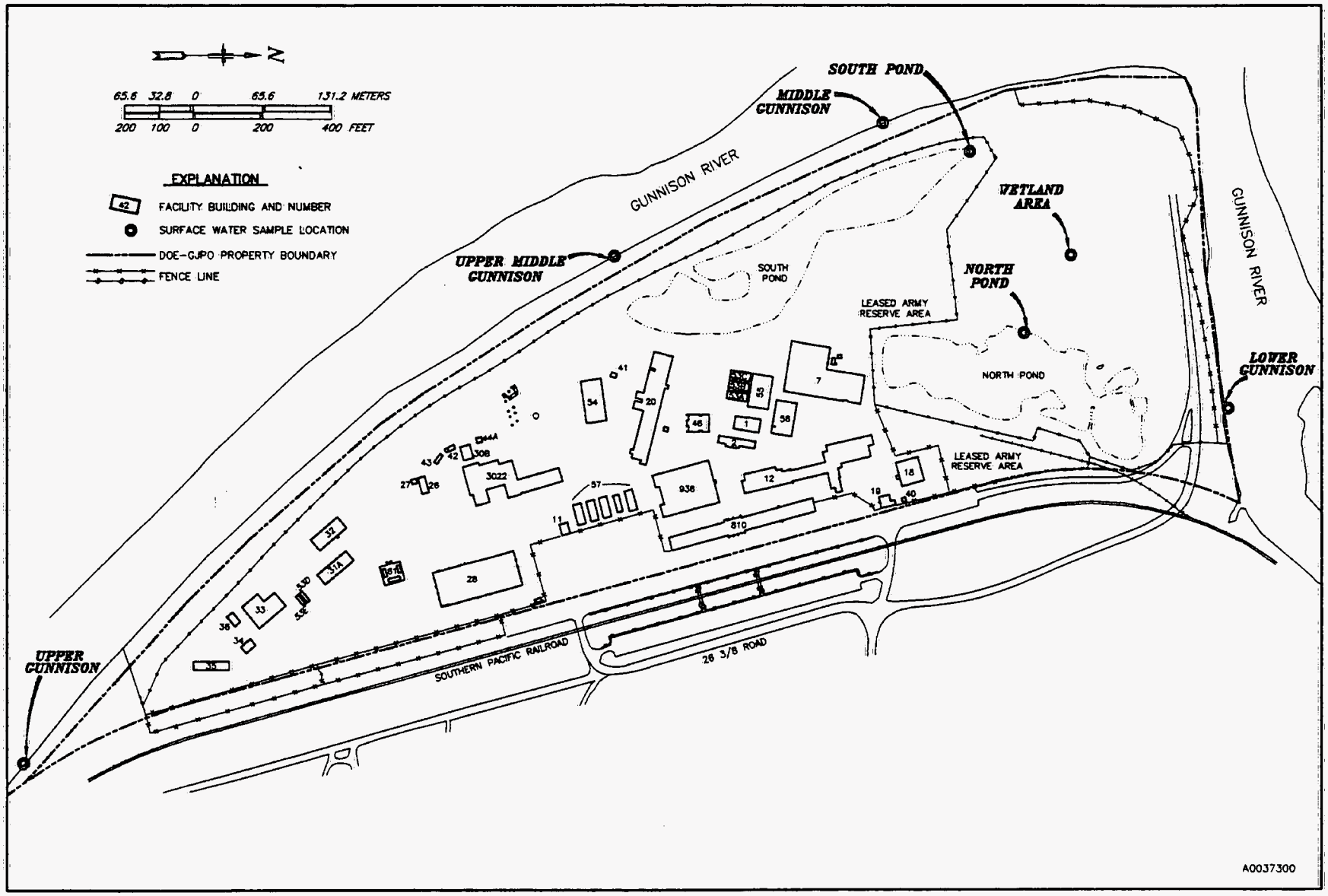

Figure 4–1. Surface-Water Sampling Locations at GJPO Facility

Table 4–2. Water Quality Constituents Analyzed for in GJPO Surface-Water Samples From 1979 to Present

Nonradiological Constituents		Radiological Constituents
Aluminum	Manganese	Gross Alpha
Ammonium-Nitrogen	Mercury	Gross Beta
Arsenic	Molybdenum	Lead-210
Barium	Nickel	Radium-226
Beryllium	Nitrate-Nitrogen	Radium-228
Cadmium	Nitrite-Nitrogen	Thorium-230
Calcium	pH	Thorium-232
Chloride	Phosphate	Uranium-234
Chromium	Potassium	Uranium-235
Cobalt	Selenium	Uranium-238
Copper	Silica	
Dissolved Oxygen	Silver	
Fecal Coliform	Sodium	
Fluoride	Specific Conductance	
Iron	Sulfate	
Lead	Total Dissolved Solids	
Magnesium	Total Organic Carbon	
	Uranium	
	Vanadium	
	Zinc	

More information about the surface-water monitoring programs and results is in the Annual Site Environmental Reports for calendar years 1979 through 1994 (Bendix 1980; Korte and Thul 1981, 1982, 1983, 1984; Korte and Wagner 1985, 1986; Sewell and Spencer 1987; DOE 1988a, 1989a, 1990b, 1991b, 1992a, 1993e, 1994g, 1995h).

4.2.2 Planned Surface Water Monitoring

4.2.2.1 Monitoring Objectives

The objectives of the GJPO surface-water monitoring program are

1. To establish a baseline of upstream water quality conditions in the Gunnison River for comparison with adjacent and downstream samples.

2. To characterize the type and extent of contamination in surface water sources.

3. To verify compliance with State surface-water quality standards.

4. To detect changes in water quality resulting from remedial action.

The historical surface-water monitoring program established a baseline of upstream water quality conditions and characterized the type and extent of contamination in surface water sources, as well as

verified compliance with State surface-water quality standards. Current and future monitoring will focus on detecting changes in water quality resulting from remedial action and maintaining compliance with State standards.

The Colorado Water Quality Control Act prohibits "injuries to the beneficial uses made of State waters," and establishes water quality standards for stream segments within Colorado. Applicable to the segment of the Gunnison River adjacent to the GJPO facility are four State use classifications: (1) Recreation Class I, (2) Cold-Water Aquatic Life Class I, (3) Domestic Water Supply, and (4) Agriculture. The most restrictive numeric standards associated with these classifications are listed in Table 4–3.

Table 4–3. CDPHE, Water Quality Control Division, Surface-Water Quality Standards for the Gunnison River[a]

Constituent	Maximum Concentration[b]		Constituent	Maximum Concentration	
Uranium	40	pCi/L	Aldrin	0.003	μg/L
Arsenic	0.360	mg/L	Dieldrin	0.003	μg/L
Cadmium	0.021	mg/L	DDT (DDD and DDE)	0.001	μg/L
Chromium (+3)	0.0696	mg/L	Endrin	0.004	μg/L
Chromium (+6)	0.011	mg/L	Heptachlor	0.001	μg/L
Copper	0.042	mg/L	Lindane	0.01	μg/L
Iron (soluble)	0.300[c]	mg/L	Methoxychlor	0.03	μg/L
Iron (total)	1.000	mg/L	Mirex	0.001	μg/L
Manganese (soluble)	0.050[c]	mg/L	Toxaphene	0.005	μg/L
Manganese (total)	1.000	mg/L	Demeton	0.1	μg/L
Mercury	0.0001	mg/L	Endosulfan	0.003	μg/L
Nickel	0.295	mg/L	Guthion	0.01	μg/L
Selenium	0.017	mg/L	Malathion	0.1	μg/L
Silver	0.001	mg/L	Parathion	0.04	μg/L
Zinc	0.372	mg/L	2,4-D	0.1	mg/L
Ammonia (30-day)	0.02	mg/L	Polychlorinated biphenyls	0.001	μg/L
Residual Chloride	0.003	mg/L	Chlorphenol	0.001	mg/L
Cyanide (free)	0.005	mg/L	Monohydric phenol	0.001	mg/L
Sulfur as Hydrogen Sulfide	0.002	mg/L	Benzidine	0.01	μg/L
Boron	0.75	mg/L			
Nitrite	0.05	mg/L			
Nitrate	10.0	mg/L			
Chloride	250.0	mg/L			
Sulfate	250.0	mg/L			
Lead	0.032	mg/L			
Dissolved Oxygen	6.0	mg/L			
pH	6.5–9.0	units			
Fecal coliform	200/100	mL[d]			

[a]pCi/L = picocurie per liter; mg/L = milligram per liter; mL = milliliter; μg/L = microgram per liter.

[b]The standards for dissolved metals are presented, unless otherwise indicated. Metals standards are associated with the Cold-Water Aquatic Life Class I use classification, unless otherwise indicated. A hardness value of 440 mg/L was used to calculate metal "table value standards."

[c]The listed standard is associated with the Domestic Water Supply standard.

[d]This concentration reflects 200 fecal coliform colonies per 100 mL.

All of the constituents in Table 4–3 (with the exception of ammonia, cyanide, boron, and the organic compounds) were measured in the Gunnison River within the previous 16 years. Of these measured constituents, only fecal coliform, copper, iron, lead, manganese, sulfate, zinc, and pH exceeded the standards established by the State; standard exceedances occurred either upstream only or both upstream and downstream of the GJPO facility and were not associated with activities or contamination on the facility. Future surface water monitoring will focus on analyzing for the constituents that occur in concentrations above background levels in the groundwater and that may contaminate the Gunnison River. The monitoring will determine whether State standards are exceeded in the Gunnison River. In addition, water samples will be analyzed for total organic carbon as an "indicator" of organic compounds; and field measurements of alkalinity, pH, and specific conductance will be taken to detect gross changes in water quality. The constituents that surface waters will be analyzed for are in Table 4–4, along with their respective reporting limits.

Table 4–4. Surface-Water Quality Analytes and Respective Reporting Limits for GJPO/GJPORAP[a]

Nonradiological Constituents	Reporting Limit		Radiological Constituents	Reporting Limit	
Arsenic	0.010	mg/L	Gross Alpha	2.0	pCi/L
Barium	0.20	mg/L	Radium-226	0.5	pCi/L
Cadmium	0.003	mg/L	Radium-228	0.5	pCi/L
Calcium	5.0	mg/L	Radium-226	0.5	pCi/L
Chloride	0.10	mg/L	Thorium-230	1.0	pCi/L
Chromium	0.010	mg/L	Thorium-232	1.0	pCi/L
Iron	0.10	mg/L	Uranium-234	0.5	pCi/L
Lead	0.003	mg/L	Uranium-238	0.5	pCi/L
Magnesium	5.0	mg/L			
Manganese	0.015	mg/L			
Molybdenum	0.050	mg/L			
Nitrate	0.01	mg/L			
Potassium	5.0	mg/L			
Selenium	0.005	mg/L			
Sodium	5.0	mg/L			
Sulfate	0.10	mg/L			
Vanadium	0.050	mg/L			
Alkalinity	None Defined				
pH	0.1	unit			
Specific Conductance	None Defined				
Total Dissolved Solids	10	mg/L			
Total Organic Carbon	0.10	mg/L			

[a]mg/L = milligram per liter; pCi/L = picocurie per liter.

Measurements of the constituents in Table 4–4 will be used to detect changes in water quality resulting from remedial action activities. Removal of all known exterior uranium mill tailings sources at the GJPO facility was completed on July 1, 1994; therefore, water quality should improve in the North Pond, South Pond, and Wetland Area as passive remediation of the alluvial aquifer occurs.

4.2.2.2 Sampling Plan

The North Pond, South Pond, Wetland Area, and Gunnison River will be sampled every 9 months for the surface-water quality constituents listed in Table 4–4. This sampling scheme will allow seasonal fluctuations in the chemical concentrations to be examined over a 3-year period and will reduce the problem of serial correlation if the data are statistically analyzed. Sampling locations are shown in Figure 4–1.

Data collection for background characterization will continue on the Gunnison River upstream of the GJPO facility. In addition, Gunnison River samples will be collected from two sites adjacent to the facility and from one site downstream of the facility. Water samples will be collected with a peristaltic pump or by container immersion at a location near the shoreline of the river. Specific sampling procedures are described in the *Sampling and Analysis Plan for Environmental Monitoring* (DOE 1994e).

Surface water samples will be analyzed by the Analytical Laboratory following procedures outlined in the *Analytical Chemistry Laboratory Handbook of Analytical and Sample Preparation Methods* (DOE 1995b). This handbook describes the precision of each of the analytical techniques and the methodology and reporting limits used by the laboratory. To ensure the integrity of the samples is maintained from the time of collection in the field through laboratory analysis, a chain-of-custody record will be maintained for each possession transfer.

QA and QC measures will be implemented during all sampling and analysis activities. The precision and accuracy of the sample results will be determined through field and laboratory QC measures. Field QC will be accomplished by the collection and analysis of field duplicates and equipment blanks; specific procedures for collection of field QC samples are described in the *Sampling and Analysis Plan for Environmental Monitoring* (DOE 1994e). Laboratory QC will be accomplished by the analysis of blind duplicates, spikes, spike duplicates, method blanks, and calibration standards, when applicable to the analytical method being performed at a frequency in accordance with the *Analytical Chemistry Laboratory Administrative Plan and Quality Control Procedures* (DOE 1995a). Details of the QA program are in Section 10.0 and Appendix A of this EMP.

4.2.2.3 Data Management

The contractor's data manager will maintain a database for all surface-water monitoring data. Data will be stored in an ORACLE database and will be backed up weekly. In addition, all reports and data will be stored in a permanent project file in the contractor's records management section.

4.2.2.4 Data Analysis and Reporting Format

Data will be analyzed to determine if monitoring objectives have been met. Compliance with State standards will be achieved when every constituent's measured value falls below the respective standard value. If a State standard is exceeded, an investigation will determine whether operations at the GJPO facility were responsible for the exceedance. Monitoring data will be summarized in the Annual Site Environmental Report.

Data will be analyzed in a time sequence to determine whether changes in water quality have occurred. Measured surface water values listed in Table 4–4 will be compared with the State standards listed in

Table 4–3. Graphical displays of concentrations as a function of time for selected constituents will be the main reporting format (Figure 4–2).

Because water quality data often vary seasonally within a single year, it is sometimes difficult to distinguish real changes in concentration from natural, seasonal changes. If seasonal changes are detected, statistical analysis may be performed to quantitatively determine if apparent trends are real. Statistical analysis also has the advantage of providing scientifically defensible data. The Mann-Kendall test, which evaluates the significance of an apparent increase or decrease in concentration over time, may be used to determine whether trends exist in the surface-water quality data. The methodology for this test is discussed at length in Gilbert (1987) and is included as Appendix B in this EMP. Other methods that could be used to detect data trends include the Sen Slope Estimate and the seasonal Kendall test, both of which are described by Gilbert (1987).

For data analysis purposes, outliers will be excluded from the data ***only*** after an investigation confirms that an error has been made in the sample collection, preparation, measurement, or data analysis process, in accordance with DOE's *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (DOE 1991a). Nondetects will be assigned a value of one-half the detection limit for statistical analysis.

4.2.3 Responsible Organizations

It is the responsibility of the DOE–GJPO Manager to direct the surface-water monitoring effort. Responsibility for planning and budgeting surface water monitoring, sampling surface water, conducting data evaluation, and preparing reports resides with the contractor's Environmental Services section.

4.3 MMTS

Several perennial and intermittent surface water sources are located in the vicinity of MMTS. Montezuma Creek, which flows through the millsite property from west to east, is the primary surface water feature in the MMTS area. It receives significant inflow from the shallow alluvial aquifer. Although generally perennial, the creek's flow can be quite low or dry during the late summer and fall. Montezuma Creek water is diverted and used for irrigation supply about 1.6 km (1 mile) upstream of the millsite. Downstream of the millsite, the creek water is used primarily for livestock watering and irrigation.

Montezuma Creek historically has been sampled upstream of the millsite at several locations (primarily SW92–01, SW92–02, and SW92–03) and on site at several different locations (primarily SW92–04 and SW92–05) (Figure 4–3). In addition, the creek has been sampled downstream at seven locations designated as W–4, SW92–06, Sorenson Site, SW92–07, SW92–08, SW92–09 and Montezuma Canyon (about 9.6 km downstream of the millsite boundary) (see Figure 4–4).

Other surface water sources include seeps, ponds, and ditches on and near the millsite property. On the millsite, the Carbonate Seep is a perennial seep located at the base of the Carbonate Tailings Pile. This seep feeds the drainage that flows between the Carbonate and Vanadium Tailings Piles, where sampling location W–2 is located. Intermittent seeps are located south of the Vanadium Tailings Pile and east of the Acid Tailings Pile and usually contain water only in the spring months. Halls Ditch crosses the northwest corner of the millsite property and is used to transport irrigation water. Since it was remediated in 1994, this ditch flows in a buried pipe through the millsite. Slade Spring is a perennial

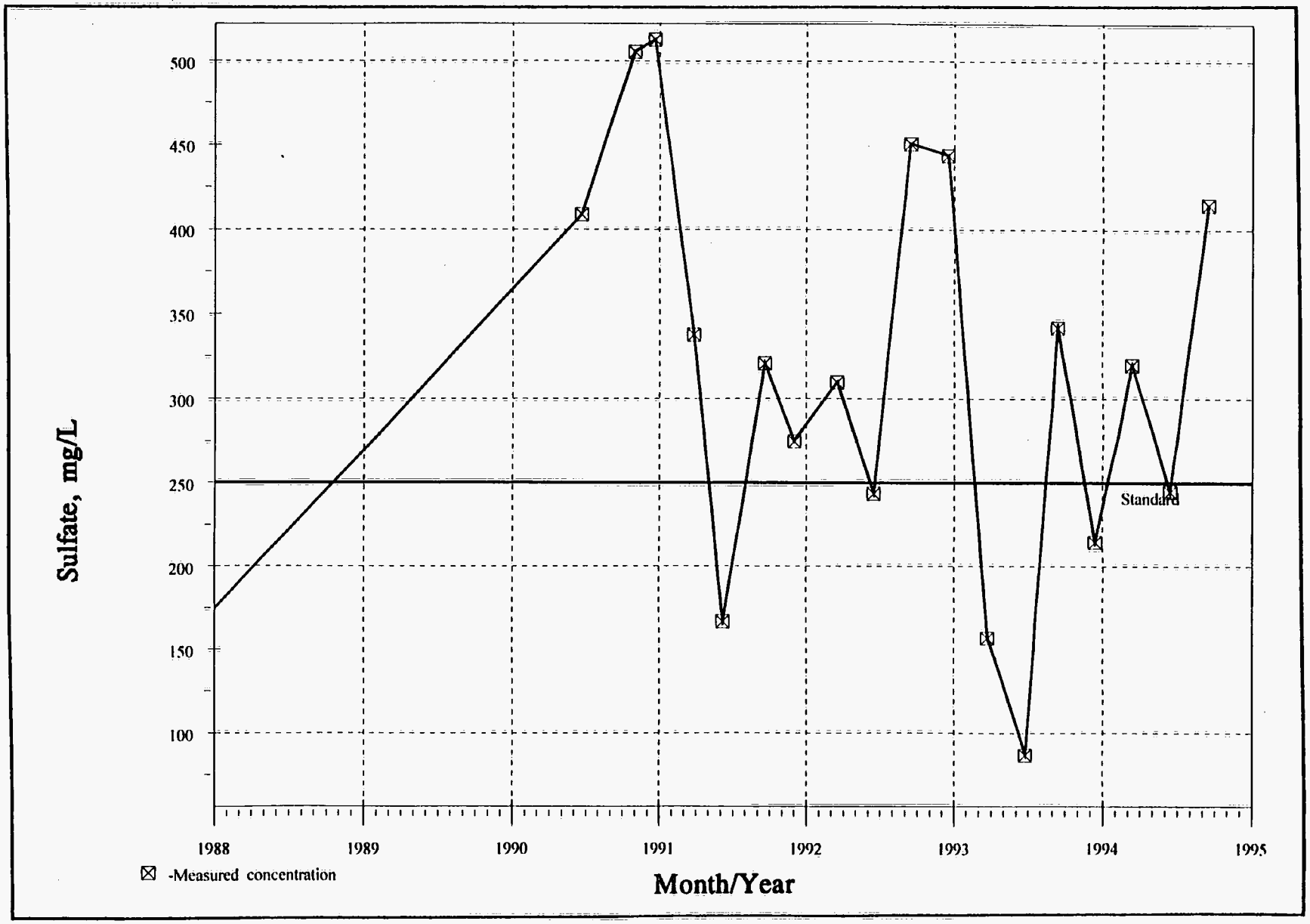

Figure 4–2. Example Illustrating Graphical Display of Water Quality Data

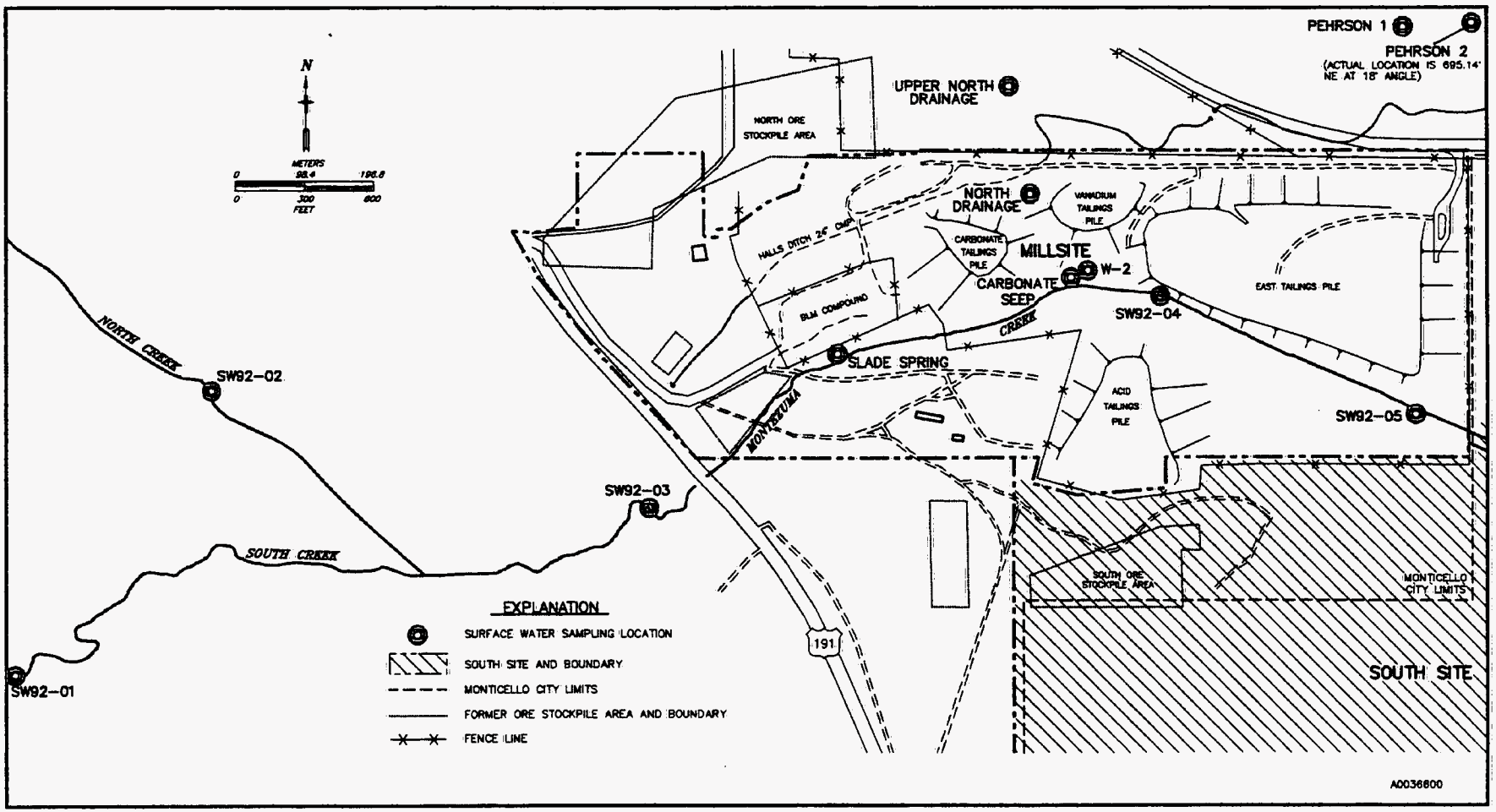

Figure 4–3. Surface-Water Sampling Locations On and Upgradient of Monticello Millsite

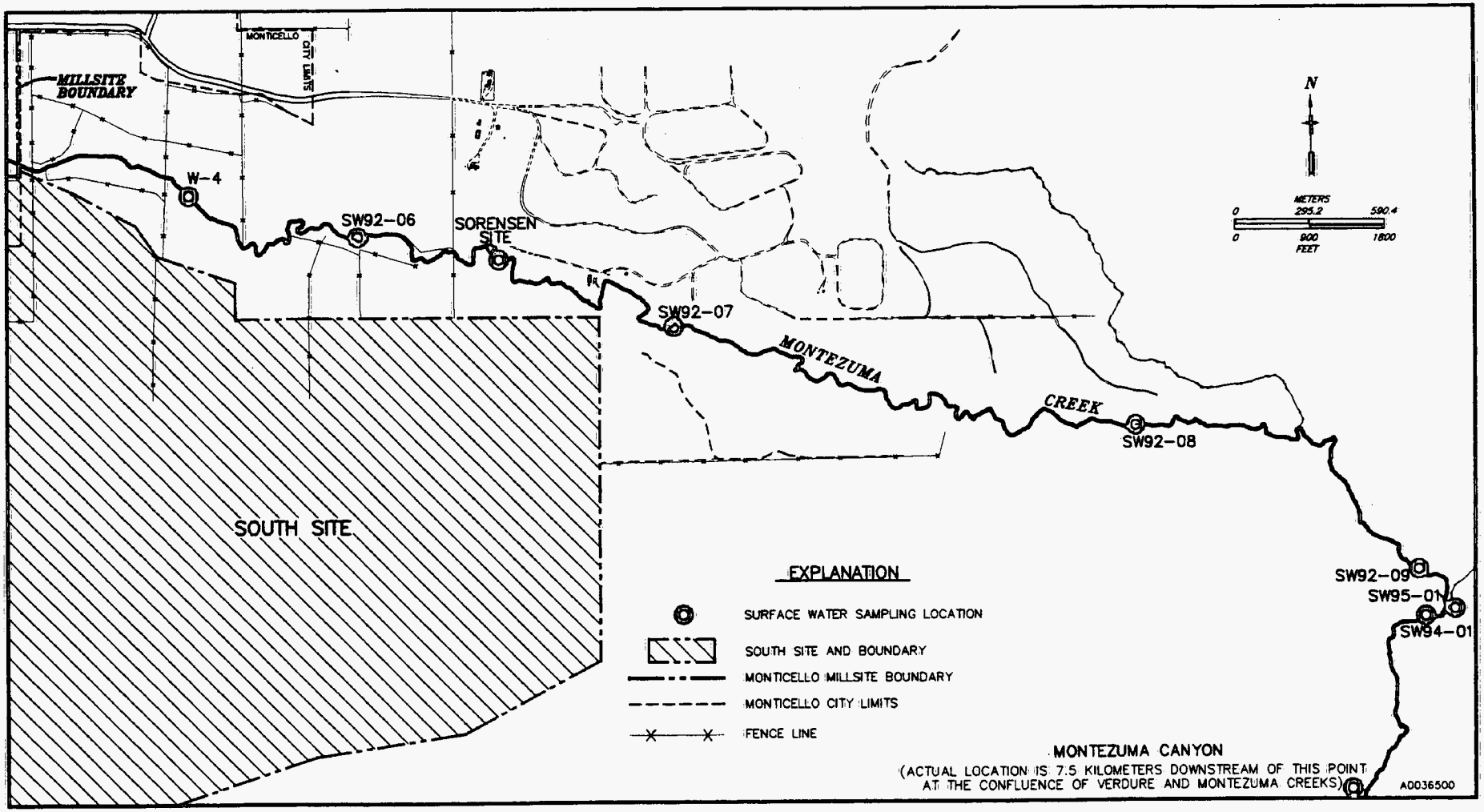

Figure 4–4. Surface-Water Sampling Locations Downgradient of Monticello Millsite

spring located near the west end of the millsite that flows into Montezuma Creek. The North Drainage sampling location is located northwest of the Vanadium Tailings Pile and collects surface runoff and seeping groundwater. Seeps outside the millsite occur along the hillslopes to the north and south of the millsite. Surface water features east of the millsite include a pond that is fed by water diverted from Montezuma Creek.

More complete descriptions of the surface water sources affected by the Monticello millsite are in the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Work Plan, Draft Final* (DOE 1995f).

4.3.1 Historical Surface Water Monitoring

Monitoring of Montezuma Creek began in 1955, when it was discovered that liquid effluent from the salt roast/carbonate leach plant was affecting water quality within the creek. At the same time, it was recognized that radium levels in the water and stream sediments were increasing as a result of uranium mill operations. Studies were subsequently initiated to address these problems. Monitoring continued sporadically until 1979, when routine surface water monitoring began. From 1979 to present, many of the surface water locations described in Section 4.3 were sampled, and samples were analyzed for a range of water quality constituents to assess the type and extent of contamination. The constituents analyzed for during this period are listed in Table 4–5. In fall 1992, sampling was initiated to support the MSGRAP RI/FS. The baseline characterization portion of the RI/FS was completed in the summer of 1993, but monitoring in support of the RI/FS is ongoing.

Background surface-water quality data were gathered from Montezuma Creek upstream of the millsite at several sampling sites, including SW92-01, SW92-03, and SW92-03 (Figure 4–3). Analyses indicated that the samples contained low or nondetectable levels of the trace elements usually associated with uranium mill tailings.

On the millsite property, samples from all of the surface water sources were contaminated with elements leached from the mill tailings piles. Higher-than-background concentrations of uranium, arsenic, molybdenum, radium, and vanadium were found in samples from surface water sources on and downstream of the millsite. Contamination from the uranium mill tailings was found in samples from Montezuma Creek as far as 9.6 km below the millsite property. The highest concentrations of mill-tailings-related contaminants typically were in samples taken from the Carbonate Seep, W-2, and Sorenson Site sampling locations (Figures 4–3 and 4–4).

The specific sites monitored during previous years have varied. Generally, background samples were taken upstream of the millsite, and samples showing contamination were obtained at several sites located on and downstream of the millsite. Sampling intervals have varied from semiannually to quarterly. More information concerning the monitoring programs is in the Annual Site Environmental Reports for calendar years 1979 through 1994 (Bendix 1980; Korte and Thul 1981, 1982, 1983, 1984; Korte and Wagner 1985, 1986; Sewell and Spencer 1987; DOE 1988b, 1989b, 1990c, 1991c, 1992b, 1993b, 1994b, 1995d).

Table 4–5. Water Quality Constituents Analyzed for in MMTS Surface-Water Samples From 1979 to Present

Nonradiological Constituents		Radiological Constituents
Inorganic	**Organic/Biological**	
Alkalinity	TCL Volatile Organic Compounds	Gross Alpha
Aluminum	TCL Semivolatile Organic Compounds	Gross Beta
Ammonia (as Nitrogen)	TCL Herbicides	Lead-210
Ammonium	TCL Pesticides/PCBs	Polonium-210
Antimony	Fecal Coriform	Radium-226
Arsenic	Total Coriform	Radon-222
Barium		Thorium-230
Beryllium		Thorium-232
Biochemical Oxygen Demand		Uranium-234
Boron		Uranium-235
Cadmium		Uranium-238
Calcium		
Chemical Oxygen Demand		
Chloride		
Chromium		
Cobalt		
Copper		
Cyanide		
Fluoride		
Iron		
Lead		
Magnesium		
Manganese		
Mercury		
Molybdenum		
Nickel		
Nitrate		
Nitrate + Nitrite (as Nitrogen)		
Nitrite		
pH		
Phosphate		
Potassium		
Selenium		
Silicon		
Silver		
Sodium		
Specific Conductance		
Strontium		
Sulfate		
Thallium		
Tin		
Total Dissolved Solids		
Total Suspended Solids		
Uranium		
Vanadium		
Zinc		

4.3.2 Planned Surface Water Monitoring

4.3.2.1 Monitoring Objectives

The objectives of the MMTS surface-water monitoring program are

1. To compare upstream water quality conditions in Montezuma Creek to conditions on and downstream of the millsite.

2. To characterize the type and extent of contamination in surface water.

3. To verify compliance with State surface-water quality standards.

4. To detect changes in water quality resulting from remedial action.

The historical surface-water monitoring program provided data for accomplishing the first two monitoring objectives. Current and future monitoring will focus on all four of the monitoring objectives.

4.3.2.2 Sampling Plan

Surface water samples will be collected from three locations upstream of the millsite (SW92–01, SW92–02, and SW92–03), six locations on the millsite (Slade Spring, North Drainage, Carbonate Seep, W–2, SW92–04, and SW92–05), and nine locations downstream of the millsite (Sorenson Site, W–4, Montezuma Canyon, SW92–06, SW92–07, SW92–08, SW92–09, SW94–01, and SW95–01), as shown in Figures 4–3 and 4–4. Sampling will occur semiannually during October and April. Constituents that will be analyzed for at surface water locations are listed in Table 4–6.

Sampling procedures, QA and QC measures, laboratory analysis procedures, and reporting limits for analytical parameters are described in the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Field Sampling Plan and Quality Assurance Project Plan, Draft Final* (DOE 1995e)

4.3.2.3 Data Management

Data storage and management will be the same as that described for GJPO/GJPORAP (Section 4.2.2.3).

4.3.2.4 Data Analysis and Reporting Format

Data analysis techniques and reporting formats will be the same as those described for GJPO/GJPORAP (Section 4.2.2.4).

4.3.3 Responsible Organizations

Responsible organizations will be the same as those described for GJPO/GJPORAP (Section 4.2.3).

Table 4–6. Surface-Water Quality Analytes for MMTS

Analytical Parameters	Analytes
Major Anions	Chloride Fluoride (Nitrate + Nitrite) as Nitrogen Sulfate
Major Cations	Ammonium Calcium Magnesium Potassium Sodium
Metals	Aluminum Arsenic Cobalt Copper Manganese Molybdenum Selenium Tin Vanadium Zinc
Radionuclides	Gross Alpha Gross Beta Lead-210 Radium-226 Radon-222 Thorium-230 Uranium-234 Uranium-235 Uranium-238
Other	Total Dissolved Solids

Section 5.0
Groundwater

5.0 Groundwater

5.1 Regulatory Requirements

Groundwater environmental surveillance programs for GJPO, GJPORAP, and MMTS are conducted to comply with the ARARs listed in Table 5–1.

5.2 GJPO/GJPORAP

Historically, the GJPO/GJPORAP groundwater monitoring program has focused on the alluvial aquifer, which is contaminated by the leached by-products of uranium mill tailings. Thickness of the alluvial aquifer is about 6 to 7.5 meters (20 to 25 feet), and its hydraulic conductivity is approximately 9 meters/day (30 feet/day). The aquifer is recharged primarily by the high flows of the Gunnison River and secondarily by precipitation. Groundwater enters the alluvial aquifer from the Gunnison River along the southern perimeter of the GJPO facility. During periods of high river runoff, groundwater flows away from the river into the alluvial aquifer; during periods of normal river runoff, groundwater is discharged into the Gunnison River along the north and west boundaries of the GJPO facility.

Underlying the alluvial aquifer is the Morrison Formation, which is composed mainly of red, green, and gray shales. The Morrison serves as an aquitard beneath the facility, as it inhibits downward groundwater flow and inhibits communication between the alluvial aquifer and the underlying Entrada Sandstone aquifer.

Complete descriptions of the hydrogeologic setting and extent of the contaminant plume in the alluvial aquifer are in the *DOE–GJPO Ground-Water Protection Management Program Plan* (DOE 1994f) and the *Final Remedial Investigation/Feasibility Study—Environmental Assessment for the U.S. Department of Energy GJPO Facility* (DOE 1989c).

5.2.1 Historical Groundwater Monitoring

Monitoring began in 1979 with water quality sampling of two on-site wells—the North and South Wells—completed in the alluvial aquifer. To detect possible contamination problems, a range of water quality constituents was analyzed for, including heavy metals, radiological constituents, inorganic ions, total organic carbon, pH, and specific conductance.

From 1979 to 1984, 56 wells were completed in the alluvium to determine background conditions and to characterize the contaminant plume. Higher-than-background concentrations of several constituents (including uranium, arsenic, radium, selenium, molybdenum, and nitrate) were measured in samples from the on-site wells. Pump tests were performed to estimate aquifer characteristics and to determine the quantity of water affected by the leached by-products. Groundwater quality was sampled semiannually for many chemical constituents; water levels were monitored on a variable schedule, from biweekly to monthly.

Table 5–1. ARARs for Groundwater Environmental Surveillance

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO, GJPORAP, and MMTS		
General Environmental Protection Program	DOE Order 5400.1, Chapter IV, Part 9	Groundwater that is or that could be affected by U.S. Department of Energy (DOE) operations shall be monitored to determine and to document the effects of operations on groundwater quality and to demonstrate compliance with applicable regulations. A groundwater monitoring plan shall be developed as a specific element of all Environmental Monitoring Plans (EMPs). The groundwater monitoring plan shall identify all DOE requirements and regulations applicable to groundwater protection and shall include a monitoring strategy. General requirements of groundwater monitoring programs include conducting monitoring on site and in the vicinity of DOE facilities • To obtain data for determining baseline conditions of groundwater quality and quantity. • To demonstrate compliance with and implementation of all applicable regulations and DOE orders. • To provide data for the early detection of groundwater pollution or contamination. • To provide a reporting mechanism for detected groundwater pollution or contamination. • To identify existing and potential groundwater contamination sources and to maintain surveillance of these sources. • To provide data on which decisions can be made concerning land disposal practices and the management and protection of groundwater resources. The elements of the groundwater monitoring program shall be specified (i.e., sampling plan, sampling, analysis, and data management), as shall the rationale or purpose for selecting these elements. Site-specific characteristics shall determine monitoring needs.

Table 5–1 (continued). ARARs for Groundwater Environmental Surveillance

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO, GJPORAP, and MMTS (continued)		
DOE Groundwater Quality Protection Strategy	DOE Draft Notice 5400.AA	Establishes DOE's framework for the protection of groundwater quality at and near DOE facilities. This protection strategy includes several key elements, some of them pertaining to monitoring. The monitoring elements require DOE • To systematically document past and present practices that may affect groundwater quality at DOE facilities. • To characterize and monitor groundwater systems underlying DOE facilities whose operations may affect groundwater quality; to determine and to document the effects of DOE operations on groundwater quality and quantity. • To implement remedial measures to clean up existing groundwater commensurate with appropriate standards.
Radiological Effluent Monitoring and Environmental Surveillance	DOE Environmental Regulatory Guide, Chapter 5	An evaluation shall be conducted and used as the basis for establishing an environmental surveillance program. The extent of the environmental surveillance program shall be based on applicable regulations, hazard potential of the effluents, quantities and concentrations of effluents, specific public interest, and the nature of potential or actual impacts on air, land, biota, and water. The results of the evaluation shall be documented in the EMP to show • Environmental measurement and sampling locations. • Procedures and equipment needed to perform the measurement and sampling. • Frequency and analyses required for each measurement and sampling location. • Minimum detection level and accuracy. • Quality assurance components. Provisions shall be made for the detection and quantification of unplanned releases of radionuclides to the environment. DOE field office and contractor staff shall ensure that groundwater monitoring plans are consistent with State and regional U.S. Environmental Protection Program (EPA) groundwater monitoring requirements under the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability Act to avoid unnecessary duplication.
Data Analysis and Statistical Treatment	DOE Environmental Regulatory Guide, Chapter 7	The statistical techniques used to support the concentration estimates, to determine their corresponding measures of reliability, and to compare radionuclide data between sampling and/or measurement points and times shall be designed with consideration of the characteristics of environmental data. Documented and approved sampling, sample-handling, analysis, and data management techniques shall be used to reduce the variability of results.

Table 5–1 (continued). ARARs for Groundwater Environmental Surveillance

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO, GJPORAP, and MMTS (continued)		
Data Analysis and Statistical Treatment (continued)	DOE Environmental Regulatory Guide, Chapter 7	The level of confidence in radiological data shall be estimated by analyzing blanks and spiked samples and by comparing the resulting concentration estimates with the known concentrations in those samples. The precision of radionuclide analytical results shall be reported as a range, variance, standard deviation, standard error, and/or a confidence interval. Outliers shall be excluded from the data only after investigation confirms that an error has been made in the sample collection, preparation, measurement, or data analysis process.
EPA Standards for Inactive Uranium Mill Tailings Sites	40 CFR Part 192 as amended by 52 Fed. Reg. 36000 (Sept. 24, 1987)	Requires DOE to establish a monitoring program to determine the extent of contamination in groundwater and around a processing site, as specified in 40 *U.S. Code of Federal Regulations* (CFR) Part 192.12(c)(1) and Part 192.11(b)(4). States that the possible presence of any of the inorganic or organic hazardous constituents identified in tailings or used in the processing operation should be analyzed for in groundwater. Requires that all contaminated groundwater be restored to the water quality levels established under 40 CFR Parts 264.92–264.94 as modified by Part 192.02(a)(3)(i) and (ii). The hydrologic and geologic assessment conducted at each site shall include a monitoring program sufficient to establish background groundwater quality through one or more upgradient wells, as specified in 40 CFR Part 192.20 (a)(2).
ARAR Specific to GJPO/GJPORAP		
Basic Standards for Groundwater (CO)	Colorado Department of Public Health and Environment (CDPHE), Water Quality Control Commission (5 CCR 1002–8)	Establishes statewide standards and a system for classifying groundwater and adopting water quality standards for such classifications to protect existing and potential beneficial uses of groundwaters.
ARARs Specific to MMTS		
Definitions for Water Pollution Rules and General Requirements	Title 19, Chapter 5, Utah Code Annotated (317–1 UAC)	Sets forth definitions and general requirements for the Utah Groundwater Quality Standards.

Table 5–1 (continued). ARARs for Groundwater Environmental Surveillance

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Specific to MMTS (continued)		
Groundwater Quality Standards (UT)	Title 19, Chapter 5, Utah Code Annotated (R317–2, UAC)	Establishes a groundwater classification system and groundwater quality standards for all groundwaters in the State of Utah.
Groundwater Protection	Title 19, Chapter 5, Utah Code Annotated (R317–8, UAC)	Establishes groundwater protection standards.

In 1984, an intensive groundwater-quality sampling program was initiated. Organic compounds, heavy metals, and radiological constituents were analyzed for; and results were compared with the UMTRCA groundwater standards established in 40 CFR Part 192. These analyses identified concentrations of arsenic, barium, radium, selenium, gross alpha, chromium, and lead that exceeded standards. Results of organic analyses indicated that six wells contained organic compounds in concentrations significantly higher than those in the background wells, but the validity of the results was questionable. Between 1984 and 1986, water levels were measured on a weekly basis as part of a groundwater model verification exercise.

Semiannual groundwater quality sampling was resumed in 1987 for a more limited list of constituents. Water quality analyses focused on known contaminants for which standards existed or were proposed. In 1990, sampling was conducted quarterly to monitor the effects of remediation at the GJPO facility; a quarterly frequency was maintained until remediation was completed on July 1, 1994.

An organic characterization of alluvial groundwater was conducted in 1991 and 1992 to follow up on the results from organic analyses in 1984. Results of the 1991 and 1992 quarterly sampling for target compound list (TLC) volatiles, semivolatiles, herbicides, and pesticides indicated that the alluvial aquifer was not contaminated with organic compounds.

A list of groundwater quality constituents analyzed for during the 16-year period from 1979 to 1995 is presented in Table 5–2.

More information concerning historical groundwater monitoring programs and results is in the Annual Site Environmental Reports for calendar years 1979 through 1994 (Bendix 1980; Korte and Thul 1981, 1982, 1983, 1984; Korte and Wagner 1985, 1986; Sewell and Spencer 1987; DOE 1988a, 1989a, 1990b, 1991b, 1992a, 1993e, 1994g, 1995h).

5.2.2 Planned Groundwater Monitoring

5.2.2.1 Monitoring Objectives

The objectives of the GJPO groundwater monitoring program are

1. To determine the baseline water quality and quantity conditions of the shallow alluvial aquifer underlying the site.

2. To characterize the type and extent of the contaminant plume in the aquifer.

3. To verify compliance with Federal and State groundwater quality standards.

4. To detect changes in water quality resulting from remedial action.

Historical groundwater monitoring programs have accomplished the first two monitoring objectives. The goals of the current and future groundwater monitoring program are to continue to measure water quality constituents for compliance with standards and to detect changes resulting from remedial action. Groundwater monitoring will continue for GJPO/GJPORAP until the contaminated groundwater is restored to levels that comply with groundwater quality standards.

Table 5–2. Water Quality Constituents Analyzed for in GJPO Groundwater Samples From 1979 to Present[a]

Nonradiological Constituents		Radiological Constituents
Inorganic	**Organic**	
Alkalinity	Total Organic Carbon	Gross Alpha
Aluminum	Total Organic Halogen	Gross Beta
Ammonium-Nitrogen	Total Phenolics	Lead-210
Arsenic	TCL Volatiles	Radium-226
Barium	TCL Semivolatiles	Radium-228
Beryllium	TCL Pesticides/PCBs	Thorium-230
Cadmium	TCL Herbicides	Thorium-232
Calcium		Uranium-234
Chloride		Uranium-235
Chromium		Uranium-238
Cobalt		
Copper		
Dissolved Oxygen		
Fecal Coliform		
Fluoride		
Iron		
Lead		
Magnesium		
Manganese		
Mercury		
Molybdenum		
Nickel		
Nitrate-Nitrogen		
Nitrite-Nitrogen		
Oxidation-Reduction Potential		
pH		
Phosphate		
Potassium		
Selenium		
Silica		
Silver		
Sodium		
Specific Conductance		
Sulphate		
Total Dissolved Solids		
Uranium		
Vanadium		
Zinc		

[a]TCL = target compound list; PCB = polychlorinated biphenyl.

Groundwater quality at the GJPO facility must comply with both Federal and State standards, as mandated by UMTRCA of 1978 and the Colorado Water Quality Control Act. The numeric standards applicable to the site are listed in 40 CFR Part 192.32 and in the Water Quality Control Commission's *Basic Standards for Ground Water* (State of Colorado 1991). These standards are listed in Tables 5–3 and 5–4.

Table 5–3. Federal Standards for Groundwater[a]

Constituent	Maximum Concentration[b]	
Arsenic	0.05	mg/L
Barium	1.0	mg/L
Cadmium	0.01	mg/L
Chromium	0.05	mg/L
Lead	0.05	mg/L
Mercury	0.002	mg/L
Selenium	0.01	mg/L
Silver	0.05	mg/L
Endrin	0.0002	mg/L
Lindane	0.004	mg/L
Methoxychlor	0.1	mg/L
Toxaphene	0.005	mg/L
2,4-D	0.1	mg/L
2,4,5-TP (Silvex)	0.01	mg/L
Radium-226 + 228	5	pCi/L[c]
Gross Alpha (excluding radon and uranium)	15	pCi/L
Uranium 234 + 238	30	pCi/L
Molybdenum	0.1	mg/L
Nitrate (as Nitrogen)	10	mg/L

[a]Federal standards taken from 40 *U.S. Code of Federal Regulations* (CFR) Part 192.32 unless otherwise noted.
[b]mg/L = milligram per liter; pCi/L = picocurie per liter.
[c]Maximum concentration taken from 40 CFR Part 192.33.

All of the constituents listed in 40 CFR 192.32 were measured historically; of these, arsenic, barium, cadmium, chromium, lead, molybdenum, nitrate, selenium, uranium, radium, and gross alpha concentrations exceeded Federal standards. Historical monitoring also showed that the State standards for radium and total dissolved solids were regularly exceeded.

Present and future monitoring for GJPO/GJPORAP will focus on constituents that do not presently meet Federal and State standards and on constituents associated with uranium mill tailings contamination for which no standards exist (e.g., manganese and vanadium). Specific conductance, pH, and alkalinity will be measured in the field to detect gross changes in water quality. Table 5–5 lists the analytes that will be measured in groundwater samples, along with their respective reporting limits. Concentrations of selected constituents listed in Table 5–5 will be compared over time to detect changes in water quality caused by remedial action. These constituents may include arsenic, barium, chromium, lead, molybdenum, nitrate, selenium, uranium, radium, and gross alpha.

Table 5–4. State of Colorado Standards for Groundwater Quality[a]

Constituent	Maximum Concentration[b]
Total Dissolved Solids	1.25 times the background value
Radiological	**pCi/L**
Cesium-134	80
Plutonium-238 + 239 + 240	15
Radium-226 + 228	5
Strontium-90	8
Thorium-230 + 232	60
Tritium	20,000
Carcinogenic Organics	**μg/L**
Aldrin	0.1
Benzene	5
Benzidine	50
Carbon Tetrachloride	5
Chlordane	0.1
Chloroethyl Ether (BIS-2)	10
DDT	0.1
1,2-Dichloroethane	5
1,2-Dichloropropane	6
Dieldrin	0.1
Dioxins	0.01
2,3,7,8-Tetrachlorodibenzo-p-dioxin	3
1,2-Diphenylhydrazine	20
Ethylene Dibromide	10
Heptachlor	0.1
Heptachlor Epoxide	0.1
Hexachlorobenzene	10
Hexachlorocyclohexane (Lindane)	4
Polychlorinated Biphenyls	0.5
Toxaphene	5
Trichloroethylene	5
2,4,6-Trichlorophenol	10
Trihalomethanes (total)	100
Vinyl Chloride	2

[a]Groundwater at the GJPO facility is classified by the State of Colorado as Class 4, "Potentially Usable Quality."

[b]pCi/L = picocurie per liter; μg/L = microgram per liter.

Table 5–4 (continued). State of Colorado Standards for Groundwater Quality[a]

Constituent	Maximum Concentration[b]
Noncarcinogenic Organics	μg/L
Aldicarb	10
Carbofuran	36
Chlorobenzene	300
1,2-Dichlorobenzene	620
1,3-Dichlorobenzene	620
1,4-Dichlorobenzene	75
1,1-Dichloroethylene	7
1,2-*Cis*-Dichloroethylene	70
1,2-*Trans*-Dichloroethylene	70
2,4-Dichlorophenol	21
Dichlorophenoxyacetic Acid (2,4-D)	100
Endrin	0.2
Ethylbenzene	680
Ethylene Glycol	7,000
Hexachlorobutadiene	14
Hexachlorocyclopentadiene	49
Isophorone	1,050
Methoxychlor	100
Nitrobenzene	10
Pentachlorobenzene	10
Pentachlorophenol	200
1,2,4,5-Tetrachlorobenzene	10
Tetrachloroethylene	10
Toluene	2,420
1,1,1-Trichloroethane	200
1,1,2-Trichloroethane	28
2,4,5-Trichlorophenol	700
Trichlorophenoxypropionic Acid (2,4,5-TP)	10

[a]Groundwater at the GJPO facility is classified by the State of Colorado as Class 4,"Potentially Usable Quality."

[b]pCi/L = picocurie per liter; μg/L = microgram per liter.

Table 5–5. Groundwater Quality Analytes and Respective Reporting Limits for GJPO/GJPORAP[a]

Nonradiological Constituent	Reporting Limit		Radiological Constituent	Reporting Limit	
Arsenic	0.010	mg/L	Gross Alpha	2.0	pCi/L
Barium	0.20	mg/L	Radium-226	0.5	pCi/L
Cadmium	0.003	mg/L	Radium-228	1.0	pCi/L
Calcium	5.0	mg/L	Uranium-234	0.5	pCi/L
Chloride	0.10	mg/L	Uranium-238	0.5	pCi/L
Chromium	0.010	mg/L	Thorium-230	1.0	pCi/L
Iron	0.10	mg/L	Thorium-232	1.0	pCi/L
Lead	0.003	mg/L			
Magnesium	5.0	mg/L			
Manganese	0.015	mg/L			
Molybdenum	0.050	mg/L			
Nitrate	0.01	mg/L			
Potassium	5.0	mg/L			
Selenium	0.005	mg/L			
Sodium	5.0	mg/L			
Sulfate	0.10	mg/L			
Total Dissolved Solids	10	mg/L			
Vanadium	0.050	mg/L			
Alkalinity	None Defined				
pH	0.1	Unit			
Specific Conductance	None Defined				
Total Organic Carbon	0.10	mg/L			

[a]mg/L = milligram per liter; pCi/L = picocurie per liter.

Mill tailings removal began in 1990 and was completed in 1994; modeling of the alluvial aquifer predicts that the groundwater will be cleaned up to below applicable standards within 50 to 80 years after the uranium mill tailings source is removed.

5.2.2.2 Sampling Plan

Twelve wells completed in the alluvial aquifer will be sampled every 9 months for the groundwater quality constituents listed in Table 5–5 (see Figure 5–1 for locations). Water levels at these wells will be measured quarterly. Sampling on a 9-month frequency will allow seasonal fluctuations in the chemical concentrations to be examined over a 3-year period and will reduce the problem of serial correlation if the data are statistically analyzed. Two of the wells (GJ84–09 and GJ84–10) are located upgradient from the mill tailings contaminant plume and will provide background water quality data. The remaining 10 wells are completed within or downgradient of areas previously contaminated with uranium mill tailings; these wells represent on-site and downgradient conditions. All wells will be visually inspected for damage on a quarterly basis. Table 5–6 lists the monitoring wells that will be sampled.

Specific procedures for sampling groundwater quality and measuring water levels are described in the *Sampling and Analysis Plan for Environmental Monitoring* (DOE 1994e); this sampling and analysis plan incorporates standard procedures published by EPA (1985, 1987b) and DOE (1987). All monitoring

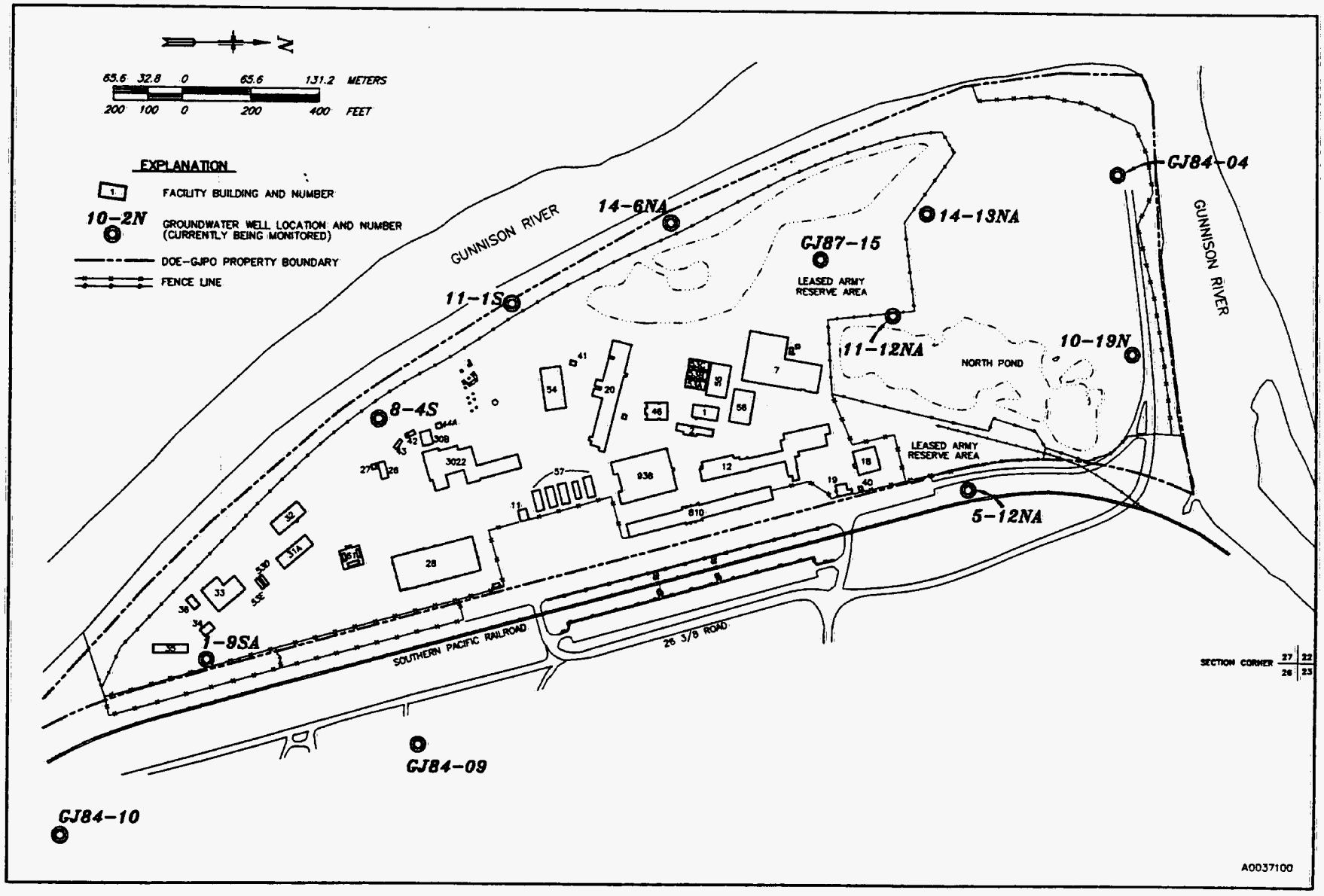

Figure 5-1. Groundwater Sampling Locations at GJPO Facility

Table 5–6. Groundwater Sampling Wells for GJPO/GJPORAP[a]

Well No.	Location	Total Depth (feet)
GJ84–09	Upgradient	31.5
GJ84–10	Upgradient	72.0
1–9SA	On Site	32.0
8–4S	On Site	22.0
11–1S	On Site	30.0
14–6NA	On Site	30.0
10–19N	On Site	28.0
14–13NA	On Site	20.4
GJ87–15	On Site	19.0
11–12NA	On Site	18.0
5–12NA	Downgradient	28.0
GJ84–04	Downgradient	23.0

[a]All well completions are in the alluvial aquifer.

wells will be permitted, constructed, and/or abandoned according to State requirements (State of Colorado 1988).

Groundwater samples will be analyzed by the Analytical Laboratory using the procedures outlined in the *Analytical Chemistry Laboratory Handbook of Analytical and Sample-Preparation Methods* (DOE 1995b). To ensure the integrity of the samples is maintained from the time of collection in the field through laboratory analysis, a chain-of-custody record will be maintained for each possession transfer.

QA and QC measures will be implemented during all sampling and analysis activities. The precision and accuracy of the sample results will be determined through field and laboratory QC measures. Field QC will be accomplished by the analysis of field duplicates and equipment blanks; specific procedures for the collection of field QC samples are described in the *Sampling and Analysis Plan for Environmental Monitoring* (DOE 1994e). Laboratory QC will be accomplished by the analysis of blind duplicates, spikes, spike duplicates, method blanks, and calibration standards, when applicable to the analytical method being performed at a frequency in accordance with the *Analytical Chemistry Laboratory Administrative Plan and Quality Control Procedures* (DOE 1995a). Details of the QA program are presented in Section 10.0 and Appendix A of this EMP.

5.2.2.3 Data Management

The contractor's data manager will maintain a database for all groundwater monitoring data. Data management will include (1) receiving laboratory results via the GJPO computer network, (2) entering information into the appropriate database, and (3) formatting the data for report preparation. Data will be stored in an ORACLE database and will be backed up weekly. All documentation will be stored in a permanent project file in the contractor's records management section.

5.2.2.4 Data Analysis and Reporting Format

Data will be analyzed and reported in the same manner as surface-water monitoring data. Procedures for data analyses and reporting, including statistical methodology, are described in Section 4.2.2.4. The analytes listed in Table 5–5 will be compared with the established standards listed in Tables 5–3 and 5–4.

5.2.3 Responsible Organizations

It is the responsibility of the DOE–GJPO Manager to direct the groundwater monitoring effort. Responsibility for planning and budgeting groundwater monitoring, sampling groundwater, conducting data evaluation, and preparing reports resides with the contractor's Environmental Services section.

5.3 MMTS

Groundwater monitoring at the Monticello millsite has focused on the underlying alluvial aquifer, which is contaminated by the leached by-products of uranium mill tailings. The aquifer is composed of a heterogeneous mixture of gravel, sand, silt, and minor amounts of clay and is an average of 4.5 meters (15 feet) thick. Hydraulic conductivities measured in the alluvium vary from 0.003 to 6 meters (0.01 to 20 feet) per day. The aquifer discharges into the local surface waters of Montezuma Creek and is recharged from infiltration of precipitation and surface water. Groundwater flow generally is to the east and southeast. The average saturated thickness of the aquifer is 3 meters (10 feet).

Underlying the alluvium and separating it from a deeper aquifer are the relatively impermeable siltstones and shales of the Mancos Shale and Dakota Sandstone Formations. These units limit the potential for migration of alluvial water into the underlying aquifer of the Burro Canyon Formation, which is used for domestic water supply. There is no evidence from groundwater well samples that the Burro Canyon aquifer is being degraded by leached by-products of uranium mill tailings.

Descriptions of the hydrogeologic setting and extent of the contaminant plume are contained in several documents, including the *DOE–GJPO Ground-Water Protection Management Program Plan* (DOE 1994f) and the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Work Plan, Draft Final* (DOE 1995f).

5.3.1 Historical Groundwater Monitoring

Groundwater quality monitoring began in 1980 to determine if contamination problems existed at the Monticello millsite. Five wells were completed in the alluvial aquifer. During the months of April, August, and December, groundwater samples were analyzed for a number of water quality constituents, including radiological constituents, heavy metals, and inorganic ions. Sampling of these wells continued semiannually until 50 additional wells were drilled in 1982 and 1983. The new wells allowed comparisons to be made between background water quality and on-site and downgradient water quality. Within the on-site and downgradient wells, samples were determined to be contaminated by uranium, molybdenum, radium, vanadium, and selenium.

In 1984 and 1985, bail tests and pump tests were performed on wells completed in the alluvial and Burro Canyon aquifers to estimate their hydraulic properties. Sampling frequencies for water levels and groundwater quality also were intensified to characterize the contaminant plume.

In 1987, semiannual groundwater quality sampling was resumed at 13 wells located upgradient, on, and downgradient of the millsite. Water levels were measured quarterly in these wells. In fall 1992, 22 additional wells were drilled as part of the MSGRAP RI/FS to develop a baseline characterization of upgradient and downgradient water quality conditions in the alluvial and Burro Canyon aquifers and in the Dakota Sandstone Formation. Twenty-six wells were sampled four times during fiscal year 1993, which completed the baseline characterization. Since fall 1993, approximately 26 wells have been sampled on a semiannual frequency.

Since 1979, many water quality parameters have been investigated at MMTS; these are listed in Table 5–7. More complete descriptions of the historical groundwater monitoring program and results are in the Annual Site Environmental Reports for calendar years 1979 through 1994 (Bendix 1980; Korte and Thul 1981, 1982, 1983, 1984; Korte and Wagner 1985, 1986; Sewell and Spencer 1987; DOE 1988b, 1989b, 1990c, 1991c, 1992b, 1993b, 1994b, 1995d).

5.3.2 Planned Groundwater Monitoring

5.3.2.1 Monitoring Objectives

The objectives of the MMTS groundwater monitoring program are

1. To determine the baseline water quality and quantity conditions of the shallow alluvial and Burro Canyon aquifers and the Dakota Sandstone Formation underlying the site.

2. To characterize the type and extent of the contaminant plumes in the alluvial aquifer.

3. To verify that the water quality within the Burro Canyon aquifer is not being degraded by contaminated alluvial groundwater.

4. To verify compliance with Federal and State groundwater quality standards.

5. To detect changes in water quality resulting from remedial action.

5.3.2.2 Sampling Plan

Twenty-nine wells were sampled in October 1995; however, the number and location of wells sampled will vary after a scheduled well installation in winter 1995 is completed. Table 5–8 lists the wells to be sampled, and Figures 5–2 and 5–3 show the locations of the wells. Sampling will occur on a semiannual frequency in October and April. Table 5–9 lists the groundwater quality constituents that will be measured. Organic compounds listed in Table 5–9 will be measured in five alluvial wells during the April sampling event only. (Note: Because the organic compounds in Table 5–9 have not been routinely detected in previous rounds, they are being proposed for deletion in future monitoring.) Water level measurements in selected wells will be conducted monthly, and all wells will be inspected for damage quarterly.

As part of the ongoing RI/FS activities, additional downgradient wells are scheduled to be installed and sampled in winter 1995. Additional wells will allow better definition of the extent of contamination in the alluvial aquifer and will help determine if water quality in the Burro Canyon aquifer is being degraded by contaminated alluvial groundwater. The rationale for the new well installations and the

Table 5–7. Water Quality Constituents Analyzed for in MMTS Groundwater Samples From 1979 to Present

Nonradiological Constituents		Radiological Constituents
Inorganic	**Organic/Biological**	
Alkalinity	TCL Volatile Organic Compounds	Gross Alpha
Aluminum	TCL Semivolatile Organic Compounds	Gross Beta
Ammonia (as N)	TCL Pesticides	Lead-210
Ammonium	TCL Herbicides	Polonium-210
Antimony	Total Coliform	Radium-226
Arsenic	Total Organic Carbon	Radium-228
Barium		Radon-222
Beryllium		Thorium-230
Boron		Thorium-232
Cadmium		Uranium-234
Calcium		Uranium-235
Chloride		Uranium-238
Chromium		
Cobalt		
Copper		
Cyanide		
Dissolved Oxygen		
Eh		
Fluoride		
Gross Alpha		
Gross Beta		
Iron		
Lead		
Magnesium		
Manganese		
Mercury		
Molybdenum		
Nickel		
Nitrate		
Nitrate (as Nitrogen)		
Nitrate + Nitrite (as Nitrogen)		
Nitrite		
pH		
Phosphate		
Potassium		
Selenium		
Silicon		
Silver		
Sodium		
Strontium		
Sulfate		
Thallium		
Tin		
Total Dissolved Solids		
Total Inorganic Carbon		
Tritium		
Turbidity		
Uranium		
Vanadium		
Zinc		

Table 5–8. Groundwater Sampling Wells at MMTS

Well No.	Aquifer	Location
92–01	Alluvium	Upgradient
92–02	Burro Canyon	Upgradient
92–03	Alluvium	Upgradient
92–04	Burro Canyon	Upgradient
92–05	Alluvium	Upgradient
92–06	Burro Canyon	Upgradient
92–13	Dakota Sandstone	Upgradient
82–30B	Alluvium	Millsite
82–40A	Alluvium	Millsite
82–42	Alluvium	Millsite
82–31B–E	Alluvium	Millsite
31SW91–03	Alluvium	Millsite
31SW91–14	Alluvium	Millsite
31SW91–23	Alluvium	Millsite
36SE93–201–2	Alluvium	Millsite
93–01	Burro Canyon	Millsite
82–07	Alluvium	Downgradient
83–70	Burro Canyon/Dakota Sandstone	Downgradient
88–85	Alluvium	Downgradient
92–07	Alluvium	Downgradient
92–08	Alluvium	Downgradient
92–09	Alluvium	Downgradient
92–10	Burro Canyon	Downgradient
92–11	Alluvium	Downgradient
92–12	Dakota Sandstone	Downgradient
31NE93–205	Burro Canyon	Crossgradient
P92–02	Alluvium	Downgradient
P92–04	Alluvium	Downgradient
P92–09	Alluvium	Downgradient

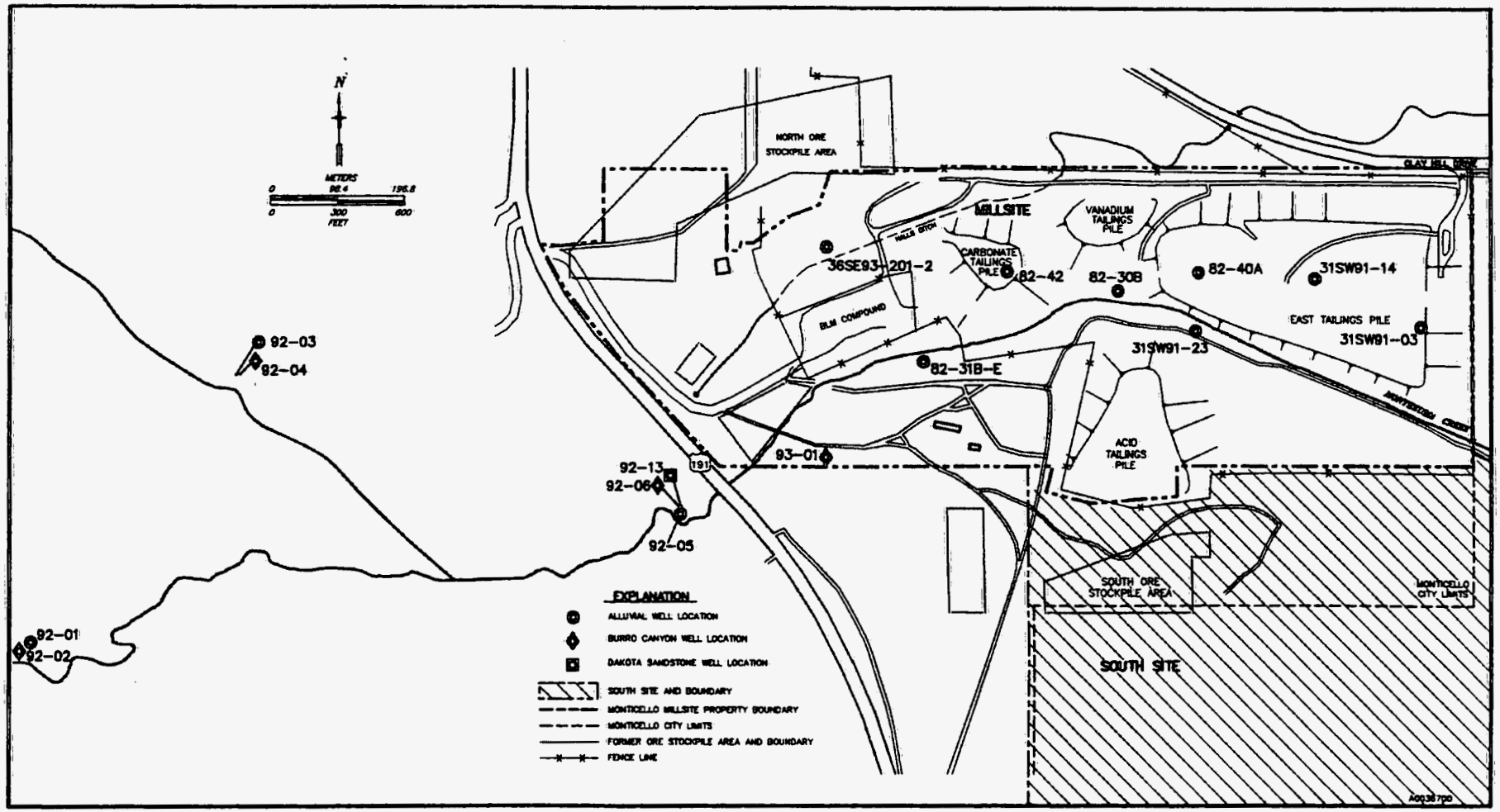

Figure 5–2. Groundwater Sampling Locations On and Upgradient of Monticello Millsite

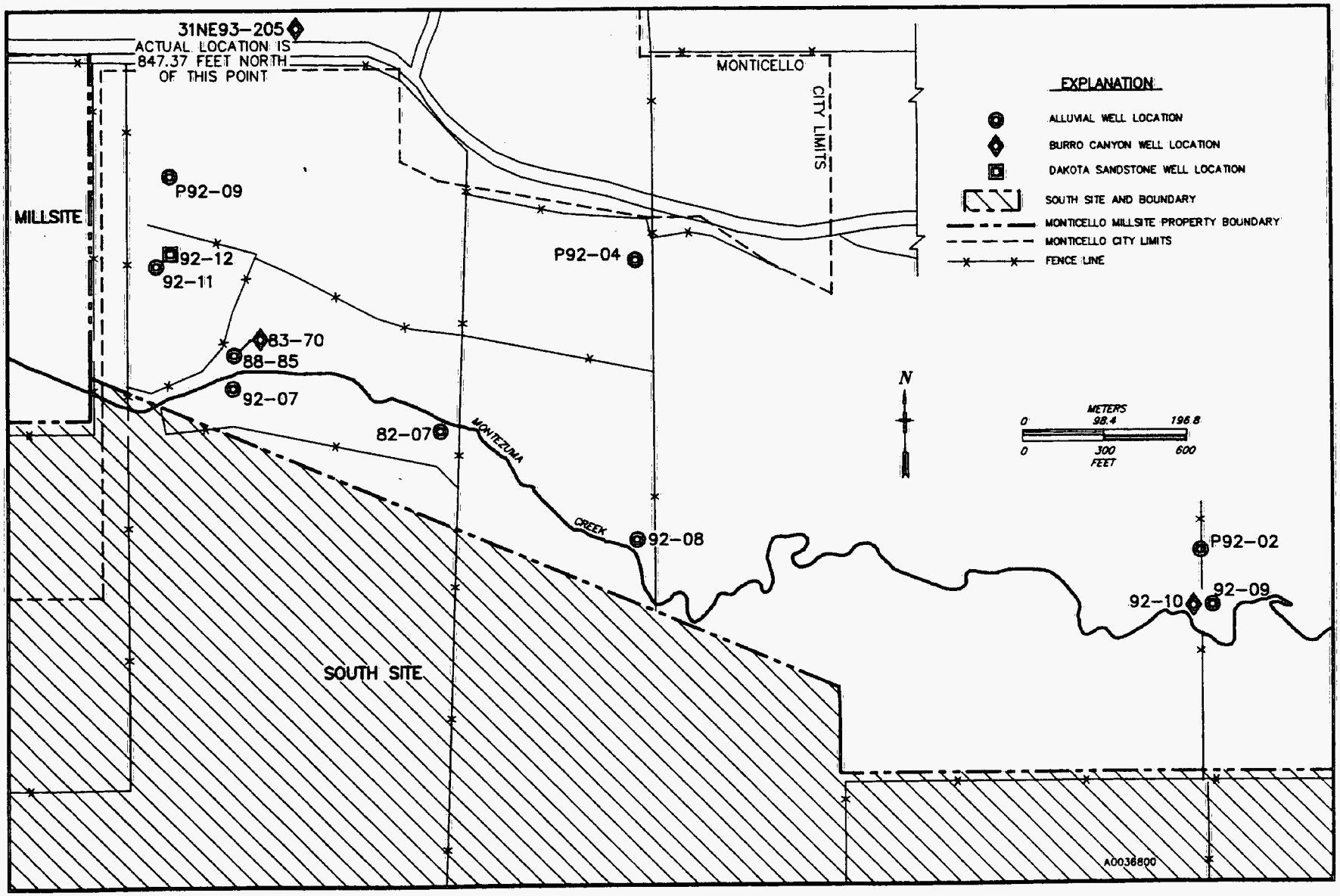

Figure 5-3. Groundwater Sampling Locations Downgradient of Monticello Millsite

Table 5–9. Groundwater Quality Analytes for MMTS[a]

Analytical Parameters	Analytes
Volatile Organic Compounds	Target Compound List[b]
Semivolatile Organic Compounds	Target Compound List[b]
Pesticides/PCBs	Aldrin Alpha-BHC Beta-BHC Delta-BHC Gamma-BHC (lindane) Alpha-Chlordane Gamma-Chlordane 4,4'-DDD 4,4'-DDE 4,4'-DDT Dieldrin Endosulfan I Endosulfan II Endosulfan Sulfate Endrin Endrin Aldehyde Heptachlor Heptachlor Epoxide Methoxychlor Toxaphene Aroclor 1016 Aroclor 1221 Aroclor 1232 Aroclor 1242 Aroclor 1248 Aroclor 1254 Aroclor 1260
Herbicides	2,4-D 2,4-DB 2,4,5-T 2,4,5-TP (Silvex) Dalapon Dichloroprop
Major Anions	Chloride Fluoride Nitrite (Nitrate + Nitrite) as Nitrogen Sulfate

[a]PCB = polychlorinated biphenyl; BHC = benzene hexachloride.

[b]Target compound list volatiles and semivolatiles are listed in the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Field Sampling Plan and Quality Assurance Project Plan, Draft Final* (DOE 1995e).

Table 5–9 (continued). Groundwater Quality Analytes for MMTS

Analytical Parameters	Analytes
Major Cations	Ammonium Calcium Magnesium Potassium Sodium
Metals	Aluminum Arsenic Cobalt Copper Manganese Molybdenum Selenium Tin Vanadium Zinc
Radionuclides	Gross Alpha Gross Beta Lead-210 Radium-226 Radon-222 Thorium-230 Uranium-234 Uranium-235 Uranium-238
Other	Total Dissolved Solids

groundwater monitoring program is in the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Work Plan, Draft Final* (DOE 1995f). The details of the groundwater monitoring program, including sampling and laboratory analysis procedures, QA and QC measures, and reporting limits for analytical parameters, are specified in the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Field Sampling Plan and Quality Assurance Project Plan, Draft Final* (DOE 1995e).

5.3.2.3 Data Management

Data storage and management will be the same as that described for GJPO/GJPORAP (see Section 5.2.2.3).

5.3.2.4 Data Analysis and Reporting Format

Data analysis techniques and reporting formats will be the same as those described for GJPO/GJPORAP (see Section 5.2.2.4).

5.3.3 Responsible Organizations

Responsible organizations will be the same as those described for GJPO/GJPORAP (see Section 5.2.3).

6.0 Air Effluent

6.1 Regulatory Requirements

Air effluent monitoring for GJPO and MMTS is conducted to verify compliance with the ARARs outlined in Table 6–1.

6.2 GJPO

Airborne radiological emissions from the GJPO facility consist of (1) radioparticulate emissions from the Sample Preparation Facility exhaust stack (Baghouse) and Analytical Laboratory and (2) radon emissions from the calibration test pads and Radon Laboratory. Emissions from the Baghouse stack (Figure 6–1) are sampled, whereas emissions from the Analytical Laboratory, calibration test pits, and Radon Laboratory are estimated using the method in 40 CFR Part 61, Appendix D.

Nonradiological emission sources from the GJPO facility consist of the Analytical Laboratory, Petrology Laboratory, and Baghouse. The Air Pollution Control Division of CDPHE issued an air emission permit for the Analytical Laboratory and granted permit exemptions for the other two sources. The permit for the Analytical Laboratory establishes limitations on (1) the annual emissions of particulate matter, volatile organic compounds, and benzene; (2) the annual consumption of acids, volatile organic compounds, and benzene; and (3) the opacity of the emissions.

The primary pollutant of concern emitted from the Petrology Laboratory is asbestos fiber that is generated from the analysis of building materials containing asbestos and from the counting of asbestos fibers on lapel air-monitoring filters. Both analyses are performed under hoods equipped with high-efficiency particulate air (HEPA) filters that have an efficiency rating of 99.97 percent for particles 0.3 micrometer (μm) or greater. The filters are replaced when the pressure differential across the filter reaches the manufacturer's recommended value for replacement. To ensure filter integrity and proper gasket sealing, filters are tested each time they are replaced, in accordance with procedures described in the *Nuclear Air Cleaning Handbook* (Burchsted et al. 1979).

Nonradiological emissions from the Baghouse consist primarily of dusts from sample-preparation activities. However, 99 percent of the dust generated during sample-preparation activities is retained by the Baghouse filtration system.

6.2.1 Historical Air Effluent Monitoring

An air-particulate sampling program was initiated for GJPORAP in December of 1985 to ensure compliance with EPA and DOE air quality standards during remediation activities. The initial sampling network consisted of three high-volume air particulate samplers mounted on 3.5-meter (11.5-foot) towers. Ambient air was sampled at 1.1 cubic meters per minute (m^3/min) for 24 hours every sixth day. In 1987, each of the air particulate samplers was equipped with a 10-μm size-selective inlet, which allowed only particles 10 μm or smaller (PM_{10}) to pass through and be sampled. During 1990, a fourth sampling station was added southeast of the on-site tailings stockpile, and the sampling frequency at

Table 6-1. ARARs for Air Effluent Monitoring

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO and MMTS		
General Environmental Protection Program	DOE Order 5400.1, Chapter IV, Part 6	An assessment of the potential radiation dose to members of the public that could result from site operations shall be made for facilities required to conduct effluent and environmental radiological monitoring. Assessments shall be made in accordance with the requirements of U.S. Department of Energy (DOE) orders in the 5400 series dealing with radiation protection of the public and environment.
Radiation Protection of the Public and the Environment	DOE Order 5400.5, Chapter I, Part 8a, Chapter II, Part 1a(1)	Demonstrations of compliance with the requirements of this order generally will be calculations that make use of information obtained from monitoring and surveillance programs. The ability to detect, quantify, and adequately respond to unplanned releases of radioactive material to the environment relies on in-place effluent monitoring of environmental transport and diffusion conditions. The exposure of members of the public to radiation sources as a consequence of routine DOE activities shall not cause an effective dose equivalent of greater than 100 millirems (mrem)/yr.
	DOE Order 5400.5 Chapter II, Part 1b(3)	Emissions of radionuclides to the ambient air from DOE facilities shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/yr, excluding radon and its daughters. To determine compliance with the standard, radionuclide emission shall be determined and effective dose equivalent values to members of the public shall be calculated using U.S. Environmental Protection Agency (EPA)-approved sampling procedures and computer models.
Radiological Effluent Monitoring and Environmental Surveillance	DOE Environmental Regulatory Guide, Chapter 3.0	All airborne emissions from DOE-controlled facilities shall be evaluated and their potential for releasing radionuclides shall be assessed. The results of this evaluation shall provide the basis for the site's effluent monitoring program, which shall be documented in the site Environmental Monitoring Plan to identify • Effluent monitoring locations for each emission point or area. • Procedures and equipment needed to perform measurements. • Frequency and analysis required for each measurement. • Minimum detection-level accuracy. • Quality assurance components. Airborne emissions from DOE-controlled facilities that have the potential for causing effective dose equivalents exceeding 0.1 mrem/yr shall be monitored in accordance with the requirements of DOE Orders 5400.1 and 5400.5.

Table 6–1 (continued). ARARs for Air Effluent Monitoring

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Specific to GJPO		
National Emission Standards for Hazardous Air Pollutants	40 CFR Part 61 Subpart H	The owners or operators of each facility shall submit an annual report to both EPA headquarters and the appropriate regional office by June 30. The report shall include the results of the monitoring, as recorded in DOE's Effluent Information System, and the dose calculations required by this regulation.
Air Pollution Emission Notification	Colorado Air Quality Act, Revised 1982	Emission of an air pollutant at a rate greater than the reporting threshold for that pollutant from any facility is prohibited until an Air Pollution Emission Notification has been filed with the Air Pollution Control Division of the Colorado Department of Public Health and Environment.
General Environmental Protection Program	DOE Order 5400.1, Chapter IV, Part 6	Airborne radiation and radioactive materials discharged from DOE facilities shall comply with the requirements of 40 CFR Part 61, Subpart H, "National Emission Standards for Hazardous Air Pollutants."
ARARs Specific to MMTS		
National Primary and Secondary Ambient Air Quality Standards	40 CFR Part 50	National primary ambient air-quality standards define levels of air quality that EPA judges to be necessary to protect public health. National secondary air quality standards define levels of air quality that EPA judges to be necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant.
Radiological Effluent Monitoring and Environmental Surveillance	DOE Environmental Regulatory Guide, Chapter 3.0	Diffuse sources shall be identified and assessed for their potential to contribute to public dose and shall be considered in designing the site effluent monitoring and environmental surveillance programs.

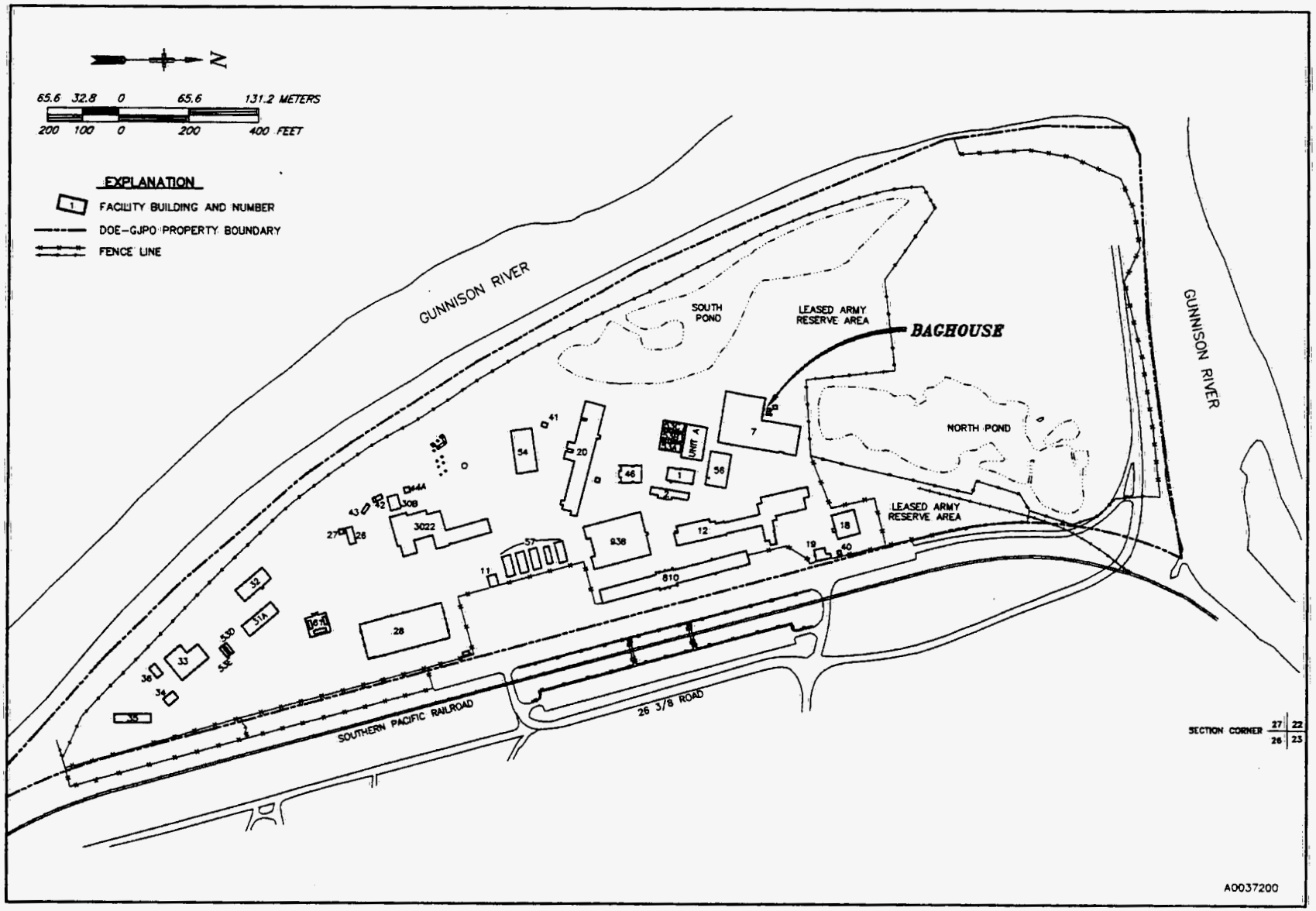

Figure 6–1. Baghouse Location at GJPO Facility

all the stations was increased from every sixth day to every third day. These changes were made in response to the increase in GJPORAP remedial activities. Air sample filters were analyzed for radium-226, thorium-230, uranium, lead, and PM_{10} particulate matter. Concentrations of air particulates never exceeded the standards established by EPA (40 CFR Part 50) or DOE (DOE Order 5400.5).

In January 1992, the air-particulate monitoring strategy was revised again. Because the 24-hour sampling period required for PM_{10} sampling was not long enough to allow radioparticulate accumulations to reach measurable levels, radioparticulate sampling was begun on a separate schedule. Samplers were run continuously for a 5-day period each month for the purpose of radioparticulate sampling only. The frequency of PM_{10} sampling was returned to once every sixth day (for a 24-hour period). Lead was removed from the analyte list because measured levels of this particulate were consistently two orders of magnitude below established standards. The ambient-air monitoring program was terminated at the conclusion of the contaminated-soil removal phase of GJPORAP on July 1, 1994.

Monitoring of Baghouse radioparticulate emissions began in 1992 with the installation of an automatic sampler. Data generated from sampling are used to determine compliance with the radiological dose limits set forth in 40 CFR Part 61, Subpart H, "National Emission Standards for Hazardous Air Pollutants" and DOE Order 5400.5. The average annual dose caused by Baghouse emissions is approximately 0.0004 mrem/yr, which is well below the EPA and DOE annual dose limit of 10 mrem/yr.

Opacity monitoring of Analytical Laboratory emissions was conducted from 1991 to 1994. Results showed that the exhaust opacity never exceeded zero. Because of this record and because the nature of work performed in the laboratory had no potential for causing visible emissions, opacity monitoring was discontinued in 1995. If the nature of work should change so that an increase in visible emissions could result, opacity monitoring will be resumed.

6.2.2 Planned Air Effluent Monitoring

6.2.2.1 Monitoring Objectives

The objectives of the GJPO air-effluent monitoring program are

1. To verify compliance with EPA and DOE radiation protection standards.

2. To verify compliance with State air-emission permit requirements.

To satisfy the first objective, air effluent monitoring of Baghouse radioparticulate emissions will be continued. Compliance with the Analytical Laboratory air emission permit will be achieved by tracking the permitted consumption rates for volatile organic compounds and acids (through the use of a mass balance approach).

6.2.2.2 Sampling Plan

Emission monitoring of the Baghouse stack will be continuous when the Baghouse is in operation. Radionuclide emissions will be sampled according to the procedures specified in 40 CFR Part 61.93(b) and according to the QA/QC performance requirements specified in 40 CFR Part 61, Appendix B, Method 114. Baghouse filters will be analyzed for the constituents listed in Table 6–2. Filters will be collected every month and will be analyzed by the Analytical Laboratory using the procedures in the *Analytical Chemistry Laboratory Handbook of Analytical and Sample-Preparation Methods* (DOE 1995b). This handbook describes the precision of each analytical technique and the methodology

Table 6–2. Air Effluent Analytes and Respective Reporting Limits for GJPO Facility[a]

Analyte	Reporting Limit[b]
Lead-210	4 pCi/filter
Polonium-210	0.5 pCi/filter
Radium-226	1 pCi/filter
Thorium-230	0.5 pCi/filter
Thorium-232	0.5 pCi/filter
Uranium (total)	1 μg/filter

[a]pCi = picocurie; μg = microgram.
[a]Reporting limit may vary, depending on matrix interferences, and is applicable to each filter measured. Reporting limits are from the *Analytical Chemistry Laboratory Handbook of Analytical and Sample-Preparation Methods* (DOE 1995b).

used by the laboratory. Table 6–2 lists the reporting limits that will be used for each constituent. Detailed procedures for sampling the Baghouse are contained in the *Sampling and Analysis Plan for Environmental Monitoring* (DOE 1994e).

6.2.2.3 Data Management

The contractor's data manager will maintain a database for air-effluent monitoring data. Data will be stored in an ORACLE database and will be backed up weekly. All paper reports, records, and data will be stored in a permanent project file in the contractor's records management section.

6.2.2.4 Data Analysis and Reporting Format

Data will be analyzed to determine if monitoring objectives have been met. Only valid data will be entered in an EPA-approved dose model (CAP88–PC) to demonstrate compliance with the public radiation dose limitations of DOE Order 5400.5 and 40 CFR Part 61, Subpart H. Compliance will be achieved if modeled values fall below the standard values. All monitoring data will be tabulated and reviewed annually, and a data summary will be presented in the Annual Site Environmental Report.

6.2.3 Responsible Organizations

The air-effluent monitoring program is the responsibility of the DOE–GJPO Manager; responsibility for implementing the program resides with the contractor's Environmental Services section.

6.3 MMTS

6.3.1 Historical Air Effluent Monitoring

Air particulate monitoring at MMTS was initiated in August 1983. The original air sampling network consisted of three high-volume air samplers that sampled ambient air at approximately 0.9 m^3/min for 24 hours every sixth day. Samples were collected on a glass-fiber filter and analyzed for total suspended particulate matter, radium-226, thorium-230, and total uranium. In March 1987, 10-μm size-selective

inlets were installed in the intake of the samplers to separate PM_{10} from larger particles. This action was driven by a change in the national ambient air-quality regulations from a total suspended-particulate standard to a PM_{10} standard.

In November 1993, seven low-volume (i.e., flow rate of 0.06 m^3/min) radioparticulate samplers were installed adjacent to the millsite and the city of Monticello in response to an increase in remedial activities; sampler locations are identified in Figure 6–2. Filters from these samplers were analyzed for radium-226, thorium-230, and total uranium. The existing high-volume samplers were then used for sampling nonradiological PM_{10} only. The low-volume samplers were operated 24 hours a day, 7 days a week. Samples were retained on a glass-fiber filter in each sampler and were collected weekly. To obtain average monthly values of radioparticulate concentrations, four weekly filter samples were composited and analyzed as one sample.

In January 1994, two high-volume PM_{10} samplers were added to the monitoring network, and the existing PM_{10} samplers were relocated to more effectively monitor off-site dust emissions (see Figure 6–2). One of the new high-volume samplers (AIR–M–7) was installed 8 km (5 miles) north of the millsite to collect background PM_{10} data.

The atmospheric radon monitoring program was initiated at MMTS in 1984 with the installation of radon detectors at 19 sampling locations. After a 12-month collection of baseline data, the sampling network was reduced to eight representative locations. In response to increased remediation activities, seven locations were added during the third quarter of 1993. Radon concentrations were measured at these 2 on-site and 13 off-site locations (Figure 6–3) with Landauer Radtrak alpha-sensitive detectors. These detectors were exposed in duplicate 1 meter above the ground surface and were analyzed quarterly (3-month exposure).

6.3.2 Planned Air Effluent Monitoring

6.3.2.1 Monitoring Objectives

The objectives of the MMTS air-effluent monitoring program are

1. To establish a baseline of air quality conditions.

2. To verify compliance with Federal ambient air-quality standards, Federal radiation protection standards, and DOE orders regulating radiation protection of the public.

Historical air effluent monitoring has accomplished both monitoring objectives; the objective of current and future air-effluent monitoring programs will be to continue to evaluate compliance.

National primary and secondary ambient air-quality standards are established at 40 CFR Part 50. The PM_{10} standard specifies an annual average of not more than 50 micrograms per cubic meter ($\mu g/m^3$) and a 24-hour maximum concentration not to exceed 150 $\mu g/m^3$. The ambient air-quality standard for lead specifies that the concentration of lead must not exceed 1.5 $\mu g/m^3$ averaged for a calendar quarter. Lead concentration measurements were suspended at MMTS in January 1992 because historical measurements were consistently two orders of magnitude below the standard. Sampling for lead will resume when the mill tailings piles are breached for movement to the permanent repository.

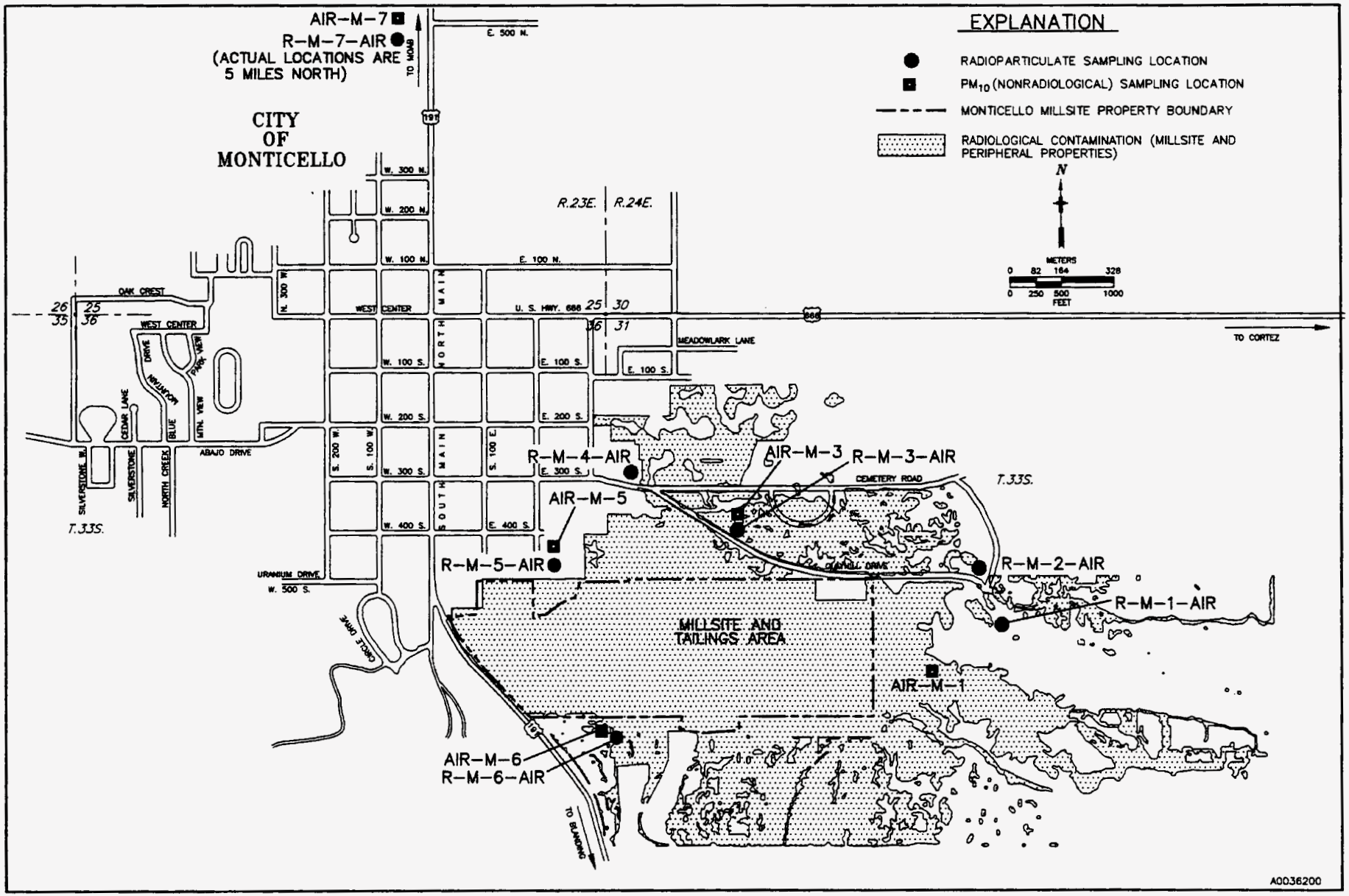

Figure 6-2. Air-Particulate Sampling Locations At and Near MMTS

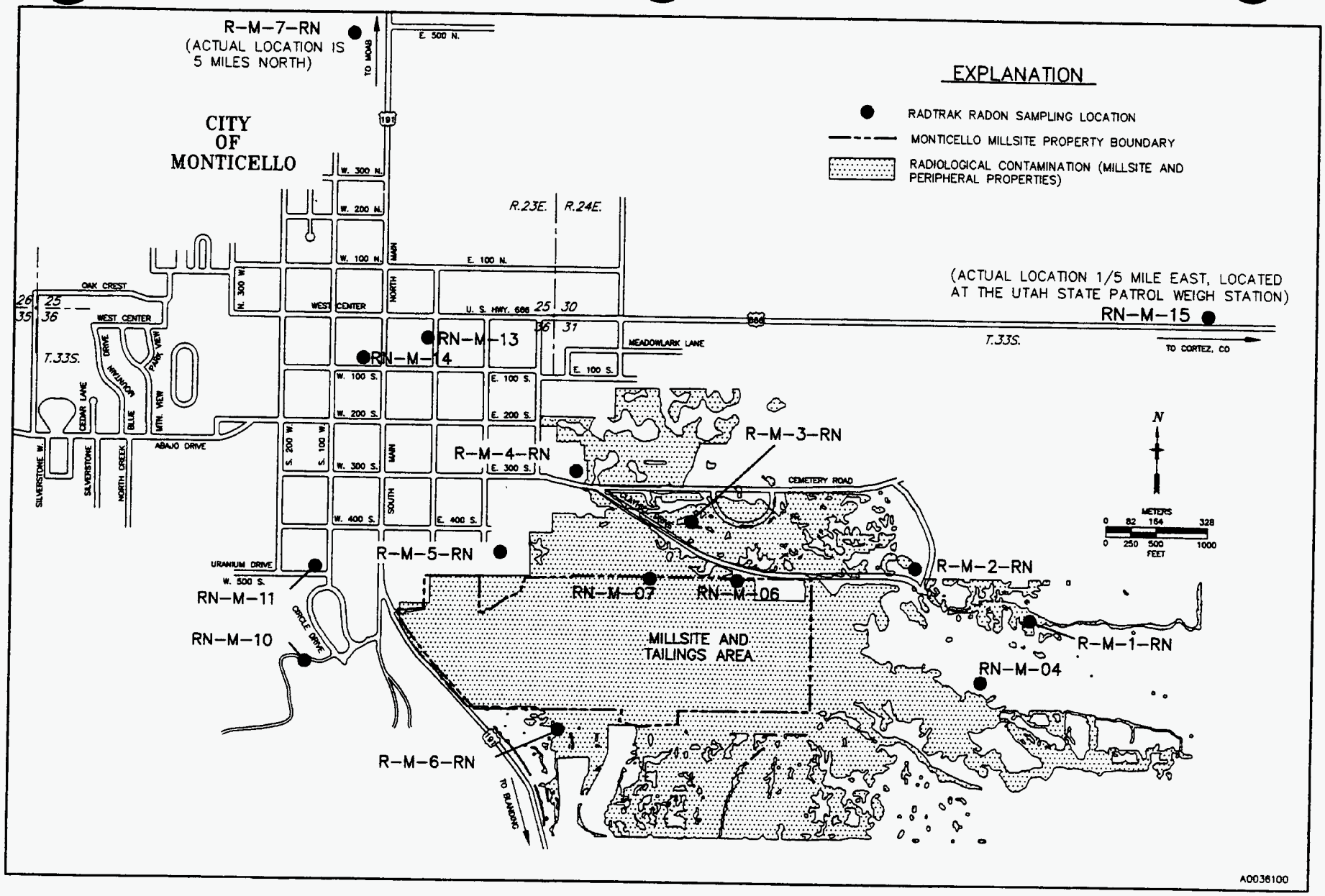

Figure 6-3. Atmospheric Radon Sampling Locations At and Near MMTS

DOE Order 5400.5 places a limit of 100 mrem/yr (all exposure modes) effective dose equivalent on members of the public as a consequence of DOE activities. In addition, DOE Order 5400.5 lists Derived Concentration Guides (DCGs) for air that provide reference values for conducting radiological environmental protection programs. DCGs for currently monitored radionuclides and radon are presented in Table 6–3.

Table 6–3. Derived Concentration Guides for Currently Monitored Radionuclides at MMTS

Radionuclide	Inhaled-Air DCG (μCi/mL[a])
Radium-226	1×10^{-12}
Radon	3×10^{-9}
Thorium-230	4×10^{-14}
Uranium	2×10^{-12}

[a]μCi/mL = microcurie per milliliter.

6.3.2.2. Sampling Plan

Air particulate sampling with five high-volume PM_{10} samplers and seven low-volume radioparticulate samplers (Figure 6–2) will continue to be conducted at and near the MMTS. PM_{10} sampling will be conducted every sixth day for a 24-hour period, and radioparticulate sampling will be conducted continuously. Both types of sampling will be conducted throughout the MMTS construction season, which is usually April through November. Atmospheric radon samplers will continue to be deployed year-round and collected quarterly at the same 15 locations at and near MMTS (Figure 6–3). Results of the PM_{10} monitoring will be used to determine compliance with the national primary and secondary ambient air-quality standards; results of the radioparticulate and radon monitoring will be used to determine compliance with the radiation protection standards in DOE Order 5400.5.

Sample-collection frequency; methodology; and maintenance, calibration, and documentation requirements for air particulate and radon sampling are described in the *Monticello Mill Tailings Site, Monitoring of Air Particulate, Radon, and Gamma Radiation Emissions Work Plan* (DOE 1994c). Air particulate filters will be analyzed in accordance with the *Analytical Chemistry Laboratory Administrative Plan and Quality Control Procedures* (DOE 1995a) and the *Analytical Chemistry Laboratory Handbook of Analytical and Sample-Preparation Methods* (DOE 1995b). The Landauer Radtrak radon detectors will be analyzed by Landauer, Inc., which is a subcontracted laboratory. Analytical procedures used by Landauer are described in the *Quality Assurance Manual for Radon Monitoring, Revision Number 7* (Landauer, Inc. 1991). Reporting limits for air effluent analytes are listed in Table 6–4.

6.3.2.3 Data Management

Data management procedures will be the same as those described for GJPO in Section 6.2.2.3.

Table 6–4. Air Effluent Analytes and Respective Reporting Limits for MMTS[a]

Analyte	Reporting Limit[b]
Radium-226	1 pCi/filter composite
Radon	0.1 pCi/L
Thorium-230	0.5 pCi/filter composite
Uranium	1 μg/filter composite

[a]pCi = picocurie; μg = microgram.

[b]Reporting limit may vary, depending on matrix interferences, and is applicable to each filter measured. Reporting limits are from the *Analytical Chemistry Laboratory Handbook of Analytical and Sample-Preparation Methods* (DOE 1995b).

6.3.2.4 Data Analysis and Reporting Format

Data will be analyzed to determine if monitoring objectives have been met. Only data of known quality will be compared to the standards listed in Section 6.3.2.1 and used in the EPA-approved dose model (CAP88–PC) to demonstrate compliance with the public radiation dose limitations of DOE Order 5400.5. Compliance with standards will be achieved if all measured and modeled values fall below the standard values. Air effluent data will be reported in the graphical format displayed in Figure 4–2, with a comparison of measured and standard values. Monitoring data will be tabulated and reviewed periodically, and a summary of the data will be presented in the Annual Site Environmental Report.

6.3.3 Responsible Organizations

Responsible organizations will be the same as those described for GJPO in Section 6.2.3.

7.0 Direct Gamma Radiation

7.1 Regulatory Requirements

The direct-gamma radiation monitoring program for MMTS is conducted to comply with the ARARs outlined in Table 7–1.

7.2 GJPO/GJPORAP

The direct-gamma radiation monitoring program at GJPO began in April 1991. Radiation measurements were made with $CaSO_4$:Dy (calcium sulfate dysprosium) thermoluminescent dosimeters (TLDs), which were configured to detect gamma radiation. Fifteen monitoring locations on the GJPO facility and surrounding areas were monitored quarterly (3-month exposure period). The program was terminated at the completion of the contaminated-soil removal phase of GJPORAP on July 1, 1994.

7.3 MMTS

7.3.1 Historical Direct-Gamma Radiation Monitoring

A direct-gamma radiation monitoring program was initiated at MMTS in April 1991 to assess the potential direct-gamma radiation dose to persons on and near the millsite, in accordance with DOE Order 5400.5 and DOE's *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (DOE 1991a). Radiation measurements were made at 12 locations with $CaSO_4$:Dy TLDs on a quarterly basis. In 1993, seven sampling locations (R–M–1–TLD through R–M–7–TLD in Figure 7–1) were added in response to an increase in remedial activities. Direct-gamma radiation measurements were included, along with radiation measurements associated with radon and air particulates, in the calculation of total off-site dose to the public to determine compliance with the DOE and EPA standard of 100 mrem/yr above background.

7.3.2 Planned Direct-Gamma Radiation Monitoring

7.3.2.1 Monitoring Objectives

The objectives of the MMTS direct-gamma radiation monitoring program are

1. To provide a means of documenting the radiological conditions at MMTS and surrounding areas.

2. To assess the potential radiation dose to residents of Monticello in accordance with DOE's *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (DOE 1991a).

3. To quantify the potential off-site dose to assess compliance with the 100 mrem/yr dose limit established by DOE Order 5400.5.

Table 7–1. ARARs for Direct-Gamma Radiation Monitoring

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Specific to MMTS		
General Environmental Protection Program	DOE Order 5400.1, Chapter IV, Part 5b	Environmental surveillance shall be conducted to monitor the effects of U.S. Department of Energy (DOE) activities on on-site and off-site environmental resources.
Radiation Protection of the Public and the Environment	DOE Order 5400.5, Chapter I, Part 8a, Chapter II, Part 1a	Dose evaluations are required to demonstrate that the exposure to members of the public to radiation sources as a consequence of DOE activities does not cause an effective dose equivalent of greater than 100 millirems per year. Demonstrations of compliance with the requirements of this order shall make use of information obtained from monitoring and surveillance programs.
Radiological Effluent Monitoring and Environmental Surveillance	DOE Environmental Regulatory Guide, Chapter 5.0, Parts 5.1, 5.5, 5.6	An evaluation shall be conducted and used as the basis for establishing an environmental surveillance program for all DOE-controlled sites. One of the "critical pathways" of exposure for population groups living within the vicinity of DOE facilities is exposure to external radiation. For DOE sites, gamma exposure should be measured or calculated. A primary objective of this evaluation is to assess the actual or potential radiation dose to persons in the site environs.
State of Utah Standards for Protection Against Radiation	Utah Administrative Codes (R447-15-105)	Limits radiation levels from external sources in unrestricted areas so that it will be unlikely for an individual to receive a dose to the whole body in excess of 0.5 roentgen equivalent man (rem) in any 1 year.

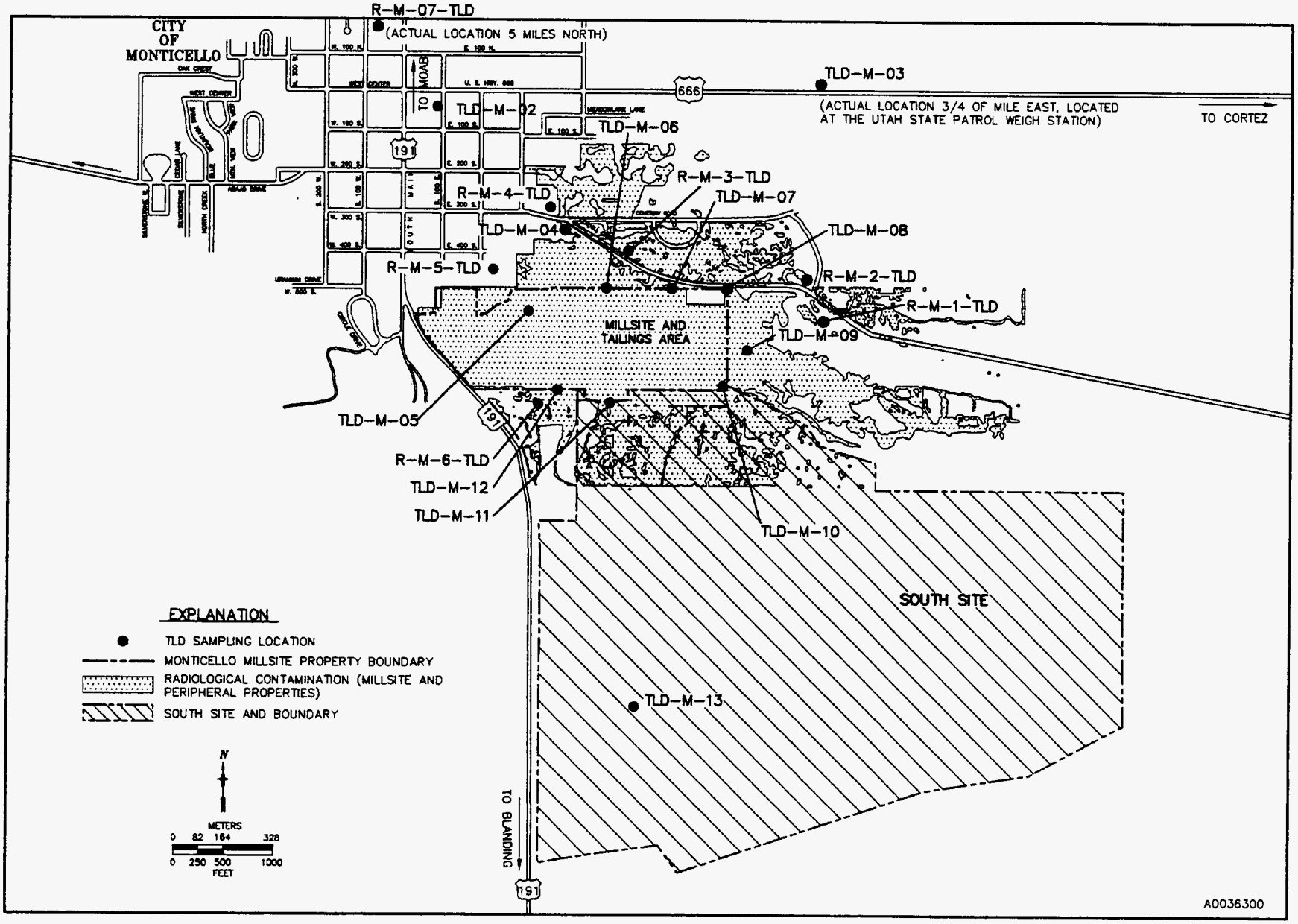

Figure 7-1. Direct-Gamma Radiation Sampling Locations At and Near MMTS

The historical direct-gamma radiation monitoring program has accomplished all of these monitoring objectives. Current and future monitoring will continue to focus on these objectives.

7.3.2.2 Sampling Plan

Direct gamma radiation will continue to be monitored at 19 locations (Figure 7–1) with $CaSO_4$:Dy TLDs. Background radiation will be measured at R–M–07–TLD, which is located in an area of similar geology and elevation as the millsite. The TLDs will be exposed quarterly (3-month exposure period), collected, and sent to Teledyne Isotopes for analysis. New TLDs will be placed in the sampling locations each quarter.

Procedures for handling and collecting TLDs are described in the *Monticello Mill Tailings Site, Monitoring of Air Particulate, Radon, and Gamma Radiation Emissions Work Plan* (DOE 1994c). The TLDs are analyzed in accordance with *Preparation and Read-Out of Teledyne Isotopes TLD Card, TIML–TLD–01, Revision 5* (Teledyne Isotopes 1990).

7.3.2.3 Data Management

The contractor's data manager will maintain a database for all direct-gamma radiation data. Data will be stored in an ORACLE database and will be backed up weekly. All records, reports, and data will be stored in a permanent project file in the contractor's records management section. In addition, all paper documentation will be maintained in a centralized file in the contractor's Environmental Services section.

7.3.2.4 Data Analysis and Reporting Format

Data will be analyzed to determine if monitoring objectives have been met. Only data of known quality will be used to determine the direct-gamma radiation dose. Radiological conditions at and near MMTS will be documented by comparing on- and near-site TLD data with TLD data from the background location. By making this comparison, an assessment of the potential direct-gamma radiation dose to persons living near MMTS can be made. Additionally, radiation exposure data from the TLDs will be used as one component in the dose evaluation to members of the public, in accordance with DOE Order 5400.5. A summary of TLD data will be presented in a tabular format in the Annual Site Environmental Reports.

7.3.3 Responsible Organizations

The direct-gamma radiation monitoring program is the responsibility of the DOE–GJPO Manager. The responsibility for implementing the monitoring program resides with the contractor's Environmental Services section.

Section 8.0
Biota

8.0 Biota

8.1 Regulatory Requirements

Biota monitoring for GJPO, GJPORAP, and MMTS is conducted to comply with the ARARs listed in Table 8–1.

8.2 GJPO/GJPORAP

8.2.1 Historical Biota Monitoring

Biota sampling was conducted at the GJPO facility between May and September 1993. Carp, cottonwood trees, and native grasses were sampled from on-site and off-site locations, and samples were analyzed for total uranium, radium-226, and thorium-230. Details of the sampling effort are presented in the *Plan for Radiological Surveillance of Biota at the Grand Junction Projects Office Facility* (DOE 1993c) and *Radiological Surveillance of Biota at the Grand Junction Projects Office Facility* (DOE 1993d).

Radiation doses to native aquatic organisms were calculated according to the methods described by Baker and Soldat (1992). Maximum 1992 surface water concentrations of uranium-234, uranium-238, radium-226, and thorium-232 (DOE 1993c) and standardized bioaccumulation rates, transfer factors, intake rates, and other factors were used to estimate the maximum total radiation dose received by algae, fish, molluscs, crustaceans, muskrats, raccoons, herons, and ducks living on or near the GJPO facility. All estimated doses were below the DOE maximum dose limit of 1 radian per day (rad/day).

8.2.2 Planned Biota Monitoring

No additional sampling is planned. Biota monitoring was discontinued because (1) a review of hunting, gardening, and agriculture practices near the GJPO facility indicated that game, vegetables, fruits, grains, and agricultural products from the vicinity of the facility were not important sources of radionuclides for human populations, and (2) maximum radionuclide concentrations in surface water at the facility did not result in radiation doses in excess of 1 rad/day for native aquatic organisms.

8.3 MMTS

8.3.1 Historical Biota Monitoring

In 1988, ecological surveys were conducted in aquatic and terrestrial areas on and downstream of the millsite. The objectives of the aquatic surveys (BIO/WEST, Inc. 1988) were (1) to document the physical habitat of Montezuma Creek, and (2) to assess species composition and estimate population densities of periphyton, plankton, benthic invertebrates, and fish in Montezuma Creek. The objective of the terrestrial survey (Western Resource Development Corporation 1988) was to assess species composition, cover, and production for various vegetation types along Montezuma Creek.

Table 8–1. ARARs for Biota Monitoring

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO, GJPORAP, and MMTS		
General Environmental Protection Program	DOE Order 5400.1, Chapter IV, Part 5b and 8d	Environmental surveillance shall be conducted to monitor the impacts of U.S. Department of Energy (DOE) activities on on-site and off-site environmental and natural resources (specifically, biota).
Radiation Protection of the Public and the Environment	DOE Order 5400.5, Chapter II, Part 3a, paragraph (5)	The absorbed dose to native aquatic organisms shall not exceed 1 radian per day.
Radiological Effluent and Environmental Surveillance	DOE Environmental Regulatory Guide, Section 5.0 and Section 8.6	A risk assessment/pathway analysis should be conducted to assess the impact of DOE activities on native biota.

8.3.2 Planned Biota Monitoring

8.3.2.1 Monitoring Objectives

The objectives of MMTS biota monitoring are

1. To collect data to support the MSGRAP Ecological Risk Assessment.

2. To determine the potential radiation dose to native aquatic organisms at or near MMTS to ensure compliance with the DOE dose limit of 1 rad/day.

8.3.2.2 Sampling Plan

Biota sampling is planned to support the MSGRAP Ecological Risk Assessment. The study design for biota sampling is presented in the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Work Plan, Draft Final* (DOE 1995f) and in the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Field Sampling Plan and Quality Assurance Project Plan, Draft Final* (DOE 1995e).

Radiation doses to native aquatic organisms will be calculated according to the methods described by Baker and Soldat (1992). Maximum surface-water concentrations of radionuclides and standardized bioaccumulation rates, transfer factors, intake rates, and other factors will be used to estimate the maximum total radiation dose received by algae, fish, molluscs, crustaceans, muskrats, raccoons, and ducks living within the MSGRAP boundary.

8.3.2.3 Data Management

The contractor's data manager will maintain a database for biota sampling data. Data will be stored in an ORACLE database and will be backed up weekly. All records, reports, and data will be stored in a permanent project file in the contractor's records management section.

8.3.2.4 Data Analysis and Reporting Format

The results of the MSGRAP Ecological Risk Assessment will be reported in the *Operable Unit III Remedial Investigation Report*, which is expected to be completed in 1996. The data analysis methods and reporting format are discussed in the *Monticello Mill Tailings Site, Operable Unit III, Remedial Investigation/Feasibility Study Work Plan, Draft Final* (DOE 1995f).

The methods and results of the radiation dose calculations for native aquatic organisms will be presented in the Annual Site Environmental Report.

8.3.3 Responsible Organizations

The biota monitoring program is the responsibility of the DOE–GJPO Manager. The responsibility for implementing the biota monitoring program resides with the contractor's Environmental Services section.

9.0 Wetland Restoration

9.1 Regulatory Requirements

Wetland restoration is required by Section 404 of the Clean Water Act. Monitoring of restored wetland areas for GJPO/GJPORAP and MMTS is required by the special conditions of a site-specific 404 permit for the GJPO facility and by DOE's *Draft Monticello Wetlands Master Plan* (DOE 1995g).

9.2 GJPO/GJPORAP

In 1989, DOE–GJPO was granted a 404 permit (No. 10040) by the U.S. Army Corps of Engineers to remove uranium mill tailings from wetland and riparian areas on the GJPO facility. In 1994 and 1995, the areas were reconstructed and revegetated in accordance with the 404 permit requirements. Approximately 0.6 hectares (1.45 acres) of wetland habitat and 1.25 hectares (3.11 acres) of riparian habitat were restored. The permit requires DOE to evaluate the effectiveness of the restoration for a 5-year period.

9.2.1 Historical Wetland Restoration Monitoring

Monitoring of the restored areas began in August 1995 and consisted of (1) determining the status of wetland plant species establishment, (2) measuring the drip-line diameter and height of a representative random sample of tree and shrub transplants, (3) determining the percent survival rate of the transplants, (4) determining the percent vegetational canopy cover, and (5) determining the percent canopy cover of desirable and seeded species as a percentage of total canopy cover. Monitoring results were summarized in an annual monitoring report and submitted to the U.S. Army Corps of Engineers.

9.2.2 Planned Wetland Restoration Monitoring

9.2.2.1 Monitoring Objectives

The objectives of GJPO/GJPORAP wetland restoration monitoring are

1. To evaluate the effectiveness of wetland restoration.

2. To verify compliance with site-specific 404 permit requirements.

9.2.2.2 Sampling Plan

Sampling parameters and methods are discussed in detail in the *Monitoring Plan for Grand Junction Projects Office Wetland/Riparian Mitigation Site* (DOE 1994a). Sampling will continue through 1999.

9.2.2.3 Data Management

Hard copies of field data sheets and monitoring reports will be stored in project files in the contractor's Environmental Services and records management sections.

9.2.2.4 Data Analysis and Reporting Format

Data will be analyzed to determine if monitoring objectives have been met. Survival rates of transplanted trees and shrubs and percent canopy cover of seeded and desirable species will be compared to 404 permit requirements. Results of the monitoring will be discussed in the annual monitoring reports submitted to the U.S. Army Corps of Engineers.

9.2.3 Responsible Organizations

Wetland restoration monitoring is the responsibility of the DOE–GJPO Manager. Responsibility for implementing the monitoring program resides with the contractor's Environmental Services section.

9.3 MMTS

During remediation of MMTS, radiologically contaminated soils will be removed from a number of wetland areas. Nearly all disturbed wetland areas will be replaced with clean fill and restored in situ. Some wetland areas that cannot be restored in situ will be re-created on the millsite. The *Draft Monticello Wetlands Master Plan* (DOE 1995g) establishes the overall plan for safeguarding wetland areas at MMTS; it identifies the wetland areas that will be remediated, the general restoration requirements, and monitoring requirements.

9.3.1 Historical Wetland Restoration Monitoring

Monitoring of restored wetland areas historically has not been conducted at MMTS.

9.3.2 Planned Wetland Restoration Monitoring

9.3.2.1 Monitoring Objective

The objective of future MMTS wetland restoration monitoring is to evaluate conformance or nonconformance with the success criteria established in the *Draft Monticello Wetlands Master Plan* (DOE 1995g).

9.3.2.2 Sampling Plan

Sampling parameters and methods for monitoring wetland areas are discussed in the *Draft Monticello Wetlands Master Plan* (DOE 1995g). Monitoring is scheduled to begin in summer 1996.

9.3.2.3 Data Management

Data management will be the same as that for GJPO/GJPORAP (see Section 9.2.2.3).

9.3.2.4 Data Analysis and Reporting Format

Data will be analyzed to determine if site-specific monitoring objectives have been met. Monitoring results will be discussed in annual monitoring reports submitted to EPA.

9.3.3 Responsible Organizations

The organizations responsible for monitoring restored wetland areas are the same as that for GJPO/GJPORAP (see Section 9.2.3). EPA Region VIII is the regulatory oversight for wetlands at MMTS.

10.0 Quality Assurance

The DOE contractor has a QA program that is designed to adopt and to implement the requirements of 10 CFR 830.120, "Quality Assurance Requirements;" as well as the philosophy of DOE Order 5700.6C, *Quality Assurance*. The contractor's QA program is supplemented with the *Quality Assurance Program Requirements for Nuclear Facilities* (ASME 1989) and the *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs* (American Society for Quality Control 1995). A comparison matrix is presented in QA Instruction 1.1 of the contractor's *Quality Assurance Manual* (Rust Geotech 1994). Appendix A of this document contains the *Quality Assurance Program Plan* that addresses specific requirements for the EMP to comply with DOE Order 5400.1.

The QA program addresses organizational responsibility, design, procedures, records, and audits. Elements such as field and laboratory QC, human factors, chain of custody, performance reporting, and independent data verification are implemented by the responsible organizations that perform the work.

Certification of the GJPO Analytical Laboratory is not required by the State of Colorado, except for public drinking-water system testing, which is not applicable to the GJPO facility. As stated in the *Federal Facility Agreement* (EPA et al. 1988) between DOE, EPA, and the State of Utah, certification of the Analytical Laboratory also is not required for the analyses associated with MMTS. The agreement states only "that laboratories used by DOE for analyses participate in a QA/QC program equivalent to that of, and approved by, EPA." Although not required by the *Federal Facility Agreement*, the Analytical Laboratory is certified in the State of Utah for environmental monitoring under RCRA for selected analytes or groups of analytes (certificate no. E–257). Subcontracted laboratories may be required to have certification for particular programs or projects, and the QA staff is responsible for ensuring that this certification is a condition of the subcontract.

The Analytical Laboratory performs analyses in support of DOE environmental monitoring programs and participates in the interlaboratory QA program coordinated by the DOE Environmental Measurements Laboratory. The Analytical Laboratory also participates in six non-DOE interlaboratory QA programs: (1) EPA Environmental Measurement Systems Laboratory for radioactive materials; (2) American Industrial Hygiene Association Proficiency Analytical Testing Program for airborne metal, silica, and asbestos; (3) American Industrial Hygiene Association Identification and Quantification of Asbestos on Bulk Materials Program; (4) EPA Water Supply Laboratory Performance Evaluation Study; (5) EPA Water Pollution Laboratory Performance Evaluation; and (6) American Industrial Hygiene Association Environmental Lead Proficiency Analytical Testing Program.

The Analytical Laboratory maintains an internal QC organization to review, verify, and evaluate QA data. As part of its audit program, the contractor's QA organization performs an evaluation of the effectiveness of the Analytical Laboratory's QC program. The contractor's Environmental Services section provides personnel with the appropriate technical expertise to perform an overall independent data review of all environmental monitoring programs to ensure the validity and integrity of reported data, methods, and processes; and to ensure the protection and retrievability of the data.

10.1 Regulatory Requirements

The QA program for environmental monitoring at GJPO/GJPORAP and MMTS is conducted to comply with the ARARs outlined in Table 10–1.

10.2 Responsible Organizations

The QA program for this EMP is the responsibility of the DOE–GJPO Manager. The contractor's QA section staff coordinator prepares and revises the *Quality Assurance Program Plan* at the direction of the contractor's Environmental Services manager.

Table 10–1. ARARs for Quality Assurance

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO, GJPORAP, and MMTS		
Quality Assurance	DOE Order 5700.6C	A quality assurance (QA) program shall be established to benefit operational programs by enhancing quality, productivity, and cost effectiveness.
General Environmental Protection Program	DOE Order 5400.1 Chapter II , Part II	A QA program shall include sampling, analysis, and data management for both radioactive and nonradioactive effluent and environmental monitoring. A summary of site results and expected results from participation in interlaboratory cross-check programs shall be included.
	DOE Order 5400.1, Chapter IV, Part 5(a)(2)	Auditable records shall be established in accordance with the requirements of DOE Order 5700.6C, *Quality Assurance*.
	DOE Order 5400.1, Chapter IV, Part 10(a)	A QA program, consistent with DOE Order 5700.6C, shall be established and shall cover each element of environmental and surveillance programs commensurate with its nature and complexity. The QA program shall include, but shall not be limited to, the following: (1) organizational responsibility, (2) program design, (3) procedures, (4) field quality control, (5) laboratory quality control (QC), (6) human factors, (7) record keeping, (8) chain-of-custody procedures, (9) audits, (10) performance reporting, and (11) independent data verification.
	DOE Order 5400.1, Chapter IV, Part 10(b)	U.S. Department of Energy (DOE) and contractor laboratories shall confirm the need for certification and shall apply to the appropriate Federal, State, or local agencies for any required certification.
	DOE Order 5400.1, Chapter IV, Part 10(c)	DOE and contractor laboratories that conduct analytical work in support of DOE environmental radiological monitoring programs for radioactive materials shall participate in the DOE interlaboratory QA program coordinated by the DOE Environmental Measurements Laboratory located in New York City.
	DOE Order 5400.1, Chapter IV	The Assistant Secretary for Environment, Safety, and Health, in consultation with the appropriate program senior official and DOE field organization, shall develop an independent data verification program as a part of the environmental monitoring program at DOE facilities. The independent data verification program shall be in place no later than 12 months after the effective date of this order (11-9-88).

Table 10–1 (continued). ARARs for Quality Assurance

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO, GJPORAP, and MMTS (continued)		
Radiological Effluent Monitoring and Environmental Surveillance	DOE Environmental Regulatory Guide, Chapter 2, Section 2.6	General QA program provisions of Chapter 10 shall be followed. Specific QA requirements for DOE facilities' effluent monitoring programs are contained in the *Quality Assurance Program Plan* associated with each facility.
	Chapter 4, Section 4.11	General QA program provisions of Chapter 10 shall be followed. QA guidance related to meteorological measurements and data processing may be found in Finkelstein et al. (1983).
	Chapter 10, Section 10.1	A *Quality Assurance Program Plan* shall be prepared and included as a section in the Environmental Monitoring Plan (EMP) and shall cover the monitoring activities at each site as described by the American Society of Mechanical Engineers (ASME; NQA–1) in the 18-criterion structure of 10 *U.S. Code of Federal Regulations* (CFR) 50. Periodic audits shall be performed to verify compliance with operational procedures and all aspects of the QA program. The following elements shall be included in the audit program: • Audits shall be performed independently in accordance with written procedures or checklists by personnel who do not have direct responsibility for performing the activities being audited. • Audit results shall be documented and reported to and reviewed by responsible management. • Follow-up actions shall be taken where indicated.
	Chapter 10, Section 10.2	Applicable existing QA requirements on all DOE programs, including monitoring and surveillance, that come from DOE field organizational orders, contractor QA programs, and environmental legislation QA requirements shall be followed.

Table 10–1 (continued). ARARs for Quality Assurance

Standard, Requirement, Criterion, or Limitation	Citation	Description
ARARs Common to GJPO, GJPORAP, and MMTS (continued)		
Radiological Effluent Monitoring and Environmental Surveillance (continued)	DOE Environmental Regulatory Guide, Chapter 10, Section 10.3	Specific operational and QC procedures are required to be documented in the EMP. • Required written procedures cover the following topics: (1) environmental and effluent sampling, (2) groundwater sampling, (3) continuous environmental and effluent monitoring systems, (4) laboratory analysis, (5) data management and calculations, (6) transport and pathway modeling, (7) dose calculations, and (8) review and reporting results. • Each site is required to maintain an analytical QC program adequate to document and to control the accuracy and precision of the analytical results. If analytical work is performed by a subcontractor, the subcontractor is required to meet these same QC requirements. • DOE monitoring organizations should participate in other interlaboratory QC programs such as the U.S. Environmental Protection Agency (EPA) Environmental Radioactivity Laboratory Intercomparison Studies Program. • Radiation measuring equipment, including portable instruments, environmental dosimeters, in situ equipment, and laboratory instruments, shall be calibrated with standards traceable to the National Institute of Standards and Technology (NIST) calibration standards or equally acceptable standards (in cases where a NIST standard does not exist).
Radioactive Waste Management	DOE Order 5820.2A, Chapter III, Part 3(1), Chapter V, Part 5(e)	QA shall be consistent with DOE Order 5700.6C; practices shall be conducted in accordance with applicable requirements of ASME NQA–1 and other national consensus standards.
ARAR Specific to GJPO/GJPORAP		
National Emission Standards Hazardous Air Pollutants	40 CFR Part 61 Subpart H	To determine compliance with the standard, radionuclide emissions shall be determined and dose equivalents to members of the public shall be calculated using EPA-approved sampling procedures and computer models.
ARAR Specific to MMTS		
Guidelines and Specifications for Preparing Quality Assurance Project Plans	EPA QAMS–005/80	Establishes QA guidelines for Comprehensive Environmental Response, Compensation, and Liability Act *Quality Assurance Program Plans*; focuses on data quality.

Section 11.0
Records Management

11.0 Records Management

Records are essential for providing evidence of technical adequacy and quality. Consistent documentation and accurate record-keeping procedures will be implemented during EMP activities. One objective of the records management program will be to maximize the usefulness of important program information by making all records legible, identifiable, and retrievable. Another objective will be to protect records from damage, destruction, deterioration, or loss. As records are identified and created during EMP activities, they will be included in the records management program.

Records generated in support of EMP activities will be subject to the requirements for maximum-level records, as described in Section 13 of the contractor's *Management Policies Manual* (Rust Geotech 1995). To fulfill one of these requirements, the contractor's Environmental Services section will employ a dual-storage system for environmental monitoring records. In addition, the provisions of the Records Management Plans for MMTS (DOE 1994d) and GJPORAP (DOE 1993a) also will apply.

Section 12.0
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12.0 References

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Appendix A
Quality Assurance Program Plan

Appendix A
Quality Assurance Program Plan for Environmental Monitoring of the Grand Junction Projects Office Facility, Grand Junction Projects Office Remedial Action Project, and Monticello Mill Tailings Site

November 1995

Prepared for
U.S. Department of Energy
Albuquerque Operations Office
Grand Junction Projects Office

Prepared by
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Grand Junction, Colorado

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Quality Assurance Program Plan for Environmental Monitoring of the Grand Junction Projects Office Facility, Grand Junction Projects Office Remedial Action Project, and Monticello Mill Tailings Site

Policy

This *Quality Assurance Program Plan* (QAPP) identifies and documents the applicable quality assurance (QA) requirements of the *Quality Assurance Manual* (Manual 101) and other QA requirements that apply to effluent monitoring and environmental surveillance. This plan is applicable to the environmental monitoring of the Grand Junction Projects Office Facility, Grand Junction Projects Office Remedial Action Project, and the Monticello Mill Tailings Site. This QAPP is one of several planning documents that provide controls for the environmental monitoring programs. All work performed on these monitoring programs must comply with this QAPP.

Prepared by:

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Reviewed and Approved By:

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Arlene G. Weiner, Environmental Services Manager — Date

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1.0 Introduction

The Environmental Monitoring Plan (EMP) was prepared in accordance with U.S. Department of Energy Order 5400.1, *General Environmental Protection Program*. The EMP establishes responsibilities for the effluent monitoring and environmental surveillance associated with the Grand Junction Projects Office (GJPO) Facility, Grand Junction Projects Office Remedial Action Project (GJPORAP), and the Monticello Mill Tailings Site (MMTS).

Implementing Documents

The following contractor manuals implement portions of the QA Program. These documents will be referenced throughout this *Quality Assurance Program Plan* as implementing documents. Section 4.0 of this plan contains a complete reference list.

- *Management Policies Manual*, Manual 100
- *Quality Assurance Manual*, Manual 101, Including Quality Assurance Instructions
- *Environmental Protection Manual*, Manual 102
- *Health and Safety Manual*, Manual 103, Volumes I and II
- *Operation Management Policies Manual*, Manual 104
- *Information Services Manual*, Manual 105
- *Project Control System Manual*, Manual 107
- *Calibration and Control Manual*, Manual 113
- *Stores, Property, and Transportation*, Manual 114
- *Environmental Procedures Catalog*, Manual 116
- *Training Manual*, Manual 117
- *Procurement Manual*

Acronyms

- ANSI — American National Standards Institute
- ASME — American Society of Mechanical Engineers
- ASQC — American Society for Quality Control
- CFR — *U.S. Code of Federal Regulations*
- DOE — Department of Energy
- EMP — Environmental Monitoring Plan
- GJPO — Grand Junction Projects Office
- GJPORAP — Grand Junction Projects Office Remedial Action Project
- M&TE — measuring and test equipment
- MMTS — Monticello Mill Tailings Site
- NQA — Nuclear Quality Assurance
- QA — Quality Assurance
- QAI — Quality Assurance Instruction
- QAPjP — *Quality Assurance Project Plan*
- QAPP — *Quality Assurance Program Plan*
- TQS — Training Qualification System

1.1 Purpose and Scope

The purpose of this *Quality Assurance Program Plan* (QAPP) is to define the quality assurance (QA) requirements and implementing documents for environmental monitoring of the GJPO facility, GJPORAP, and MMTS. This QAPP is based on the Rust QA Program as defined in the Rust *Quality Assurance Manual* (Manual 101). The Rust QA Program implements the specific requirements of 10 CFR 830.120, "Quality Assurance Requirements," and DOE Order 5700.6C, "Quality Assurance." The philosophy and requirements have been supplemented with the requirements of ASME NQA-1, "Quality Assurance Program Requirements for Nuclear Facilities," and ANSI/ASQC E4–1994, "Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs," and the *Management Policies Manual* (Manual 101).

The Rust QA requirements have been graded to meet the needs of the program. Applying the graded approach allows control over items or activities to be commensurate with their importance and level of risk. This QAPP has been prepared to provide assurance that the work performed will be of the quality required to satisfy EMP objectives.

The EMP contains the rationale and design criteria for the program; identifies the extent and frequency of historical and planned monitoring and measurements; and identifies procedures for laboratory analysis and the preparation and distribution of reports to verify compliance with the applicable local, State, and Federal laws and regulations, including the applicable DOE orders.

1.2 Revisions

The QAPP will be revised by the QA Coordinator and the Program Manager as required to meet the needs of the EMP. Revisions to the QAPP will be prepared by the QA Coordinator and reviewed and approved by the Program Manager. Shading will be used to identify sections that were changed. (Note: This revision of the QAPP does not contain shaded sections, as it is has been reorganized to reflect the 10–criteria format of the Rust *Quality Assurance Manual*).

Distribution of the QAPP is controlled by the Rust Information Support Services section for the EMP Program Manager.

2.0 Program Quality Level

The Rust Program Manager responsible for the EMP has determined an overall quality level of "Q"– level, as defined in the *Quality Assurance Manual* (Manual 101). The "Q"– level notifies personnel at a glance that the program may have additional QA requirements. The "Q"– level is applicable for environmental surveillance and effluent monitoring of GJPO, GJPORAP, and MMTS, because these activities are conducted to verify compliance with State and Federal regulations. Sections of the QAPP that have been identified as "Q"– level are clearly stated within the applicable criterion.

3.0 Program Quality Assurance Requirements

The QA Program is documented in the Rust *Quality Assurance Manual* (Manual 101), program-specific QAPPs, and task-specific *Quality Assurance Project Plans* (QAPjPs). QAPjPs will be prepared for the environmental monitoring programs when the need for additional site–specific QA requirements are identified.

This QAPP describes the applicable requirements of the *Quality Assurance Manual* (Manual 101) through the use of a graded approach. The applicability and level of each criterion contained in the *Quality Assurance Manual* (Manual 101) are defined for implementation by the EMP. This section of the QAPP uses the graded approach listing each criterion, stating the applicable level (Standard or "Q"), and providing modifications to the QA requirements as necessary to meet program demands.

Quality Assurance Instructions (QAIs), contained within the *Quality Assurance Manual* (Manual 101) and other Company Manuals, are referenced throughout this QAPP when applicable.

Management

3.1 Criterion 1, Quality Assurance Program

The Standard Requirements of the Criterion and the following QAIs apply:

QAI 1.1, Responsible Organizations for QA Program Implementation – The matrices contained in this QAI may be used as a cross reference of the Rust QA Program for a comparison to DOE Order 5700.6C, ANSI/ASQC E4–1994 and International Standards Organization (ISO) 9001-87.

QAI 1.2, Notification of Incoming Work – The Program Manager will notify the QA Coordinator or the QA Manager of new work or significant changes in scope. This information will be used to determine if revision of the QAPP or other documents is required.

QAI 1.3, Suspension of Activities – Rust personnel are responsible for suspending activities when conditions are identified that have the potential to jeopardize safety, quality, or the environment. When significantly adverse conditions are identified and management response has not been initiated or is ineffective, the Program Manager may order a suspension of activities. A suspension of activities may be ordered by the QA Manager if conditions affecting quality have not been addressed by the Program Manager. Suspension of activities for subcontractors will be issued through the Rust Contracts and Procurement Section. In all cases the justification must be thoroughly documented.

QAI 1.4, Development and Approval of QA Program Plans – The Program Manager, assisted by the QA Coordinator, is responsible for maintaining this plan. The QAPP will be reviewed by affected organizations and the QA Manager. Approval of the Program Manager is required. Records of review will be maintained in the Rust QA Section files.

QAI 1.5, Administrative and Technical Planning – The Program Manager is responsible for assigning the planning of program activities.

Rust's requirements for planning documents are presented in this QAI and the *Management Policies Manual* (M-100), Section 2, "Documentation Systems."

As appropriate, planning documents should address administrative, technical, safety, and QA issues. The EMP Program Manager is responsible for assigning responsibility for preparation of planning documents. The following are primary EMP planning documents:

- *Environmental Monitoring Plan for the Grand Junction Projects Office Facility, Grand Junction Projects Office Remedial Action Project, and the Monticello Mill Tailings Site.*

  The EMP defines the mission and objectives of environmental surveillance and effluent monitoring.

- *Quality Assurance Program Plan for the Environmental Monitoring of Grand Junction Projects Office Facility, Grand Junction Projects Office Remedial Action Project, and the Monticello Mill Tailings Site.*

  The QAPP defines the requirements of the Rust *Quality Assurance Manual* that are applicable to the EMP.

Revisions to program planning documents must be reviewed by the affected organizations, and comment resolution must be documented. Records showing document review for the current version will be maintained by the originator.

Prior to starting physical work on the program, when directed by Program Management, or following up a Stop Work Order, a Work Readiness Review will be performed in accordance with this QAI and the procedures described in the *Operations Management Policy Manual* (Manual 104).

QAI 1.6, QA Organizational Interfaces – Rust's functional organization structure is contained in the *Management Policies Manual* (Manual 100), Section 12, "Organization Functions and Responsibilities." Rust management is responsible for implementing the QA Program. The EMP Program Manager is responsible for ensuring the QA Program is adequately defined and implemented for the environmental monitoring program through the use of this QAPP. Verification of quality will be performed by personnel other than those responsible for performing the work. QA staff may also verify the achievement of quality by surveillance and audit. Individuals who have been identified as responsible for verification of quality shall be provided access to activities and the documentation supporting those activities.

QAI 1.7, QA Review of Documents That Implement the QA Program – Documents and procedures that implement the QA Program or cross organizational lines will be reviewed by the QA Coordinator in accordance with this QAI.

3.2 Criterion 2, Personnel Training and Qualification

The Standard Requirements of the Criterion and the following QAIs apply:

QAI 2.1, Training and Indoctrination of Employees – Rust personnel will be trained in accordance with the *Management Policies Manual* (Manual 100), Section 14, "Training." All Rust personnel will be familiarized with program requirements and plans prior to assignment of work. The Rust *Training Manual* (Manual 117), defines company training requirements. Training must be documented and the records submitted to the Rust Training and Development organization.

No program–specific training is anticipated. Supervisors are responsible for ensuring that assigned personnel are familiar with the applicable planning documents and procedures. The manager for each

activity is responsible for ensuring that personnel are trained and qualified for the work they are assigned and that they receive additional training (as needed) when new responsibilities are assigned or when new technologies must be implemented. Should special training be needed for the performance of a task, the Program Manager will notify the line manager who is responsible for ensuring personnel are trained and qualified. Position, company, and program training requirements will be defined in the Training Qualification System (TQS).

QAI 2.2, Certification of Personnel – Activities performed by the QA Section will be performed by personnel qualified/certified in accordance with this QAI and internal Desk Instructions.

3.3 Criterion 3, Quality Improvement

The Standard Requirements of the Criterion and the following QAIs apply:

QAI 3.1, Quality Improvement – The Program Manager is responsible for encouraging and documenting quality improvement for the EMP. Implementation mechanisms are listed in this QAI.

QAI 3.3, Dissemination of Lessons Learned – The Program Manager may generate a report for lessons learned as a result of program activities and forward it to QA with a suggested distribution list. The Program Manager will also disseminate lessons learned reports received from QA to the applicable program personnel. The Lessons Learned program provides information to the Program Manager that may prevent problems or improve performance.

QAI 3.4, Nonconformance Reporting, Disposition, and Closure – This system will be used to report and evaluate any nonconforming activities, data, or items that occurred during environmental monitoring. The EMP QA Coordinator should be called on for advice or assistance in the evaluation of conditions and the subsequent treatment of identified nonconformances.

Formal reporting is not required for nonconforming items discovered before their delivery or transmittal to other internal organizations. These items will be documented and evaluated internal to the organization.

QAI 3.5, Corrective Action Request System – The Program Manager will be responsible for evaluating, investigating, and documenting corrective actions. The QA Coordinator will track and verify the corrective actions.

3.4 Criterion 4, Documents and Records

The "Q"–Level Requirements of this Criterion are applicable. The applicable "Q" requirements for environmental surveillance and effluent monitoring are receipt control, storage procedures, and records storage facilities. The higher level is applicable for the environmental surveillance and monitoring of GJPO, GJPORAP, and MMTS because these activities verify compliance with local, State and Federal regulations.

The *Management Policies Manual* (Manual 100), Section 13, "Records Management," establishes Company-wide responsibilities for planning, generation, classification, indices, protection, storage, and disposition. Section 11.0 of the EMP describes how the EMP records will be managed. The Records Management Plans for MMTS and GJPORAP are also applicable to EMP records.

Records must be legible, accurate, identifiable, and retrievable. Records are to be protected against damage, deterioration, or loss.

3.5 Criterion 5, Work Processes

The Standard Requirements of the Criterion and the following QAIs apply:

QAI 5.1, Preparation of Instructions, Procedures, and Drawings – The procedures that implement the requirements of the QA Program are listed under "Implementing Documents." Procedures written to control the work prescribed by the EMP will comply with the *Management Policies Manual* (Manual 100), Section 2, "Documentation Systems," which explains the company system for procedures. Procedures may be changed by revision, or temporary changes may be made through properly approved Program Directives in accordance with the *Operations Management Policy Manual* (Manual 104).

The *Environmental Procedures Catalog* (Manual 116) contains general field procedures for a variety of tasks. These procedures may be adopted or modified for use with the EMP.

Individual organizations involved in sampling, testing, and materials acceptance are responsible for including specific control, identification, traceability, and storage requirements in their instructions, procedures, drawings, and other documents that control work.

Samples collected in accordance with the EMP will be correctly identified and traceable to the sampling location. Standard procedures in the *Environmental Procedures Catalog* (Manual 116) will be used by Rust field personnel for identification, traceability, and control of samples. When appropriate, chain-of-custody procedures will be implemented.

Identification must be maintained either on or with the sample or in documents that can be traced to the sample. Samples must be identified so as to maintain traceability and clear association with the sampling location.

Project documents, including changes, will be reviewed for adequacy, completeness, and correctness before approval and issue. Reviews and comment resolution or other disposition will be documented. Review and approval of changes will be performed by the same organizations as the original document. Minor changes, such as inconsequential editorial or typographical corrections, may be authorized by the originator of the document and do not require the same review as the original document.

QAI 5.2, Control of Processes – Process control is achieved and maintained through the use of qualified personnel, instructions, procedures, and drawings. No special processes are anticipated.

QAI 5.3, Test Control – Test control is applicable to equipment standardization, operating checks, or other comparisons that are a part of the operations, start-up, or test procedures for the collection and analysis of environmental monitoring samples. Documentation of operational checks and/or standardization must be maintained as detailed in procedures specific to the equipment.

Procedures implemented by the Rust *Stores, Property, and Transportation (SPAT) Manual* (Manual 114) satisfy the requirements for shipping, handling, and storage of items to prevent deterioration or damage.

3.6 Criterion 6, Design

The Standard and "Q"-Level Requirements of the Criterion are applicable. Computer software requirements and the following QAIs also apply:

QAI 6.1, QA Review of Design Input and Output Documents – QA will review design documents when the design organization has determined that QA review may be beneficial. This review will be performed in accordance with QA Desk Instructions.

QAI 6.2, Computer Program Software Testing – Computer programs used in modeling or data reduction will be subject to verification or validation before use. The Rust *Information Services Manual* (Manual 105) contains the instructions for verification and validation of software. Activity managers and computer users involved with software applications development and/or modification must coordinate these software activities through the Information Systems section.

QAI 6.3, Design of Data Collection Programs – The collection of data for evaluation will be performed using the data collection design process described in this QAI.

3.7 Criterion 7, Procurement

The Standard Requirements of the Criterion and the following QAIs apply:

QAI 7.1, Review of Procurement Documents – The *Management Policies Manual* (Manual 100), Section 5, "Procurement," and the *Procurement Manual* (Unnumbered document) contain additional requirements and procedural elements that apply to procurement document control.

QAI 7.2, Procurement-Related Nonconformances – Nonconformance reports for purchased items and services will be processed in accordance with this QAI and QAI 3.4.

QAI 7.3, Supplier Selection – The QA Section will participate in the selection of suppliers for procurement requisitions that require a supplier pre-award evaluation or survey and other procurements when assistance is requested by the Contracts and Procurement section or the Program Manager.

QAI 7.4, Procurement Acceptance Planning – The requirements of this QAI may be invoked as a result of the QA procurement document review described in QAI 7.1. The *Management Policies Manual* (Manual 100), Section 15, "Stores, Property, and Transportation," contains additional requirements and elements of procedure that apply to the control of purchased items and services.

3.8 Criterion 8, Inspection and Acceptance Testing

The Standard Requirements of this Criterion are applicable:

Measuring and Test Equipment (M&TE) used in assessment, verification, or analysis to generate project data must be calibrated in accordance with the provisions of *Calibration and Control Program Manual* (Manual 113). All other M&TE must be identified and classified as described in the *Calibration and Control Program Manual* (Manual 113), including instruments used to meet environmental and radiological requirements.

Inspections that verify and ensure conformance to specified requirements shall be planned, performed, and

documented in accordance with written instructions, procedures, or checklists. Acceptance inspections must be performed by individuals other than those who performed the work. Final inspections must include a review and examination of records. Reinspection is required for any items that have been modified, repaired, replaced, or reworked after final inspection.

Identification and control of items will also be specified in instructions, procedures, and drawings that control a specific task. Items having a limited operating life will be marked to show the expiration date.

Assessment

3.9 Criterion 9, Management Assessment

The Standard Requirements of the Criterion and the following QAIs apply:

QAI 9.1, Management Elements Assessment – EMP management elements are integrated into the regular management functions described in the *Management Policies Manual* (Manual 100); *Operations Management Policy Manual* (Manual 104); and *Project Control System Manual* (Manual 107).

QAI 9.2, Management Performance Assessments – The Program Manager in association with the Associate General Manager of Operations will identify, plan, schedule and appoint teams to perform Management Self-Assessments and Management Independent Assessments with support from the QA Manager.

QAI 9.3, Management Compliance Assessment – The Program Manager will ensure that EMP related assessments, such as Technical Self-Assessments or Compliance Assessments, scheduled by the Associate General Manager of Operations are performed.

3.10 Criterion 10, Independent Assessment

The Standard Requirements of the Criterion and the following QAIs apply:

QAI 10.1, Performance and Reporting of Independent Audits and Assessments – Audits will be conducted by qualified auditors, including Lead Auditors certified in accordance with QAI 2.2, "Certification of Personnel." Audits of the EMP or elements within the EMP will be performed by QA personnel, as necessary, to evaluate implementation of and compliance with the requirements of the QA Program.

Lead Auditors will be independent of the program, although the QA Coordinator for the program may assist. Technical expertise may be provided by persons outside the QA organization.

QAI 10.2, Surveillances – Surveillances of the EMP will be performed by the QA Section, as necessary, to evaluate implementation of and compliance with the requirements of the QA Program.

QAI 10.3, External Audit/Appraisal Tracking – The QA Coordinator will assist the Program Manager in responding to the appraisal, completing corrective actions, and verifying/certifying completion of the corrective actions.

4.0 References

Rust Geotech (continually updated). *Management Policies Manual* (Manual 100), Grand Junction Projects Office (internal document).

_____, *Quality Assurance Manual* (Manual 101), Grand Junction Projects Office (internal document).

_____, *Environmental Protection Manual* (Manual 102), Grand Junction Projects Office (internal document).

_____, *Health and Safety Manual* (Manual 103), Volumes I and II, Grand Junction Projects Office (internal document).

_____, *Operations Management Policies Manual* (Manual 104), Grand Junction Projects Office (internal document).

_____, *Information Services Manual* (Manual 105), Grand Junction Projects Office (internal document).

_____, *Project Control System Manual* (Manual 107), Grand Junction Projects Office (internal document).

_____, *Calibration and Control Program Manual* (Manual 113), Grand Junction Projects Office (internal document).

_____, *Stores, Property, and Transportation (SPAT) Manual* (Manual 114), Grand Junction Projects Office (internal document).

_____, *Environmental Procedures Catalog* (Manual 116), Grand Junction Projects Office (internal document).

_____, *Training Manual* (Manual 117), Grand Junction Projects Office (internal document).

_____, *Procurement Manual,* Grand Junction Projects Office (internal document).

Appendix B
Methodology for Performing the Mann-Kendall Statistical Test

Appendix B
Methodology for Performing the Mann-Kendall Statistical Test

Methodology for Performing the Mann-Kendall Statistical Test

The Mann-Kendall test is one method for detecting trends in data. This nonparametric (distribution-free) test assumes that the observations are independent (seasonality is not present). Because most data collected over time are seasonally affected, it is recommended that seasonal variability in the data be removed before calculating the Mann-Kendall statistic.

One method for removing seasonal effects is to calculate the Z-scores by season, as described in Dixon and Massey (1969). The first step in determining a Z-score is to calculate the mean and standard deviation for each season, as shown in Table B–1.

Table B–1. Sample Z-Scores Calculated by Season[a]

Year	Spring	Summer	Fall	Winter
1980	5	4	5	4
1981	6	6	7	6
1982	7	8	8	7
1983	9	8	7	8
1984	11	10	10	9
Σ =	38	36	37	34
n =	5	5	5	5
$\bar{X}$ =	7.6	7.2	7.4	6.8
$\hat{\sigma}$ =	2.15	2.04	1.62	1.72

[a] Σ = summation; n = total number of values; $\bar{X}$ = arithmetic mean; and $\hat{\sigma}$ = standard deviation.

In Table B–1, the Z-score is calculated for each value by subtracting the mean for the appropriate season and then dividing by the appropriate standard deviation. For example, the seasonal effects are removed from the spring 1980 value of 5 as follows:

$$\frac{5 - 7.6}{2.15} = -1.21$$

After performing this calculation for each of the values in the data table, the resulting Z-scores can be used to compute the Mann-Kendall statistic that is described in the following text excerpted from Gilbert (1987).

Note: Table A.21, which lists the probability values for the Mann-Kendall statistic "S" (as cited in Hollander and Wolfe [1973]), follows the excerpt from Gilbert. References cited in this appendix follow Table A.21.

Chapter 16

Mann-Kendall Test

(excerpted from *Statistical Methods for Environmental Pollution Monitoring* [Gilbert 1987] with permission from the publishers)

16.3.3 Intervention Analysis and Box-Jenkins Models

If a long time sequence of equally spaced data is available, intervention analysis may be used to detect changes in average level resulting from a natural or man-induced intervention in the process. This approach, developed by Box and Tiao (1975), is a generalization of the autoregressive integrated moving-average (ARIMA) time series models described by Box and Jenkins (1976). Lettenmaier and Murray (1977) and Lettenmaier (1978) study the power of the method to detect trends. They emphasize the design of sampling plans to detect impacts from polluting facilities. Examples of its use are in Hipel et al. (1975) and Roy and Pellerin (1982).

Box-Jenkins modeling techniques are powerful tools for the analysis of time series data. McMichael and Hunter (1972) give a good introduction to Box-Jenkins modeling of environmental data, using both deterministic and stochastic components to forecast temperature flow in the Ohio River. Fuller and Tsokos (1971) develop models to forecast dissolved oxygen in a stream. Carlson, MacCormick, and Watts (1970) and McKerchar and Delleur (1974) fit Box-Jenkins models to monthly river flows. Hsu and Hunter (1976) analyze annual series of air pollution SO_2 concentrations. McCollister and Wilson (1975) forecast daily maximum and hourly average total oxidant and carbon monoxide concentrations in the Los Angeles Basin. Hipel, McLeod, and Lennox (1977*a*, 1977*b*) illustrate improved Box-Jenkins techniques to simplify model construction. Reinsel et al. (1981*a*, 1981*b*) use Box-Jenkins models to detect trends in stratospheric ozone data. Two introductory textbooks are McCleary and Hay (1980) and Chatfield (1984). Box and Jenkins (1976) is recommended reading for all users of the method.

Disadvantages of Box-Jenkins methods are discussed by Montgomery and Johnson (1976). At least 50 and preferably 100 or more data collected at equal (or approximately equal) time intervals are needed. When the purpose is forecasting, we must assume the developed model applies to the future. Missing data or data reported as trace or less-than values can prevent the use of Box-Jenkins methods. Finally, the modeling process is often nontrivial, with a considerable investment in time and resources required to build a satisfactory model. Fortunately, there are several packages of statistical programs that contain codes for developing time series models, including Minitab (Ryan, Joiner, and Ryan 1982), SPSS (1985), BMDP (1983), and SAS (1985). Codes for personal computers are also becoming available.

16.4 MANN-KENDALL TEST

In this section we discuss the nonparametric Mann-Kendall test for trend (Mann, 1945; Kendall, 1975). This procedure is particularly useful since missing values are allowed and the data need not conform to any particular distribution. Also, data reported as trace or less than the detection limit can be used (if it is acceptable in the context of the population being sampled) by assigning them a common value that is smaller than the smallest measured value in the data set. This approach can be used because the Mann-Kendall test (and the seasonal Kendall test in Chapter 17) use only the relative magnitudes of the data rather

than their measured values. We note that the Mann-Kendall test can be viewed as a nonparametric test for zero slope of the linear regression of time-ordered data versus time, as illustrated by Hollander and Wolfe (1973, p. 201).

16.4.1 Number of Data 40 or Less

If n is 40 or less, the procedure in this section may be used. When n exceeds 40, use the normal approximation test in Section 16.4.2. We begin by considering the case where only one datum per time period is taken, where a time period may be a day, week, month, and so on. The case of multiple data values per time period is discussed in Section 16.4.3.

The first step is to list the data in the order in which they were collected over time: $x_1, x_2, \ldots, x_n$, where x_i is the datum at time i. Then determine the sign of all $n(n-1)/2$ possible differences $x_j - x_k$, where $j > k$. These differences are $x_2 - x_1, x_3 - x_1, \ldots, x_n - x_1, x_3 - x_2, x_4 - x_2, \ldots, x_n - x_{n-2}, x_n - x_{n-1}$. A convenient way of arranging the calculations is shown in Table 16.1.

Let $\text{sgn}(x_j - x_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $x_j - x_k$:

$$\begin{aligned} \text{sgn}(x_j - x_k) &= 1 \quad \text{if } x_j - x_k > 0 \\ &= 0 \quad \text{if } x_j - x_k = 0 \\ &= -1 \quad \text{if } x_j - x_k < 0 \end{aligned} \qquad \textbf{16.1}$$

Then compute the Mann-Kendall statistic

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k) \qquad \textbf{16.2}$$

which is the number of positive differences minus the number of negative differences. These differences are easily obtained from the last two columns of Table 16.1. If S is a large positive number, measurements taken later in time tend to be larger than those taken earlier. Similarly, if S is a large negative number, measurements taken later in time tend to be smaller. If n is large, the computer code in Appendix B may be used to compute S. This code also computes the tests for trend discussed in Chapter 17.

Suppose we want to test the null hypothesis, H_0, of no trend against the alternative hypothesis, H_A, of an upward trend. Then H_0 is rejected in favor of H_A if S is positive and if the probability value in Table A18 corresponding to the computed S is less than the a priori specified α significance level of the test. Similarly, to test H_0 against the alternative hypothesis H_A of a downward trend, reject H_0 and accept H_A if S is negative and if the probability value in the table corresponding to the absolute value of S is less than the a priori specified α value. If a two-tailed test is desired, that is, if we want to detect either an upward or downward trend, the tabled probability level corresponding to the absolute value of S is doubled and H_0 is rejected if that doubled value is less than the a priori α level.

EXAMPLE 16.1

We wish to test the null hypothesis H_0, of no trend versus the alternative hypothesis, H_A, of an upward trend at the $\alpha = 0.10$

Table 16.1 Differences in Data Values Needed for Computing the Mann-Kendall Statistic S to Test for Trend

Data Values Listed in the Order Collected Over Time							*No. of + Signs*	*No. of − Signs*
x_1	x_2	x_3	x_4	$\cdots$	x_{n-1}	x_n		
	$x_2 - x_1$	$x_3 - x_1$	$x_4 - x_1$	$\cdots$	$x_{n-1} - x_1$	$x_n - x_1$		
		$x_3 - x_2$	$x_4 - x_2$	$\cdots$	$x_{n-1} - x_2$	$x_n - x_2$		
			$x_4 - x_3$	$\cdots$	$x_{n-1} - x_3$	$x_n - x_3$		
				$\ddots$	$\vdots$	$\vdots$		
					$x_{n-1} - x_{n-2}$	$x_n - x_{n-2}$		
						$x_n - x_{n-1}$		
						$S =$	$\left(\begin{matrix}\text{sum of}\\ +\text{ signs}\end{matrix}\right)$	$+ \left(\begin{matrix}\text{sum of}\\ -\text{ signs}\end{matrix}\right)$

Table 16.2 Computation of the Mann-Kendall Trend Statistic S for the Time Ordered Data Sequence 10, 15, 14, 20

Time	*1*	*2*	*3*	*4*		*No. of +*		*No. of −*
Data	*10*	*15*	*14*	*20*		*Signs*		*Signs*
		15 − 10	14 − 10	20 − 10		3		0
			14 − 15	20 − 15		1		1
				20 − 14		1		0
				S	=	5	−	1 = 4

significance level. For ease of illustration suppose only 4 measurements are collected in the following order over time or along a line in space: 10, 15, 14, and 20. There are 6 differences to consider: 15 − 10, 14 − 10, 20 − 10, 14 − 15, 20 − 15, and 20 − 14. Using Eqs. 16.1 and 16.2, we obtain $S = +1 + 1 + 1 - 1 + 1 + 1 = +4$, as illustrated in Table 16.2. (Note that the sign, not the magnitude of the difference is used.) From Table A18 we find for $n = 4$ that the tabled probability for $S = +4$ is 0.167. This number is the probability of obtaining a value of S equal to +4 or larger when $n = 4$ and when no upward trend is present. Since this value is greater than 0.10, we cannot reject H_0.

If the data sequence had been 18, 20, 23, 35, then $S = +6$, and the tabled probability is 0.042. Since this value is less than 0.10, we reject H_0 and accept the alternative hypothesis of an upward trend.

Table A18 gives probability values only for $n \leq 10$. An extension of this table up to $n = 40$ is given in Table A.21 in Hollander and Wolfe (1973).

16.4.2 Number of Data Greater Than 40

When n is greater than 40, the normal approximation test described in this section is used. Actually, Kendall (1975, p. 55) indicates that this method may be used for n as small as 10 unless there are many tied data values. The test procedure is to first compute S using Eq. 16.2 as described before. Then compute the variance of S by the following equation, which takes into account that ties may be present:

$$\mathrm{VAR}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \qquad \textbf{16.3}$$

where g is the number of tied groups and t_p is the number of data in the pth group. For example, in the sequence {23, 24, trace, 6, trace, 24, 24, trace, 23} we have $g = 3$, $t_1 = 2$ for the tied value 23, $t_2 = 3$ for the tied value 24, and $t_3 = 3$ for the three trace values (considered to be of equal but unknown value less than 6).

Then S and VAR(S) are used to compute the test statistic Z as follows:

$$\begin{aligned} Z &= \frac{S-1}{[\mathrm{VAR}(S)]^{1/2}} && \text{if } S > 0 \\ &= 0 && \text{if } S = 0 \\ &= \frac{S+1}{[\mathrm{VAR}(S)]^{1/2}} && \text{if } S < 0 \end{aligned} \qquad \textbf{16.4}$$

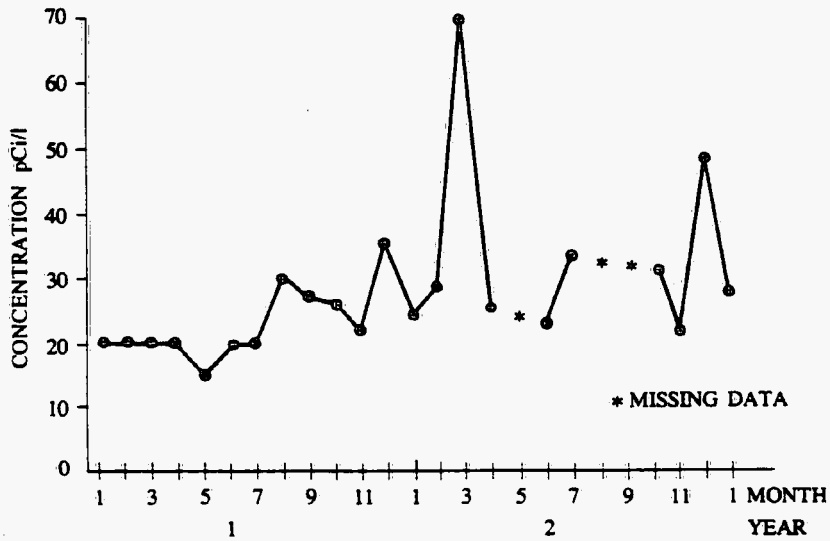

Figure 16.2 Concentrations of ^{238}U in ground water in well E at the former St. Louis Airport storage site for January 1981 through January 1983 (after Clark and Berven, 1984).

A positive (negative) value of Z indicates an upward (downward) trend. If the null hypothesis, H_0, of no trend is true, the statistic Z has a standard normal distribution, and hence we use Table A1 to decide whether to reject H_0. To test for either upward or downward trend (a two-tailed test) at the α level of significance, H_0 is rejected if the absolute value of Z is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from Table A1. If the alternative hypothesis is for an upward trend (a one-tailed test), H_0 is rejected if Z (Eq. 16.4) is greater than $Z_{1-\alpha}$. We reject H_0 in favor of the alternative hypothesis of a downward trend if Z is negative and the absolute value of Z is greater than $Z_{1-\alpha/2}$. Kendall (1975) indicates that using the standard normal tables (Table A1) to judge the statistical significance of the Z test will probably introduce little error as long as $n \geq 10$ unless there are many groups of ties and many ties within groups.

EXAMPLE 16.2

Figure 16.2 is a plot of $n = 22$ monthly ^{238}U concentrations $x_1, x_2, x_3, \ldots, x_{22}$ obtained from a groundwater monitoring well from January 1981 through January 1983 (reported in Clark and Berven, 1984). We use the Mann-Kendall procedure to test the null hypothesis at the $\alpha = 0.05$ level that there is no trend in ^{238}U groundwater concentrations at this well over this 2-year period. The alternative hypothesis is that an upward trend is present.

There are $n(n-1)/2 = 22(21)/2 = 231$ differences to examine for their sign. The computer code in Appendix B was used to obtain S and Z (Eqs. 16.2 and 16.4). We find that $S = +108$. Since there are 6 occurrences of the value 20 and 2 occurrences of both 23 and 30, we have $g = 3$, $t_1 = 6$, and $t_2 = t_3 = 2$. Hence, Eq. 16.3 gives

$$\begin{aligned}\mathrm{VAR}(S) &= \tfrac{1}{18}[22(21)(44+5) \\ &\quad - 6(5)(12+5) - 2(1)(4+5) - 2(1)(4+5)] \\ &= 1227.33\end{aligned}$$

or $[\mathrm{VAR}(S)]^{1/2} = 35.0$. Therefore, since $S > 0$, Eq. 16.4 gives $Z = (108 - 1)/35.0 = 3.1$. From Table A1 we find $Z_{0.95} = 1.645$. Since Z exceeds 1.645, we reject H_0 and accept the alternative hypothesis of an upward trend. We note that the three missing values in Figure 16.2 do not enter into the calculations in any way. They are simply ignored and constitute a regrettable loss of information for evaluating the presence of trend.

16.4.3 Multiple Observations per Time Period

When there are multiple observations per time period, there are two ways to proceed. First, we could compute a summary statistic, such as the median, for each time period and apply the Mann-Kendall test to the medians. An alternative approach is to consider the $n_i \geq 1$ multiple observations at time i (or time period i) as ties in the time index. For this latter case the statistic S is still computed by Eq. 16.2, where n is now the sum of the n_i, that is, the total number of observations rather than the number of time periods. The differences between data obtained at the same time are given the score 0 no matter what the data values may be, since they are tied in the time index.

When there are multiple observations per time period, the variance of S is computed by the following equation, which accounts for ties in the time index:

$$\begin{aligned}\mathrm{VAR}(S) = \frac{1}{18}\Bigg[&n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p-1)(2t_p+5) \\ &- \sum_{q=1}^{h} u_q(u_q-1)(2u_q+5)\Bigg] \\ &+ \frac{\sum_{p=1}^{g} t_p(t_p-1)(t_p-2)\sum_{q=1}^{h} u_q(u_q-1)(u_q-2)}{9n(n-1)(n-2)} \\ &+ \frac{\sum_{p=1}^{g} t_p(t_p-1)\sum_{q=1}^{h} u_q(u_q-1)}{2n(n-1)} \qquad \textbf{16.5}\end{aligned}$$

where g and t_p are as defined following Eq. 16.3, h is the number of time periods that contain multiple data, and u_q is the number of multiple data in the qth time period. Equation 16.5 reduces to Eq. 16.3 when there is one observation per time period.

Equations 16.3 and 16.5 assume all data are independent and, hence, uncorrelated. If observations taken during the same time period are highly correlated, it may be preferable to apply the Mann-Kendall test to the medians of the data in each time period rather than use Eq. 16.5 in Eq. 16.4.

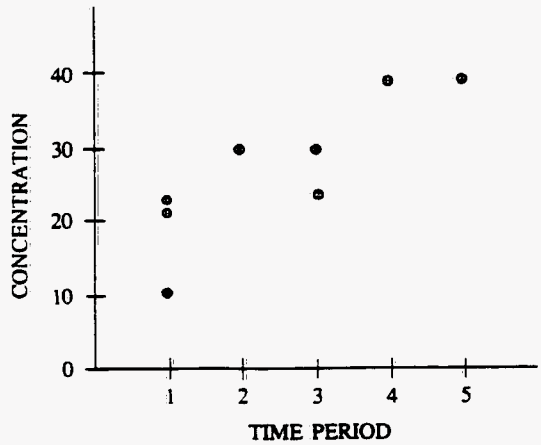

Figure 16.3 An artificial data set to illustrate the Mann-Kendall test for trend when ties in both the data and time are present.

EXAMPLE 16.3

To illustrate the computation of S and VAR(S), consider the following artificial data set:

(concentration, time period)

= (10, 1), (22, 1), (21, 1), (30, 2), (22, 3), (30, 3), (40, 4), (40, 5)

as plotted in Figure 16.3. There are 5 time periods and $n = 8$ data. To illustrate computing S, we lay out the data as follows:

Time Period :	1	1	1	2	3	3	4	5
Data :	10	22	21	30	22	30	40	40

We shall test at the $\alpha = 0.05$ level the null hypothesis, H_0, of no trend versus the alternative hypothesis, H_A, of an upward trend, a one-tailed test.

Now, look at all 8(7)/2 = 28 possible data pairs, remembering to give a score of 0 to the 4 pairs within the same time index. The differences are shown in Table 16.3. Ignore the magnitudes of the differences, and sum the number of positive and negative signs to obtain $S = 19$. It is clear from Figure 16.3 that there are $g = 3$ tied data groups (22, 30, and 40) with $t_1 = t_2 = t_3 = 2$. Also, there are $h = 2$ time index ties (times 1 and 3) with $u_1 = 3$ and $u_2 = 2$. Hence, Eq. 16.5 gives

$$\mathrm{VAR}(S) = \frac{1}{18}[8(7)(16 + 5) - 3(2)(1)(4 + 5) - 3(2)(6 + 5) - 2(1)(4 + 5)] + 0 + \frac{[3(2)(1)][3(2) + 2(1)]}{2(8)(7)}$$

$$= 58.1$$

or $[\mathrm{VAR}(S)]^{1/2} = 7.6$. Hence, Eq. 16.4 gives $Z = (19 - 1)/7.6$

Table 16.3 Illustration of Computing S for Example 16.3

Time Period	*1*	*1*	*1*	*2*	*3*	*3*	*4*	*5*	*Sum of + Signs*	*Sum of − Signs*
Data	*10*	*22*	*21*	*30*	*22*	*30*	*40*	*40*		
		NC	NC	+20	+12	+20	+30	+30	5	0
			NC	+8	0	+8	+18	+18	4	0
				+9	+1	+9	+19	+19	5	0
					−8	0	+10	+10	2	1
						NC	+18	+18	2	0
							+10	+10	2	0
								0	0	0
								S	= 20	− 1
									= 19	

NC = Not computed since both data values are within the same time period.

= 2.4. Referring to Table A1, we find $Z_{0.95}$ = 1.645. Since $Z >$ 1.645, reject H_0 and accept the alternative hypothesis of an upward trend.

16.4.4 Homogeneity of Stations

Thus far only one station has been considered. If data over time have been collected at $M > 1$ stations, we have data as displayed in Table 16.4 (assuming one datum per sampling period). The Mann-Kendall test may be computed for each station. Also, an estimate of the magnitude of the trend at each station can be obtained using Sen's (1968*b*) procedure, as described in Section 16.5.

When data are collected at several stations within a region or basin, there may be interest in making a basin-wide statement about trends. A general statement about the presence or absence of monotonic trends will be meaningful if the trends at all stations are in the same direction—that is, all upward or all downward. Time plots of the data at each station, preferably on the same graph to make visual comparison easier, may indicate when basin-wide statements are possible. In many situations an objective testing method will be needed to help make this decision. In this section we discuss a method for doing this that

Table 16.4 Data Collected over Time at Multiple Stations

		Station 1				...		*Station M*			
		Sampling Time				...		*Sampling Time*			
		1	*2*		*K*			*1*	*2*		*K*
Year	1	x_{111}	x_{211}	...	x_{K11}	...	1	x_{11M}	x_{21M}	...	x_{K1M}
	2	x_{121}	x_{221}	...	x_{K21}	...	2	x_{12M}	x_{22M}	...	x_{K2M}
	⋮						⋮				
	L	x_{1L1}	x_{2L1}	...	x_{KL1}	...	L	x_{1LM}	x_{2LM}	...	x_{KLM}
Mann-Kendall Test			S_1			...		S_M			
			Z_1			...		Z_M			

M = number of stations
K = number of sampling times per year
L = number of years
x_{ilj} = datum for the ith sampling time in the lth year at the jth station

makes use of the Mann-Kendall statistic computed for each station. This procedure was originally proposed by van Belle and Hughes (1984) to test for homogeneity of trends between seasons (a test discussed in Chapter 17).

To test for homogeneity of trend direction at multiple stations, compute the homogeneity chi-square statistic, χ^2_{homog}, where

$$\chi^2_{homog} = \chi^2_{total} - \chi^2_{trend} = \sum_{j=1}^{M} Z_j^2 - M\bar{Z}^2 \qquad \textbf{16.6}$$

$$Z_j = \frac{S_j}{[\mathrm{VAR}(S_j)]^{1/2}} \qquad \textbf{16.7}$$

S_j is the Mann-Kendall trend statistic for the jth station,

and $\bar{Z} = \frac{1}{M}\sum_{j=1}^{M} Z_j$

If the trend at each station is in the same direction, then χ^2_{homog} has a chi-square distribution with $M - 1$ degrees of freedom (df). This distribution is given in Table A19. To test for trend homogeneity between stations at the α significance level, we refer our calculated value of χ^2_{homog} to the α critical value in Table A19 in the row with $M - 1$ df. If χ^2_{homog} exceeds this critical value, we reject the H_0 of homogeneous station trends. In that case no regional-wide statements should be made about trend direction. However, a Mann-Kendall test for trend at each station may be used. If χ^2_{homog} does not exceed the α critical level in Table A19, then the statistic $\chi^2_{trend} = M\bar{Z}^2$ is referred to the chi-square distribution with 1 df to test the null hypothesis H_0 that the (common) trend direction is significantly different from zero.

The validity of these chi-square tests depends on each of the Z_j values (Eq. 16.7) having a standard normal distribution. Based on results in Kendall (1975), this implies that the number of data (over time) for each station should exceed 10. Also, the validity of the tests requires that the Z_j be independent. This requirement means that the data from different stations must be uncorrelated. We note that the Mann-Kendall test and the chi-square tests given in this section may be computed even when the number of sampling times, K, varies from year to year and when there are multiple data collected per sampling time at one or more times.

EXAMPLE 16.4

We consider a simple case to illustrate computations. Suppose the following data are obtained:

	Time				
	1	*2*	*3*	*4*	*5*
Station 1	10	12	11	15	18
Station 2	10	9	10	8	9

We wish to test for homogeneous trend direction at the $M = 2$ stations at the $\alpha = 0.05$ significance level. Equation 16.2 gives $S_1 = 1 + 1 + 1 + 1 - 1 + 1 + 1 + 1 + 1 + 1 = +9 - 1 =$

8 and $S_2 = -1 + 0 - 1 - 1 + 1 - 1 + 0 - 1 - 1 + 1 = 2 - 6 = -4$. Equation 16.3 gives

$$\mathrm{VAR}(S_1) = \frac{5(4)(15)}{18} = 16.667 \quad \text{and} \quad \mathrm{VAR}(S_2)$$

$$= \frac{[5(4)(15) - 2(1)(9) - 2(1)(9)]}{18} = 14.667$$

Therefore Eq. 16.4 gives

$$Z_1 = \frac{7}{(16.667)^{1/2}} = 1.71 \quad \text{and} \quad Z_2 = \frac{-3}{(14.667)^{1/2}} = -0.783$$

Thus

$$\chi^2_{\text{homog}} = 1.71^2 + (-0.783)^2 - 2\left(\frac{1.71 - 0.783}{2}\right)^2 = 3.1$$

Referring to the chi-square tables with $M - 1 = 1$ df, we find the $\alpha = 0.05$ level critical value is 3.84. Since $\chi^2_{\text{homog}} < 3.84$, we cannot reject the null hypothesis of homogeneous trend direction over time at the 2 stations. Hence, an overall test of trend using the statistic χ^2_{trend} can be made. [Note that the critical value 3.84 is only approximate (somewhat too small), since the number of data at both stations is less than 10.] $\chi^2_{\text{trend}} = M\bar{Z}^2 = 2(0.2148) = 0.43$. Since $0.43 < 3.84$, we cannot reject the null hypothesis of no trend at the 2 stations.

We may test for trend at each station using the Mann-Kendall test by referring $S_1 = 8$ and $S_2 = -4$ to Table A18. The tabled value for $S_1 = 8$ when $n = 5$ is 0.042. Doubling this value to give a two-tailed test gives 0.084, which is greater than our prespecified $\alpha = 0.05$. Hence, we cannot reject H_0 of no trend for station 1 at the $\alpha = 0.05$ level. The tabled value for $S_2 = -4$ when $n = 5$ is 0.242. Since $0.484 > 0.05$, we cannot reject H_0 of no trend for station 2. These results are consistent with the χ^2_{trend} test before. Note, however, that station 1 still appears to be increasing over time, and the reader may confirm it is significant at the $\alpha = 0.10$ level. This result suggests that this station be carefully watched in the future.

16.5 SEN'S NONPARAMETRIC ESTIMATOR OF SLOPE

As noted in Section 16.3.2, if a linear trend is present, the true slope (change per unit time) may be estimated by computing the least squares estimate of the slope, b, by linear regression methods. However, b computed in this way can deviate greatly from the true slope if there are gross errors or outliers in the data. This section shows how to estimate the true slope at a sampling station by using a simple nonparametric procedure developed by Sen (1968b). His procedure is an extension of a test by Theil (1950), which is illustrated by Hollander and Wolfe (1973, p. 205). Sen's method is not greatly affected by

gross data errors or outliers, and it can be computed when data are missing. Sen's estimator is closely related to the Mann-Kendall test, as illustrated in the following paragraphs. The computer code in Appendix B computes Sen's estimator.

First, compute the N' slope estimates, Q, for each station:

$$Q = \frac{x_{i'} - x_i}{i' - i} \qquad \textbf{16.8}$$

where $x_{i'}$ and x_i are data values at times (or during time periods) i' and i, respectively, and where $i' > i$; N' is the number of data pairs for which $i' > i$. The median of these N' values of Q is Sen's estimator of slope. If there is only one datum in each time period, then $N' = n(n - 1)/2$, where n is the number of time periods. If there are multiple observations in one or more time periods, then $N' < n(n - 1)/2$, where n is now the total number of observations, not time periods, since Eq. 16.8 cannot be computed with two data from the same time period, that is, when $i' = i$. If an x_i is below the detection limit, one half the detection limit may be used for x_i.

The median of the N' slope estimates is obtained in the usual way, as discussed in Section 13.3.1. That is, the N' values of Q are ranked from smallest to largest (denote the ranked values by $Q_{[1]} \leq Q_{[2]} \leq \cdots \leq Q_{[N'-1]} \leq Q_{[N']}$) and we compute

$$\begin{aligned} \text{Sen's estimator} &= \text{median slope} \\ &= Q_{[(N'+1)/2]} && \text{if } N' \text{ is odd} \\ &= \tfrac{1}{2}\left(Q_{[N'/2]} + Q_{[(N'+2)/2]}\right) && \text{if } N' \text{ is even} \qquad \textbf{16.9} \end{aligned}$$

A $100(1 - \alpha)\%$ two-sided confidence interval about the true slope may be obtained by the nonparametric technique given by Sen (1968b). We give here a simpler procedure, based on the normal distribution, that is valid for n as small as 10 unless there are many ties. This procedure is a generalization of that given by Hollander and Wolfe (1973, p. 207) when ties and/or multiple observations per time period are present.

1. Choose the desired confidence coefficient α and find $Z_{1-\alpha/2}$ in Table A1.
2. Compute $C_\alpha = Z_{1-\alpha/2}[\mathrm{VAR}(S)]^{1/2}$, where $\mathrm{VAR}(S)$ is computed from Eqs. 16.3 or 16.5. The latter equation is used if there are multiple observations per time period.
3. Compute $M_1 = (N' - C_\alpha)/2$ and $M_2 = (N' + C_\alpha)/2$.
4. The lower and upper limits of the confidence interval are the M_1th largest and $(M_2 + 1)$th largest of the N' ordered slope estimates, respectively.

EXAMPLE 16.5

We use the data set in Example 16.3 to illustrate Sen's procedure. Recall that the data are

Time Period	1	1	1	2	3	3	4	5
Data	10	22	21	30	22	30	40	40

There are $N' = 24$ pairs for which $i' > i$. The values of individual

Table 16.5 Illustration of Computing an Estimate of Trend Slope Using Sen's (1968*b*) Nonparametric Procedure (for Example 16.5). Tabled Values Are Individual Slope Estimates, Q

Time Period	*1*	*1*	*1*	*2*	*3*	*3*	*4*	*5*
Data	*10*	*22*	*21*	*30*	*22*	*30*	*40*	*40*
		NC	NC	+20	+6	+10	+10	+7.5
			NC	+8	0	+4	+6	+4.5
				+9	+0.5	+4.5	+6.33	+4.75
					−8	0	+5	+3.33
						NC	+18	+9
							+10	+5
								0

NC = Cannot be computed since both data values are within the same time period.

slope estimates Q for these pairs are obtained by dividing the differences in Table 16.3 by $i' - i$. The 24 Q values are given in Table 16.5.

Ranking these Q values from smallest to largest gives

−8, 0, 0, 0, 0.5, 3.33, 4, 4.5, 4.5, 4.75, 5, 5, 6, 6, 6.33, 7.5, 8, 9, 9, 10, 10, 10, 18, 20

Since $N' = 24$ is even, the median of these Q values is the average of the 12th and 13th largest values (by Eq. 16.8), which is 5.5, the Sen estimate of the true slope. That is, the average (median) change is estimated to be 5.5 units per time period.

A 90% confidence interval about the true slope is obtaied as follows. From Table A1 we find $Z_{0.95} = 1.645$. Hence,

$$C_\alpha = 1.645[\mathrm{VAR}(S)]^{1/2} = 1.645[58.1]^{1/2} = 12.54$$

where the value for VAR(S) was obtained from Example 16.3. Since $N' = 24$, we have $M_1 = (24 - 12.54)/2 = 5.73$ and $M_2 + 1 = (24 + 12.54)/2 + 1 = 19.27$. From the list of 24 ordered slopes given earlier, the lower limit is found to be 2.6 by interpolating between the 5th and 6th largest values. The upper limit is similarly found to be 9.3 by interpolating between the 19th and 20th largest values.

16.6 CASE STUDY

This section illustrates the procedures presented in this chapter for evaluating trends. The computer program in Appendix B is used on the hypothetical data listed in Table 16.6 and plotted in Figure 16.4. These data, generated on a computer, represent measurements collected monthly at two stations for 48 consecutive months. The model for station 1 is $x_{il1} = \exp[0.83e_{il} - 0.35] - 1.0$, where x_{il1} is the datum for month i in year l at station 1. The model used at station 2 was $x_{il2} = \exp[0.83e_{il} - 0.35] - 1.0 + 0.40(i/12 + l)$. For both stations the measurement errors e_{il} were generated to have mean 0 and variance 1. The data for station 1 are lognormally distributed with no trend.

Table 16.6 Simulated Monthly Data at Two Stations over a Four-Year Period

NUMBER OF YEARS = 4
NUMBER OF STATIONS = 2

STATION 1 YEAR	NUMBER OF DATA POINTS 48 MONTH	STATION 1	STATION 2 YEAR	NUMBER OF DATA POINTS 48 MONTH	STATION 2
1	1	6.00	1	1	5.09
1	2	5.41	1	2	5.07
1	3	4.58	1	3	4.93
1	4	4.34	1	4	4.94
1	5	4.77	1	5	5.15
1	6	4.54	1	6	11.82
1	7	4.50	1	7	5.48
1	8	5.02	1	8	5.18
1	9	4.38	1	9	5.79
1	10	4.27	1	10	5.11
1	11	4.33	1	11	5.10
1	12	4.33	1	12	5.94
2	13	5.00	2	13	6.91
2	14	5.02	2	14	7.11
2	15	4.14	2	15	5.40
2	16	5.16	2	16	6.77
2	17	6.33	2	17	5.35
2	18	5.49	2	18	6.04
2	19	4.54	2	19	5.45
2	20	6.62	2	20	6.95
2	21	4.64	2	21	5.54
2	22	4.45	2	22	5.71
2	23	4.57	2	23	6.14
2	24	4.09	2	24	7.13
3	25	5.06	3	25	5.80
3	26	4.83	3	26	5.91
3	27	4.92	3	27	5.88
3	28	6.02	3	28	7.21
3	29	4.77	3	29	8.29
3	30	5.03	3	30	6.00
3	31	7.15	3	31	6.28
3	32	4.30	3	32	5.69
3	33	4.15	3	33	6.52
3	34	5.13	3	34	6.27
3	35	5.28	3	35	6.46
3	36	4.31	3	36	6.94
4	37	6.53	4	37	6.28
4	38	5.11	4	38	6.74
4	39	4.31	4	39	6.91
4	40	4.64	4	40	7.81
4	41	4.87	4	41	6.53
4	42	4.89	4	42	6.26
4	43	4.92	4	43	7.01
4	44	4.94	4	44	7.42
4	45	4.69	4	45	8.35
4	46	4.50	4	46	6.27
4	47	4.80	4	47	6.69
4	48	4.80	4	48	6.99

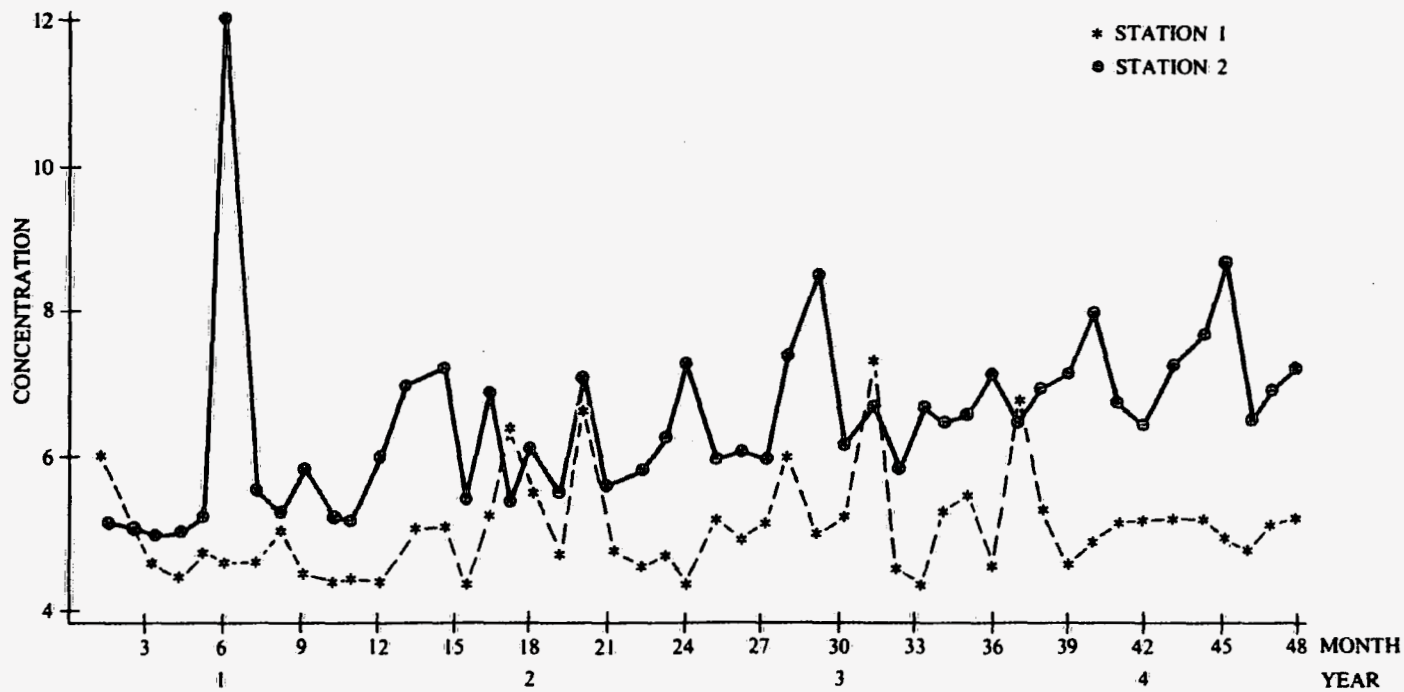

Figure 16.4 Data at two stations each month for four years. Data were simulated using the lognormal independent model given by Hirsch, Slack, and Smith (1982, Eq. 14b). Simulated data were obtained by D. W. Engel.

and the data for station 2 are lognormal with a trend of 0.4 units per year or 0.0333 units per month. These models were among those used by Hirsch, Slack, and Smith (1982) to evaluate the power of the seasonal Kendall test for trend, a test we discuss in Chapter 17.

The results obtained from the computer code in Appendix B are shown in Table 16.7. The first step is to decide whether the two stations have trends in the same direction. In this example we know it is not so, since one station has a trend and the other does not. But in practice this a priori information will not be available.

Table 16.7 shows that the chi-square test of homogeneity (Eq. 16.6) is highly significant ($\chi^2_{homog} = 10.0$; computed significance level of 0.002). Hence, we ignore the chi-square test for trend that is automatically computed by the program and turn instead to the Mann-Kendall test results for each station. This test for station 1 is nonsignificant (*P* value of 0.70), indicating no strong evidence for trends, but that for station 2 is highly significant. All of these test results agree with the true situation. Sen's estimates of slope are 0.002 and 0.041 per month for stations 1 and 2, whereas the true values are 0.0 and 0.0333, respectively. The computer code computes $100(1 - \alpha)\%$ confidence limits for the true slope for $\alpha = 0.20$, 0.10, 0.05, and 0.01. For this example the 95% confidence limits are −0.009 and 0.012 for station 1, and 0.030 and 0.050 for station 2.

The computer code allows one to split up the 48 observations at each station into meaningful groups that contain multiple observations. For instance, suppose

Table 16.7 Chi-Square Tests for Homogeneity of Trends at the Two Stations, and Mann-Kendall Tests for Each Station

HOMOGENEITY TEST RESULTS				
CHI-SQUARE STATISTICS		df	PROB. OF A LARGER VALUE	
TOTAL	23.97558	2	0.000	
HOMOGENEITY	10.03524	1	0.002	Trend not equal at the 2 stations
TREND	13.94034	1	0.000	Not meaningful

STATION	SEASON	MANN-KENDALL S STATISTIC	Z STATISTIC	n	PROB. OF EXCEEDING THE ABSOLUTE VALUE OF THE Z STATISTIC (TWO-TAILED TEST) IF n > 10
1	1	45.00	0.39121	48	0.696
2	1	549.00	4.87122	48	0.000

		SEN SLOPE CONFIDENCE INTERVALS			
STATION	SEASON	ALPHA	LOWER LIMIT	SLOPE	UPPER LIMIT
1	1	0.010	-0.013	0.002	0.016
		0.050	-0.009	0.002	0.012
		0.100	-0.007	0.002	0.011
		0.200	-0.005	0.002	0.009
2	1	0.010	0.026	0.041	0.054
		0.050	0.030	0.041	0.050
		0.100	0.032	0.041	0.048
		0.200	0.034	0.041	0.046

Table 16.8 Analyses of the Data in Table 16.6 Considering the Data as Twelve Multiple Observations in Each of Four Years

NUMBER OF YEARS = 4
NUMBER OF SEASONS = 1
NUMBER OF STATIONS = 2

HOMOGENEITY TEST RESULTS

SOURCE	CHI-SQUARE	df	PROB. OF A LARGER VALUE
TOTAL	21.45468	2	0.00
HOMOGENEITY	5.79732	1	0.016
TREND	15.65736	1	0.000

STATION	SEASON	MANN-KENDALL S STATISTIC	Z STATISTIC	n	PROB. OF EXCEEDING THE ABSOLUTE VALUE OF THE Z STATISTIC (TWO-TAILED TEST) IF n > 10
1	1	119.00	1.08623	48	0.277
2	1	489.00	4.49132	48	0.000

		SEN SLOPE CONFIDENCE INTERVALS			
STATION	SEASON	ALPHA	LOWER LIMIT	SLOPE	UPPER LIMIT
1	1	0.010	-0.120	0.080	0.225
		0.050	-0.065	0.080	0.190
		0.100	-0.037	0.080	0.176
		0.200	-0.014	0.080	0.153
2	1	0.010	0.290	0.467	0.670
		0.050	0.353	0.467	0.620
		0.100	0.370	0.467	0.600
		0.200	0.390	0.467	0.575

we regard the data in this example as 12 multiple data points in each of four years. Applying the code using this interpretation gives the results in Table 16.8.

The conclusions of the tests are the same as obtained in Table 16.7 when the data were considered as one time series of 48 single observations. However, this may not be the case with other data sets or groupings of multiple observations. Indeed, the Mann-Kendall test statistic Z for station 1 is larger in Table 16.8 than in Table 16.7, so that the test is closer to (falsely) indicating a significant trend when the data are grouped into years. For station 2 the Mann-Kendall test in Table 16.8 is smaller than in Table 16.7, indicating the test has less power to detect the trend actually present. The best strategy appears to be to not group data unnecessarily. The estimates of slope are now 0.080 and 0.467 per year, whereas the true values are 0.0 and 0.40, respectively.

16.7 SUMMARY

This chapter began by identifying types of trends and some of the complexities that arise when testing for trend. It also discussed graphical methods for detecting

Probabilities for the Mann-Kendall Nonparametric Test for Trend

This table of critical values is excerpted from *Nonparametric Statistical Methods* (Hollander and Wolfe 1973) and is reprinted here by permission from John Wiley & Sons, Inc. Each entry in Table A.21 is the probability that the Mann-Kendall statistic "S" equals or exceeds the specified value of S when no trend is present. In this table, the "x" is equivalent to the S described in Chapter 16 of *Statistical Methods for Environmental Pollution Prevention Monitoring* (Gilbert 1987). Section 16.4.1 of Gilbert discusses how these tables are used with the Mann-Kendall test for trend analysis.

Table A 21. Upper tail probabilities for the null distribution of Kendall's K statistic: n = 4(1)40

For a given n, the entry in the table for the point S is $P_o\{K \geq S\}$. Under these conditions, if S is such that $P_o\{K \geq S\} = \alpha$, then $k(\alpha,n) = S$. For certain n, the entries are terminated at S_o, where S_o is the smallest possible value of S such that $P_o\{K \geq S\}$ is zero to three decimal places. [For n = 4(4)40 or n = 5(4)37 all even integers between — n(n-1)/2 and n(n -1)/2 have positive probability and for n = 6(4)38 or n = 7(4)39 all odd integers between — n(n -1)/2 and n(n -1)/2 have positive probability.]

	n								
S	4	5	8	9	12	13	16	17	20
0	.625	.592	.548	.540	.527	.524	.518	.516	.513
2	.375	.408	.452	.460	.473	.476	.482	.484	.487
4	.167	.242	.360	.381	.420	.429	.447	.452	.462
6	.042	.117	.274	.306	.369	.383	.412	.420	.436
8		.042	.199	.238	.319	.338	.378	.388	.411
10		.008	.138	.179	.273	.295	.345	.358	.387
12			.089	.130	.230	.255	.313	.328	.362
14			.054	.090	.190	.218	.282	.299	.339
16			.031	.060	.155	.184	.253	.271	.315
18			.016	.038	.125	.153	.225	.245	.293
20			.007	.022	.098	.126	.199	.220	.271
22			.002	.012	.076	.102	.175	.196	.250
24			.001	.006	.058	.082	.153	.174	.230
26			.000	.003	.043	.064	.133	.154	.211
28				.001	.031	.050	.114	.135	.193
30				.000	.022	.038	.097	.118	.176
32					.016	.029	.083	.102	.159
34					.010	.021	.070	.088	.144
36					.007	.015	.058	.076	.130
38					.004	.011	.048	.064	.117
40					.003	.007	.039	.054	.104
42					.002	.005	.032	.046	.093
44					.001	.003	.026	.038	.082
46					.000	.002	.021	.032	.073
48						.001	.016	.026	.064
50						.001	.013	.021	.056
52						.000	.010	.017	.049
54							.008	.014	.043
56							.006	.011	.037
58							.004	.009	.032
60							.003	.007	.027
62							.002	.005	.023
64							.002	.004	.020
66							.001	.003	.017
68							.001	.002	.014
70							.001	.002	.012
72							.000	.001	.010
74								.001	.008
76								.001	.007
78								.000	.006
80									.005
82									.004
84									.003
86									.002
88									.002
90									.002
92									.001
94									.001
96									.001
98									.001
100									.000

Adapted from L. Kaarsemaker and A. van Wijngaarden, Tables for use in rank correlation. *Statist. Neerl. 7, 41-54 (1953)*, with the permission of the authors, and the editors of *Statistica Neerlandica*.

Table A21. (continued)

	n								
S	6	7	10	11	14	15	18	19	22
1	.500	.500	.500	.500	.500	.500	.500	.500	.500
3	.360	.386	.431	.440	.457	.461	.470	.473	.478
5	.235	.281	.364	.381	.415	.423	.441	.445	.456
7	.136	.191	.300	.324	.374	.385	.411	.418	.434
9	.068	.119	.242	.271	.334	.349	.383	.391	.412
11	.028	.068	.190	.223	.295	.313	.354	.365	.390
13	.008	.035	.146	.179	.259	.279	.327	.339	.369
15	.001	.015	.108	.141	.225	.248	.300	.314	.348
17		.005	.078	.109	.194	.218	.275	.290	.328
19		.001	.054	.082	.165	.190	.250	.267	.308
21		.000	.036	.060	.140	.164	.227	.245	.289
23			.023	.043	.117	.141	.205	.223	.270
25			.014	.030	.096	.120	.184	.203	.252
27			.008	.020	.079	.101	.165	.184	.234
29			.005	.013	.063	.084	.147	.166	.217
31			.002	.008	.050	.070	.130	.149	.201
33			.001	.005	.040	.057	.115	.133	.186
35			.000	.003	.031	.046	.100	.119	.171
37				.002	.024	.037	.088	.105	.157
39				.001	.018	.029	.076	.093	.144
41				.000	.013	.023	.066	.082	.131
43					.010	.018	.056	.072	.120
45					.007	.014	.048	.062	.109
47					.005	.010	.041	.054	.099
49					.003	.008	.034	.047	.089
51					.002	.006	.029	.040	.080
53					.002	.004	.024	.034	.072
55					.001	.003	.020	.029	.064
57					.001	.002	.016	.025	.058
59					.000	.001	.013	.021	.051
61						.001	.011	.017	.045
63						.001	.009	.014	.040
65						.000	.007	.012	.035
67							.005	.010	.031
69							.004	.008	.027
71							.003	.006	.024
73							.003	.005	.021
75							.002	.004	.018
77							.001	.003	.015
79							.001	.003	.013
81							.001	.002	.011
83							.001	.002	.010
85							.000	.001	.008
87								.001	.007
89								.001	.006
91								.001	.005
93								.000	.004
95									.003
97									.003
99									.002
101									.002
103									.002
105									.001
107									.001
109									.001
111									.001
113									.001
115									.000

Table A21. (continued)

S	n = 21	24	25	28	29	32	33	36	37	40
0	.512	.510	.509	.508	.507	.506	.506	.505	.505	.505
2	.488	.490	.491	.492	.493	.494	.494	.495	.495	.495
4	.464	.471	.472	.477	.478	.481	.482	.484	.484	.486
6	.441	.451	.454	.461	.463	.468	.469	.473	.474	.477
8	.417	.432	.436	.446	.448	.455	.457	.462	.464	.468
10	.394	.413	.418	.430	.434	.442	.445	.452	.453	.459
12	.371	.394	.400	.415	.419	.430	.433	.441	.443	.449
14	.349	.375	.382	.400	.405	.417	.421	.430	.433	.440
16	.327	.356	.364	.385	.390	.405	.409	.420	.423	.431
18	.306	.338	.347	.370	.376	.392	.397	.409	.413	.422
20	.285	.320	.330	.355	.362	.380	.385	.399	.403	.413
22	.265	.303	.314	.341	.348	.368	.373	.388	.393	.404
24	.246	.286	.297	.326	.334	.356	.362	.378	.383	.395
26	.228	.270	.282	.312	.321	.344	.350	.368	.373	.386
28	.210	.254	.266	.298	.308	.332	.339	.358	.363	.377
30	.193	.238	.251	.285	.295	.320	.328	.347	.353	.369
32	.177	.223	.237	.272	.282	.309	.317	.338	.344	.360
34	.162	.209	.222	.259	.270	.298	.306	.328	.334	.351
36	.147	.195	.209	.246	.257	.287	.295	.318	.325	.343
38	.134	.181	.196	.234	.246	.276	.285	.308	.315	.334
40	.121	.169	.183	.222	.234	.265	.274	.299	.306	.326
42	.109	.156	.171	.211	.223	.255	.264	.290	.297	.318
44	.098	.145	.159	.200	.212	.244	.254	.280	.288	.309
46	.088	.134	.148	.189	.201	.234	.244	.271	.279	.301
48	.079	.123	.138	.178	.191	.224	.235	.262	.271	.293
50	.070	.113	.128	.168	.181	.215	.225	.254	.262	.285
52	.062	.104	.118	.158	.171	.206	.216	.245	.254	.277
54	.055	.095	.109	.149	.162	.197	.207	.237	.245	.270
56	.049	.087	.101	.140	.153	.188	.199	.228	.237	.262
58	.043	.079	.093	.131	.144	.179	.190	.220	.229	.255
60	.037	.072	.085	.123	.136	.171	.182	.212	.222	.247
62	.032	.066	.078	.115	.128	.163	.174	.204	.214	.240
64	.028	.059	.071	.108	.120	.155	.166	.197	.206	.233
66	.024	.054	.065	.101	.112	.147	.158	.189	.199	.226
68	.021	.048	.059	.094	.105	.140	.151	.182	.192	.219
70	.018	.044	.054	.087	.099	.133	.144	.175	.185	.212
72	.015	.039	.049	.081	.092	.126	.137	.168	.178	.205
74	.013	.035	.044	.075	.086	.119	.130	.161	.171	.199
76	.011	.031	.040	.070	.080	.113	.124	.155	.165	.192
78	.009	.028	.036	.065	.075	.107	.117	.148	.158	.186
80	.008	.025	.032	.060	.070	.101	.111	.142	.152	.180
82	.007	.022	.029	.055	.065	.095	.106	.136	.146	.174
84	.005	.019	.026	.051	.060	.090	.100	.130	.140	.168
86	.005	.017	.023	.047	.056	.085	.095	.124	.134	.162
88	.004	.015	.021	.043	.052	.080	.090	.119	.129	.156
90	.003	.013	.018	.039	.048	.075	.085	.114	.123	.151
92	.002	.011	.016	.036	.044	.070	.080	.108	.118	.146
94	.002	.010	.014	.033	.041	.066	.075	.103	.113	.140
96	.002	.009	.013	.030	.037	.062	.071	.099	.108	.135
98	.001	.007	.011	.027	.034	.058	.067	.094	.103	.130
100	.001	.006	.010	.025	.031	.054	.063	.089	.098	.125
102	.001	.006	.009	.023	.029	.051	.059	.085	.094	.121
104	.001	.005	.008	.021	.026	.048	.055	.081	.090	.116
106	.001	.004	.007	.019	.024	.044	.052	.077	.085	.111
108	.000	.003	.006	.017	.022	.041	.049	.073	.081	.107
110		.003	.005	.015	.020	.039	.046	.069	.077	.103
112		.003	.004	.014	.018	.036	.043	.066	.074	.099
114		.002	.004	.012	.017	.033	.040	.062	.070	.095
116		.002	.003	.011	.015	.031	.037	.059	.067	.091
118		.001	.003	.010	.014	.029	.035	.056	.063	.087
120		.001	.002	.009	.012	.027	.032	.053	.060	.083
122		.001	.002	.008	.011	.025	.030	.050	.057	.080
124		.001	.002	.007	.010	.023	.028	.047	.054	.076
126		.001	.001	.006	.009	.021	.026	.044	.051	.073
128		.001	.001	.006	.008	.019	.024	.042	.048	.070
130		.000	.001	.005	.007	.018	.023	.039	.046	.067
132			.001	.004	.007	.016	.021	.037	.043	.064
134			.001	.004	.006	.015	.019	.035	.041	.061
136			.001	.003	.005	.014	.018	.033	.039	.058
138			.000	.003	.005	.013	.017	.031	.037	.055

Table A21. (continued)

S	n = 21	24	25	28	29	32	33	36	37	40
140				.003	.004	.012	.015	.029	.034	.053
142				.002	.004	.011	.014	.027	.032	.050
144				.002	.003	.010	.013	.025	.031	.048
146				.002	.003	.009	.012	.024	.029	.046
148				.002	.003	.008	.011	.022	.027	.043
150				.001	.002	.007	.010	.021	.025	.041
152				.001	.002	.007	.009	.020	.024	.039
154				.001	.002	.006	.008	.018	.022	.037
156				.001	.002	.006	.008	.017	.021	.035
158				.001	.001	.005	.007	.016	.020	.034
160				.001	.001	.005	.006	.015	.018	.032
162				.001	.001	.004	.006	.014	.017	.030
164				.000	.001	.004	.005	.013	.016	.029
166					.001	.003	.005	.012	.015	.027
168					.001	.003	.004	.011	.014	.026
170					.001	.003	.004	.010	.013	.024
172					.001	.002	.004	.010	.012	.023
174					.000	.002	.003	.009	.011	.022
176						.002	.003	.008	.011	.020
178						.002	.003	.008	.010	.019
180						.002	.002	.007	.009	.018
182						.001	.002	.006	.009	.017
184						.001	.002	.006	.008	.016
186						.001	.002	.006	.007	.015
188						.001	.002	.005	.007	.014
190						.001	.001	.005	.006	.014
192						.001	.001	.004	.006	.013
194						.001	.001	.004	.005	.012
196						.001	.001	.004	.005	.011
198						.001	.001	.003	.005	.011
200						.000	.001	.003	.004	.010
202							.001	.003	.004	.009
204							.001	.003	.004	.009
206							.001	.002	.003	.008
208							.001	.002	.003	.008
210							.000	.002	.003	.007
212								.002	.003	.007
214								.002	.002	.006
216								.001	.002	.006
218								.001	.002	.005
220								.001	.002	.005
222								.001	.002	.005
224								.001	.002	.004
226								.001	.001	.004
228								.001	.001	.004
230								.001	.001	.004
232								.001	.001	.003
234								.001	.001	.003
236								.001	.001	.003
238								.000	.001	.003
240									.001	.002
242									.001	.002
244									.001	.002
246									.001	.002
248									.000	.002
250										.002
252										.002
254										.001
256										.001
258										.001
260										.001
262										.001
264										.001
266										.001
268										.001
270										.001
272										.001
274										.001
276										.001
278										.001
280										.000

Table A21. (continued)

S	n = 23	26	27	30	31	34	35	38	39
1	.500	.500	.500	.500	.500	.500	.500	.500	.500
3	.479	.483	.484	.486	.487	.488	.489	.490	.490
5	.458	.465	.467	.472	.473	.477	.478	.480	.481
7	.438	.448	.451	.458	.460	.465	.466	.470	.472
9	.417	.431	.434	.444	.446	.453	.455	.460	.462
11	.397	.414	.418	.430	.433	.442	.444	.450	.452
13	.377	.397	.402	.416	.420	.430	.433	.440	.443
15	.357	.380	.386	.402	.407	.418	.422	.431	.433
17	.338	.363	.371	.389	.394	.407	.411	.421	.424
19	.319	.347	.355	.375	.381	.396	.400	.411	.414
21	.301	.331	.340	.362	.368	.384	.389	.401	.405
23	.283	.316	.325	.349	.355	.373	.378	.392	.396
25	.265	.300	.310	.336	.343	.362	.368	.382	.387
27	.248	.285	.296	.323	.331	.351	.357	.373	.377
29	.232	.270	.281	.310	.318	.340	.347	.363	.368
31	.216	.256	.268	.298	.306	.329	.336	.354	.359
33	.201	.242	.254	.286	.295	.319	.326	.345	.350
35	.187	.229	.241	.274	.283	.308	.316	.336	.341
37	.173	.216	.228	.262	.272	.298	.306	.327	.333
39	.160	.203	.216	.251	.261	.288	.296	.318	.324
41	.147	.191	.204	.239	.250	.278	.286	.309	.315
43	.135	.179	.192	.228	.239	.268	.277	.300	.307
45	.124	.168	.181	.218	.229	.259	.267	.291	.298
47	.114	.157	.170	.208	.219	.249	.258	.283	.290
49	.104	.147	.160	.198	.209	.240	.249	.274	.282
51	.094	.137	.150	.188	.199	.231	.240	.266	.274
53	.086	.127	.141	.178	.190	.222	.232	.258	.266
55	.078	.118	.132	.169	.181	.213	.223	.250	.258
57	.070	.110	.123	.160	.172	.205	.215	.242	.250
59	.063	.102	.115	.152	.164	.196	.206	.234	.243
61	.057	.094	.107	.144	.155	.188	.198	.227	.235
63	.051	.087	.099	.136	.147	.180	.191	.219	.228
65	.046	.080	.092	.128	.140	.173	.183	.212	.221
67	.041	.073	.085	.121	.132	.165	.176	.205	.214
69	.036	.067	.079	.114	.125	.158	.168	.198	.207
71	.032	.062	.073	.107	.118	.151	.161	.191	.200
73	.028	.057	.067	.100	.112	.144	.154	.184	.193
75	.025	.052	.062	.094	.105	.137	.148	.177	.187
77	.022	.047	.057	.088	.099	.131	.141	.171	.180
79	.019	.043	.052	.083	.093	.125	.135	.165	.174
81	.017	.039	.048	.077	.088	.119	.129	.158	.168
83	.015	.035	.044	.072	.082	.113	.123	.152	.162
85	.013	.032	.040	.067	.077	.107	.117	.147	.156
87	.011	.029	.036	.063	.072	.102	.112	.141	.150
89	.009	.026	.033	.059	.068	.097	.107	.135	.145
91	.008	.023	.030	.054	.063	.092	.101	.130	.139
93	.007	.021	.027	.051	.059	.087	.096	.125	.134
95	.006	.019	.025	.047	.055	.082	.092	.120	.129
97	.005	.017	.022	.043	.052	.078	.087	.115	.124
99	.004	.015	.020	.040	.048	.074	.083	.110	.119
101	.004	.013	.018	.037	.045	.070	.078	.105	.114
103	.003	.012	.016	.034	.041	.066	.074	.101	.109
105	.003	.010	.015	.032	.038	.062	.070	.096	.105
107	.002	.009	.013	.029	.036	.058	.066	.092	.101
109	.002	.008	.012	.027	.033	.055	.063	.088	.096
111	.001	.007	.010	.025	.031	.052	.059	.084	.092
113	.001	.006	.009	.023	.028	.049	.056	.080	.088
115	.001	.005	.008	.021	.026	.046	.053	.076	.084
117	.001	.005	.007	.019	.024	.043	.050	.073	.081
119	.001	.004	.006	.017	.022	.040	.047	.069	.077
121	.000	.004	.006	.016	.020	.038	.044	.066	.074
123		.003	.005	.014	.019	.035	.042	.063	.070
125		.003	.004	.013	.017	.033	.039	.060	.067
127		.002	.004	.012	.016	.031	.037	.057	.064
129		.002	.003	.011	.014	.029	.034	.054	.061
131		.002	.003	.010	.013	.027	.032	.051	.058
133		.001	.003	.009	.012	.025	.030	.049	.055
135		.001	.002	.008	.011	.023	.028	.046	.053

Table A21. (continued)

S	n = 23	26	27	30	31	34	35	38	39
137		.001	.002	.007	.010	.022	.026	.044	.050
139		.001	.002	.006	.009	.020	.025	.041	.048
141		.001	.001	.006	.008	.019	.023	.039	.045
143		.001	.001	.005	.007	.017	.022	.037	.043
145		.001	.001	.005	.007	.016	.020	.035	.041
147		.000	.001	.004	.006	.015	.019	.033	.039
149			.001	.004	.006	.014	.017	.031	.037
151			.001	.003	.005	.013	.016	.029	.035
153			.001	.003	.004	.012	.015	.028	.033
155			.000	.003	.004	.011	.014	.026	.031
157				.002	.004	.010	.013	.025	.029
159				.002	.003	.009	.012	.023	.028
161				.002	.003	.008	.011	.022	.026
163				.002	.003	.008	.010	.021	.025
165				.001	.002	.007	.010	.019	.023
167				.001	.002	.007	.009	.018	.022
169				.001	.002	.006	.008	.017	.021
171				.001	.002	.005	.007	.016	.020
173				.001	.001	.005	.007	.015	.018
175				.001	.001	.005	.006	.014	.017
177				.001	.001	.004	.006	.013	.016
179				.001	.001	.004	.005	.012	.015
181				.000	.001	.003	.005	.011	.014
183					.001	.003	.005	.011	.014
185					.001	.003	.004	.010	.013
187					.001	.003	.004	.009	.012
189					.001	.002	.003	.009	.011
191					.000	.002	.003	.008	.010
193						.002	.003	.008	.010
195						.002	.003	.007	.009
197						.002	.002	.007	.009
199						.001	.002	.006	.008
201						.001	.002	.006	.007
203						.001	.002	.005	.007
205						.001	.002	.005	.006
207						.001	.001	.004	.006
209						.001	.001	.004	.006
211						.001	.001	.004	.005
213						.001	.001	.004	.005
215						.001	.001	.003	.004
217						.001	.001	.003	.004
219						.000	.001	.003	.004
221							.001	.003	.004
223							.001	.002	.003
225							.001	.002	.003
227							.001	.002	.003
229							.000	.002	.003
231								.002	.002
233								.002	.002
235								.001	.002
237								.001	.002
239								.001	.002
241								.001	.002
243								.001	.001
245								.001	.001
247								.001	.001
249								.001	.001
251								.001	.001
253								.001	.001
255								.001	.001
257								.001	.001
259								.000	.001
261									.001
263									.001
265									.001
267									.001
269									.000

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