TA50

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GROUND WATER DISCHARGE PLAN APPLICATION

for the

TA-50 Radioactive Liquid Waste Treatment Facility

Prepared By
Los Alamos National Laboratory

August 16, 1996

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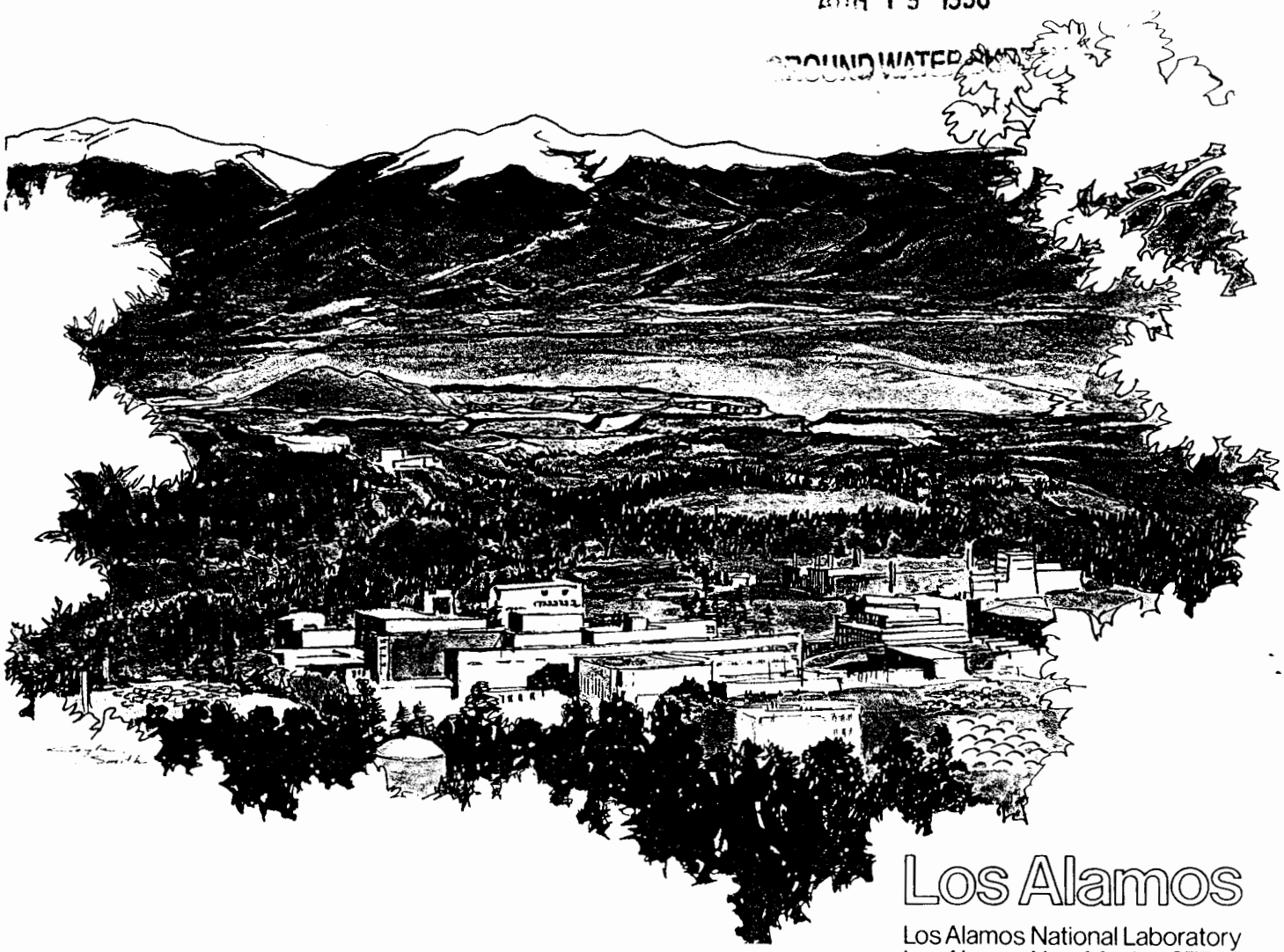
GROUNDWATER



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REFERENCES

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Executive Summary

This Ground Water Discharge Plan Application is being submitted in response to the New Mexico Environment Department's (NMED) letter of April 3, 1996, in which a discharge plan was requested for the discharge of nitrates and other non-NPDES contaminants from Los Alamos National Laboratory's (LANL) Radioactive Liquid Waste Treatment Facility (RLWTF) at Technical Area (TA)-50 (See Map 1.0). Treated effluent from the RLWTF is discharged into Mortandad Canyon at NPDES Outfall 051 (See Appendix B for information on Outfall 051).

The RLWTF was constructed in 1963 and since that time has been in continuous operation. Figures 1.0 and 1.2 present a site plan and aerial photograph of the RLWTF, respectively. The treatment technologies currently used include chemical flocculation, precipitate settling, filtration, and solidification via cementation. The solidified waste is transferred from TA-50 to TA-54, Area G, for storage and disposal. In 1993 the RLWTF initiated a comprehensive program to non-destructively test (NDT) all process tanks and refurbish or replace, as appropriate. In April, 1992, the Laboratory initiated a Best Available Technology (BAT) evaluation to identify technologies necessary to ensure compliance with Department of Energy (DOE) Order 5400.5, "Radiation Protection of the Public and the Environment". Based upon the BAT evaluation, the RLWTF developed a two-phased plan to upgrade treatment processes; The basic configuration proposed is for an ultrafiltration (TUF) step followed by reverse osmosis (RO) in Phase I and nitrate removal in Phase II. The completion dates for Phase I and II upgrades are June 30, 1997, and January 31, 1998, respectively.

Nitrate (NO3-N) and fluoride (F) concentrations in Mortandad Canyon's alluvial ground water presently exceed WQCC ground water standards but current trends are downward. Cyanide (CN) and total dissolved solids (TDS) have, on occasion, been discharged by the RLWTF at concentrations greater than WQCC ground water standards but recent (1990-1995) monitoring data does not show elevated concentrations in the alluvial ground water. Research by Purtymun (1977) indicates that once the concentrations of nitrates (NO3-N) and fluorides (F) in the effluent are reduced then concentrations of those contaminants in the alluvial ground water will naturally decline due to the relatively rapid turn-over of water and chemicals in storage.

The Laboratory is proposing to implement the following corrective actions for this Ground Water Discharge Plan Application: First, RLWTF treatment processes will be upgraded during Phase I and II to enable the treated effluent to meet or exceed WQCC ground water standards for nitrate (NO3-N) and fluoride; and Second, using a network of six ground water monitoring wells the Laboratory will closely monitor the quality of Mortandad Canyon's alluvial ground water to demonstrate that the improvements in water quality are consistent with the NMWQCC standards.

MAP 1.0

TA-50 RLW Treatment Facility Ground Water Discharge Plan

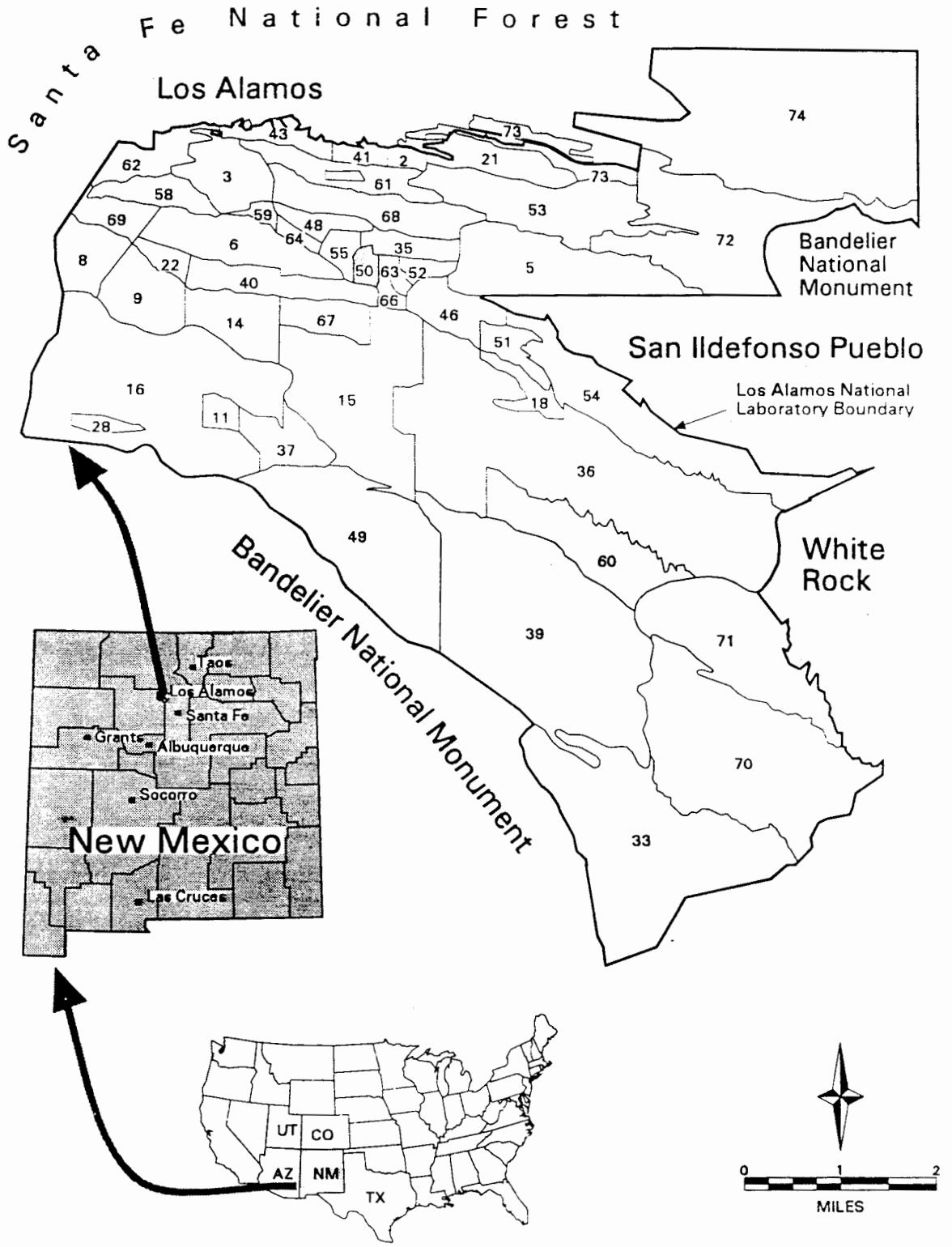

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FIGURE 1.0

TA-50 RLW Treatment Facility Ground Water Discharge Plan - Site Plan

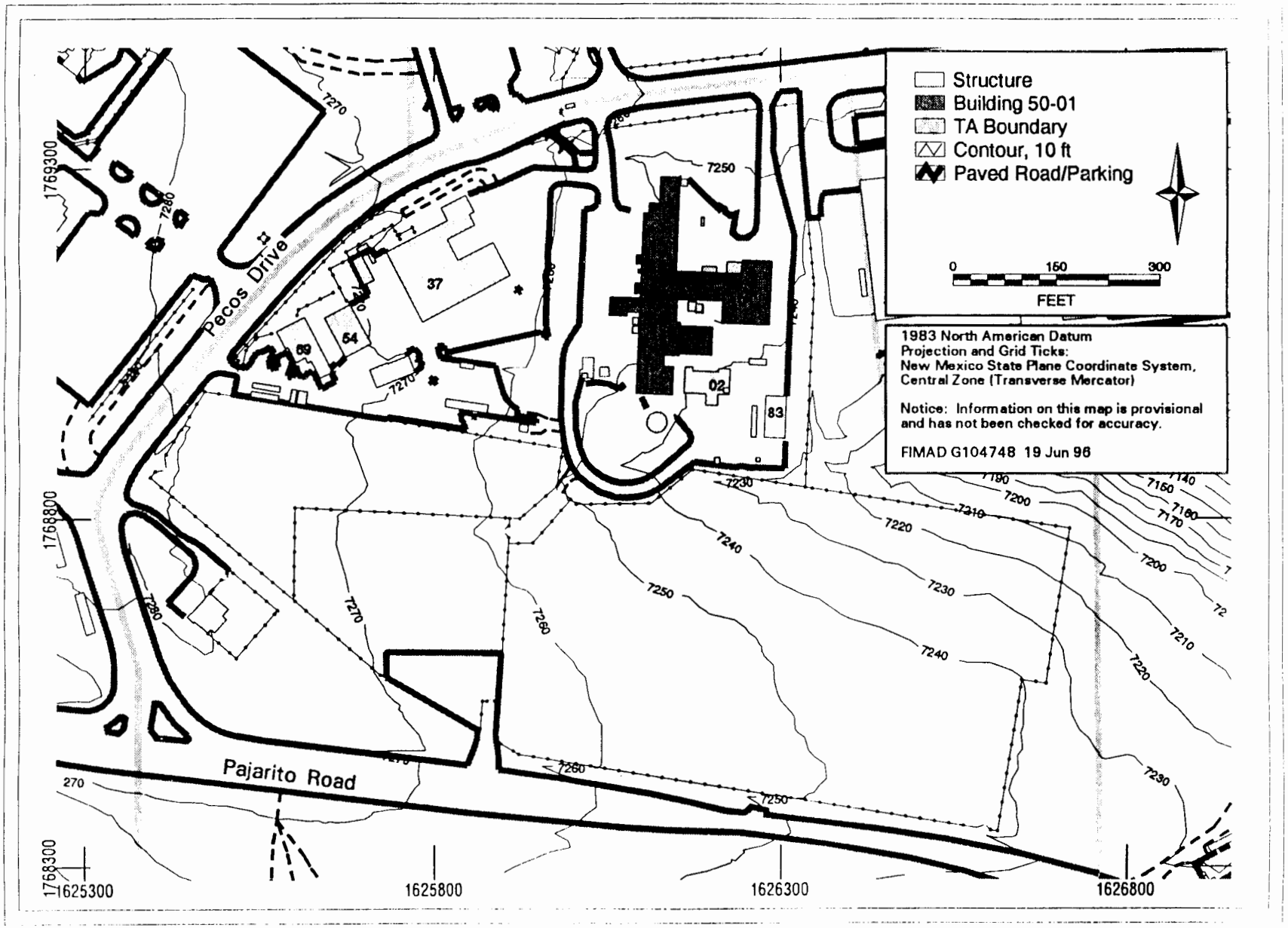

FIGURE 1.1

PART A

Name of Facility:

TA-50 Radioactive Liquid Waste Treatment Facility
Los Alamos National Laboratory
Los Alamos, New Mexico

Name of Persons Responsible for Discharge:

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1. Location of Discharge Site:

- **County:** Los Alamos
- **Latitude/Longitude of Discharge Point:**

  Latitude: 35° 51' 58.3"

  Longitude: 106° 17' 48.5"
- **Vicinity Map**: See Map 1.0
- **Distance to Los Alamos in Miles**: Approx. 1.0 mile to the LA Townsite

2. Type of Operation, Facility or Development:

Wastewater plant for the treatment of low-level, radioactive liquid waste.

3. **Current and Proposed Method(s) of Treatment, Storage, and Disposal of Effluent.**

A. Current Collection, Process, and Monitoring Systems

Collection System

Liquid waste is conveyed to the RLWTF via a gravity flow pipeline termed the collection system (See Map 2.0). The main pipeline branches to approximately six technical areas, and is eventually connected to sinks and drains within those facilities. The RLWTF is responsible for the collection system up to the first manhole leading up to the facility it serves, as well as some required instrumentation for process tankage within the confines of those facilities. The collection system was replaced in 1984 with a double encased polyethylene pipe to meet waste compatibility and secondary containment issues.

The collection system is continuously monitored for breach of containment and consists of conductivity monitors strategically located within manholes along the collection system. These monitors are designed to alarm at the presence of liquid and to date, no breach of containment has been detected. The monitors alarm the RLWTF operators as well as the utilities Central Alarm Station which is manned 24 hours a day.

Process Tanks

In 1993, the RLWTF initiated a Non-Destructive Testing (NDT) Program to demonstrate the integrity of the facility's process tanks. While all tanks in use were found to be corrosion free, tank upgrades were initiated by the RLWTF to establish secondary containment and leak detection or inspectability. A summary of tank upgrades is presented below and in Table 1.0.

• Influent Tanks:

(1) TA-50-2 WM-2 Tank Farm: Four (4) new 20,000 gallon carbon steel above ground tanks with secondary containment and leak detection are currently being installed. Construction is scheduled for completion in December, 1996. These tanks will replace the existing below ground, single-walled, 75,000 gallon influent tank.

(2) TA-50-2 WM-2: A new 20,000 gallon carbon steel double-wall tank is currently being installed inside of the existing concrete tank. The presence of the existing concrete tank will provide an effective tertiary containment barrier and allow for visual inspection. This project is scheduled for completion in October, 1996.

(3) TA-50-66 Process Tank: In 1994 the existing tank was replaced with a new 5,000 gallon stainless steel tank. Secondary containment for this tank is provided by a concrete vault with a chemical resistant lining. This tank is used for accumulating process waste that requires pretreatment.

• Treatment Vessels:

(1) TA-50-01 Clarifiers: Currently, the primary treatment vessels of the RLWTF are two, 25,000 gallon, concrete tanks with steel flocculator chambers. In 1994, both vessels were scheduled for non-destructive testing and revitalization through descaling, surface preparation, and re-coating with an epoxy liner. Non-Destructive Testing (NDT) of the clarifiers showed that the concrete walls and reinforcing steel was sound and corrosion-free. One clarifier has completed the revitalization process and the second is currently in progress.

Treatment System

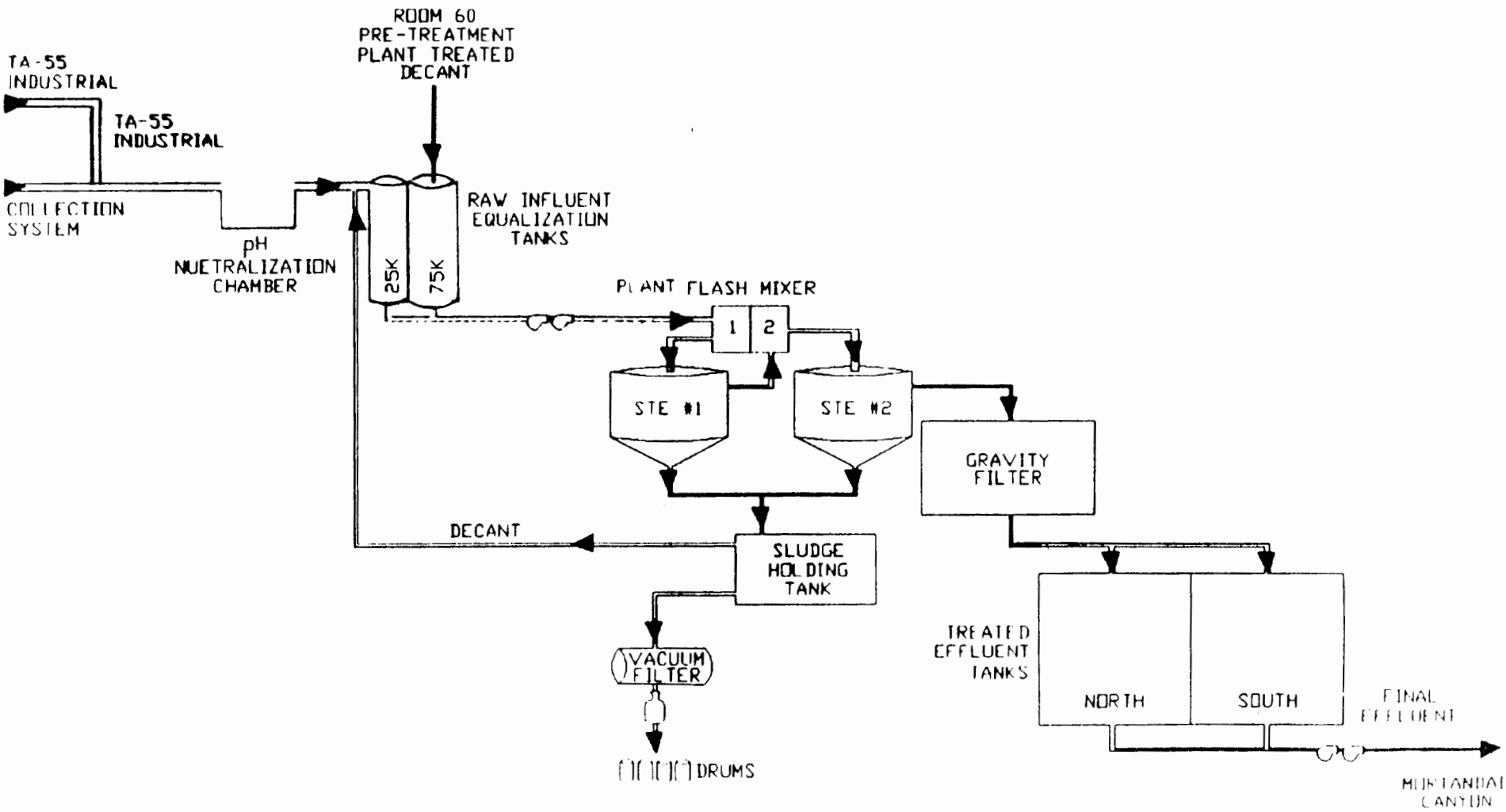
As illustrated in Figure 2.0, RLWTF Current Treatment Processes, liquid waste is first collected in influent tanks to provide storage capacity before batch treatment in a single shift, eight hour per day operation. During operation, waste is pumped to the chemical feeders where ferric sulfate and lime are added to form a ferric hydroxide flocculant. Floc particles containing radionuclides settle by gravity to the bottom of the clarifier to form a sludge layer and the supernatant flows over the weir at the top of the clariflocculator. The sludge is transferred to a sludge holding tank in preparation for filtration which is accomplished by a rotary vacuum filter. The filter cake resulting from this operation then consists of the separated Low Level Waste that is drummed and disposed of at TA-54, Area G. Supernatant, decanted from the top of the sludge holding tanks, and filtrate, from the rotary vacuum filter, are recycled to the influent holding tanks.

The clarifier supernatant is passed through an anthracite gravity filter to remove any unsettled floc. Carbon dioxide is bubbled through the gravity filter plenum to lower the pH to below 9 and to reduce scale formation resulting from clarifier operations. The filtered effluent is then collected in effluent holding tanks where pH, and gross radioactivity measurements are performed. The contents of the tank are then discharged through NPDES Outfall 051 to Mortandad Canyon.

Waste Acceptance Criteria and Administrative Controls

An integral part of the RLWTF's operations is LANLs program for administratively controlling influent quality. Each group or division that generates radioactive liquid waste is represented by a Waste Management Coordinator. At some sites, one person may represent several groups. The Waste Management Coordinator, the primary contact between generators and the RLWTF, has the authority to implement administrative controls for the group or division represented.

Figure 2.0 RLWTF CURRENT TREATMENT PROCESSES



The Waste Management Coordinator must ensure that:

- Waste streams not identified and listed under the Laboratory's National Pollution Discharge Elimination System (NPDES) permit are not discharged into the RLWTF's collection system;
- Operating personnel are familiar with pertinent administrative requirements, and waste management regulations;
- The radioactivity level of liquid waste is kept to a minimum and does not exceed the recommended limits as set forth in the RLWTF's Waste Acceptance Criteria (WAC). A copy of the RLWTF's WAC has been included in Appendix C;
- Listed hazardous wastes as defined by the Resource Conservation and Recovery Act (RCRA) and PCB wastes subject to regulation under the Toxic Substances Control Act (TSCA) are not discharged into the radioactive liquid waste collection system;
- The RLWTF is notified immediately of unusual or accidental discharges that may violate waste management regulations so that it may take corrective actions; and
- The RLWTF is contacted to coordinate disposal of radioactive liquid waste that does not meet requirements for discharge to the radioactive liquid waste collection system.

Collection System Monitoring

The RLWTF utilizes a microprocessor-based control system to monitor: Flows in the RLW collection system; Process tank levels; and Discharge volumes into the collection system at each of the primary waste generator sites. Alarms are received at both the RLWTF and at the continuously-manned Utilities Control Center. Control Center personnel call key RLWTF personnel at home if an alarm condition occurs during off-hours.

B. Proposed Treatment System Upgrades

Introduction

In order to meet the Derived Concentration Guidelines (DCGs) established by Department of Energy (DOE) Order 5400.5 and NMWQCC ground water standards, the RLWTF needs to upgrade current treatment processes. The RLWTF has begun implementation of a two-phased plan to meet: (1) DCGs and WQCC ground water standards for fluoride (F) in Phase I; and (2) the WQCC ground water standard for nitrate (NO3-N) in Phase II. The discussion which follows presents a description of the proposed Phase I and II treatment process upgrades at the RLWTF.

Phase I Treatment System Upgrades to the RLWTF

RLWTF personnel have completed engineering and pilot testing of the technologies available for Phase I treatment process upgrades. Based upon successful testing, RLWTF personnel have selected Tubular Ultrafiltration (TUF) followed by Reverse Osmosis (RO) as the preferred treatment process upgrade for Phase I. These process upgrades will enable the RLWTF to:

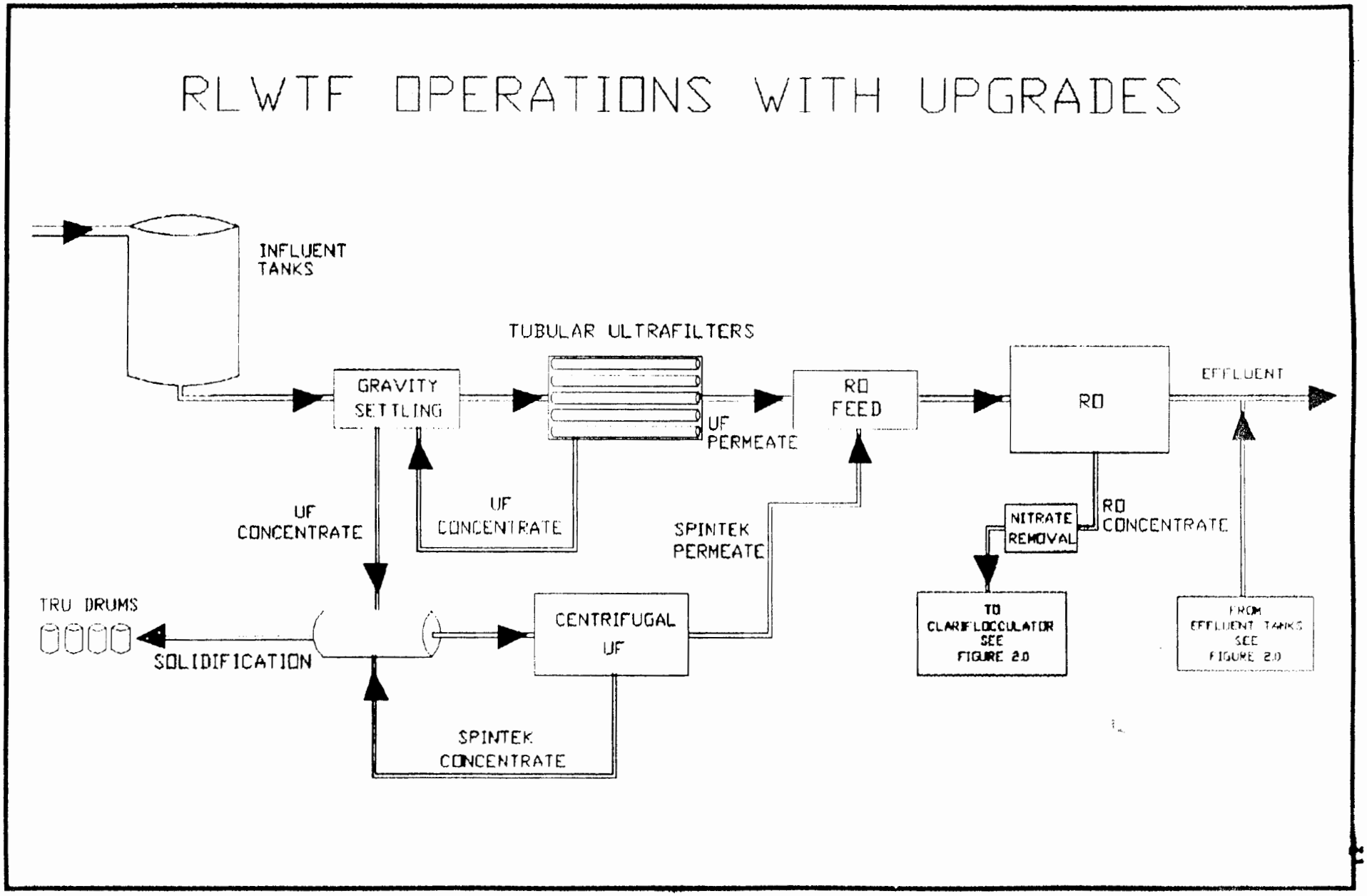
- Ensure that treated effluent is discharged below the Derived Concentration Guidelines (DCGs) for radionuclides set forth in DOE Order 5400.5, "Radiation Protection of the Public and the Environment";
- Reduce fluoride concentrations in the treated effluent by reducing its source, the food grade lime used during flocculation; and
- Concentrate nitrates in the wastestream for removal under Phase II.

TUF provides enhanced effluent quality by removing suspended solids and separating the majority of radioactivity from the waste stream. It provides effluent free of suspended solids to allow efficient operation of the RO which follows. Filtration capabilities of RO operate at the molecular level rejecting dissolved solids from the waste stream at greater than 96% rejection rates. The use of RO has been widely demonstrated in industry and municipalities when high purity product water is a requirement.

Figure 2.1 presents the RLWTF treatment process after implementation of the Phase I process upgrades: TUF and RO. The RO unit is the final treatment process prior to discharge and the RO membrane is expected to reject all constituents at the concentrations set forth in the WQCC ground water standards. The reject, or concentrate stream from the RO unit will be diverted to the clarifier for further radionuclide removal and subsequent blending back into the RLWTF effluent stream.

In March, 1996, LANL's Waste Management Program Office contracted with an independent industry consultant to evaluate the treatment options most appropriate for the RLWTF. The consultant's assessment was that the basic TUF and RO process configuration proposed by the RLWTF for Phase I was sound and should meet the design basis performance objectives.

FIGURE 2.1


RLWTF OPERATIONS WITH UPGRADES
INFLUENT TANKS
TUBULAR ULTRAFILTERS
GRAVITY SETTLING
UF PERMEATE
RO FEED
RO
EFFLUENT
UF CONCENTRATE
UF CONCENTRATE
SPINTEK PERMEATE
NITRATE REMOVAL
RO CONCENTRATE
TRU DRUMS
SOLIDIFICATION
CENTRIFUGAL UF
TO CLARIFLOCCULATOR SEE FIGURE 2.0
FROM EFFLUENT TANKS SEE FIGURE 2.0
SPINTEK CONCENTRATE

Phase II Treatment System Upgrades at the RLWTF

The objective of Phase II upgrades is to remove nitrates in the RO reject stream to below WQCC ground water standards. The RLWTF and an independent industry consultant conducted separate assessments of the best technologies available for nitrate removal and determined that three treatment processes warrant further study:

(1) Evaporation. Evaporation through the use of a low-temperature evaporator or other system will be evaluated through pilot testing on surrogate waste;

(2) Biological Denitrification. To evaluate biological denitrification, a pilot scale reactor vessel is currently being fabricated to be used for simulation of full scale operation. This vessel and associated hardware will be used to determine the operational parameters of this system; and

(3) Selective Ion Exchange. The RLWTF has procured the hardware to begin pilot work to evaluate selective ion exchange for nitrate removal. Currently, RLWTF personnel are in contact with vendors for this type of resin.

Parallel engineering evaluations of these three options will produce the engineering data necessary to select the system that is most applicable to the RLWTF's waste stream. Additional criteria to be evaluated are the volume and disposal form of secondary wastes, the overall cost and operability of the process, and safety to operating personnel. A schedule for implementation of Phase II upgrades has been presented in Table 1.0. Installation and test-out of Phase II equipment will be completed by January 31, 1998.

If preliminary results of pilot testing of the Biological Denitrification Process or the Selective Ion Exchange Process indicates that one of these options exhibits satisfactory contaminant removal and operational performance, the DOE and Laboratory will determine the feasibility of scale-up and subsequent installation and start-up of an interim treatment unit prior to completion of the final evaluation of all three processes. Determination of satisfactory contaminant removal and operational performance for interim use will be made by DOE and the Laboratory in coordination with NMED.

Table 1.0. Summary of Completed, In Progress, and Proposed Upgrades to the RLWTF.

Plant Integrity Upgrades	Start Date	Completion Date
• Eliminate Influent from the Solids Section of the Grit Chamber.	August, 1990	September, 1990
• Install New Neutralization Chamber & Monitoring Station to Eliminate Grit Chamber Function.	August, 1990	August, 1993
• Install New Collection Lines from TA-55 to TA-50.	August, 1990	June, 1995
• Replace WM-66 Acid Tank with New SS Tank.	January, 1994	August, 1994
• Non-Destructive Testing of All Concrete Tanks.	June, 1994	December, 1994
• Non-Destructive Testing of all Steel Tanks.	May, 1993	September, 1993
• Refurbish Clarifiers (2).	August, 1995	October, 1996
• Install New Influent Tank Farm.	Dec., 1993	December, 1996
• Video Inspect Pipelines & Pressure Test Equipment.	April, 1995	On-Going
Phase I Process Upgrades: TUF and RO	**Start Date**	**End Date**
• BAT Evaluation Conducted per DOE Order 5400.5.	April, 1992	May, 1995
• Engineering of Phase I Upgrades.	February, 1994	June, 1996
• Procurement, Installation, and Start-Up.	May, 1996	March, 1997
• Test-Out Period.	March, 1997	June, 1997
• Phase I Fully Operational.	----	June, 1997
Phase II Process Upgrades: Nitrate Removal	**Start Date**	**End Date**
• BAT Evaluation Conducted.	April, 1992	May, 1995
• Parallel Evaluation of Available Technologies by RLWTF and an Independent Consultant.	March, 1996	June, 1996
• NEPA Review of Process Upgrades.	February, 1996	September, 1996
• Parallel Engineering of 3 Options.	July, 1996	June, 1997
• Parallel Pilot Testing of 3 Options:		
1) Evaporation.	October, 1996	May, 1997
2) Biological Denitrification.	October, 1996	April, 1997
3) Selective Ion Exchange.	October, 1996	March, 1997
• Evaluation of Pilot Testing.	May, 1997	June, 1997
• Selection of Nitrate Removal Process.	June, 1997	July, 1997
• Procurement of Equipment, Installation and Start-Up.	July, 1997	January, 1998
• Phase II Upgrades Fully Operational.	----	January, 1998

B. Proposed Treatment System Upgrades (Continued)

Nitric Acid Recovery System (NARS) at TA-55

In addition to process upgrades at the RLWTF, the Laboratory is also initiating source reduction of nitrates as a means of enhancing treatment process efficiency. TA-55, the major source of nitrates in the RLWTF influent, will install a Nitric Acid Recovery System (NARS) which is capable of recycling the nitric acid used in plutonium stabilization operations. The system will process 1 Liter per minute (L/min) of 2 M to 5 M solution drawn from the existing nitric acid storage tanks and generate a product stream of 45 parts per million (ppm) nitric acid for discharge to the RLWTF. NARS is scheduled for completion in June, 1998, although efforts are being made to accelerate implementation of this system.

4. **Quantity of Discharge:**

There are 20,885 gallons of effluent per each effluent tank batch discharged. Typically, the RLWTF discharges 0, 1, or 2 tanks of treated effluent on a run day resulting in daily discharge volumes of 0 gallons per day (gpd), 20,885 gpd or 41,770 gpd, respectively. Discharges only occur on days when the plant is in operation, typically 4 to 6 days per week. During a typical operating week the RLWTF discharges between 2 and 8 tanks of treated effluent. The large variability in discharge quantities is due to fluctuations in influent flow. Based on these figures, it can be estimated that the RLWTF will discharge between 104 and 416 times during a year, or between 2.17 million gallons (MG) per year and 8.69 MG per year. In 1994, the RLWTF discharged 5.506 MG to NPDES Outfall 051. Reference: Appendix D. RLWTF Annual Report for 1994.

5. **Method Used to Meter or Calculate the Discharge Rate:**

Effluent is stored in two identical effluent tanks which overflow into each other. During the treatment process, an effluent tank will be filled until it overflows into the adjoining effluent tank. At this point the tank is considered full. As an effluent tank is discharged, the discharge pumps shut off automatically when the water in the tank has dropped to a set level. In this way the volume of water discharged from either tank will always be the same (20,885 gallons). Tank volume is verified periodically by filling the tank to its on/off control point using a metered source of industrial water.

6. Flow Characteristics:

The discharge pump produces an average flow rate of 720 gallons per minute when operating. The flow of treated effluent discharged at the NPDES Outfall is intermittent due to the RLWTF's method of discharging in batches.

7. **Discharge Quality.**

Since the existing RLWTF treatment process was designed in the early 1960's for radionuclide removal, the facility's current effluent quality does not routinely meet all of the WQCC ground water standards. NPDES compliance and RLWTF operational data, summarized in Tables 1.1 and 1.2, respectively, shows that the RLWTF's treated effluent has consistently exceeded WQCC ground water standards for fluoride (F) and nitrate (NO3-N), and occasionally exceeded the standards for cyanide (CN) and total dissolved solids (TDS). See Appendix D for the complete data record for 1994 for RLWTF operational monitoring of treated effluent.

8. **Location of Water Supply and Injection Wells.**

Map 3.0 shows that no water supply wells or injection wells are located within 1 mile of the RLWTF discharge point (NPDES Outfall 051)

9. **Location of Seeps, Springs, Bodies of Water or Water Courses.**

All seeps, springs, bodies of water, and water courses are presented on Map 3.0.

10. **Location of Monitor Wells**

Monitoring of the Mortandad Canyon alluvial ground water will be conducted through an existing network of six (6) monitoring wells constructed during the period 1960 through 1974. Tables 2.0 and 2.1 present the coordinates, elevations, construction and completion dates, and completion depths for these wells. Map 4.0 illustrates the location of the monitoring wells in Mortandad Canyon.

One of the monitoring wells selected for the Monitoring Plan, MCO-3, has been out-of-service since 1993 due to erosion around the well casing. While it is expected that repairs can be made and the well will be brought back into service, as a contingency plan the Laboratory proposes to substitute a surface water sampling station, GS-1, if MCO-3 is unavailable for sampling. GS-1 is an appropriate substitute for MCO-3 because the alluvium in that reach of Mortandad Canyon is very thin (7 ft. at MCO-3), thus creating a intimate relationship between surface and ground water, i.e. the quality of water at MCO-3 closely mirrors the quality at GS-1.

CONSTITUENT	1994 AVERAGE	1994 MAX	1994 MIN	1995 AVERAGE	1995 MAX	1995 MIN	1996 AVERAGE	1996 MAX	1996 MIN	WQCC 3103. STANDARDS
CADMIUM	0.00062	0.005	<0.0001	0.0004	0.002	<0.0001	0.0009	0.003	0.0001	0.01
CHROMIUM	0.0047	0.024	<0.0004	0.007	0.044	<0.001	0.0111	0.035	<0.005	0.05
COPPER	0.10	0.22	0.03	0.11	0.4	0.043	0.12	0.28	0.04	1
IRON	0.12	0.5	0.02	0.2	3.4	0.03	0.09	0.17	0.03	1
MERCURY	0.0003	0.0006	0.0001	0.0004	0.002	0.00004	0.001	0.0111	<0.0002	0.002
NICKEL	0.037	0.092	<0.015	0.038	0.095	<0.015	0.025	0.055	0.014	0.2
LEAD	0.004	0.02	<0.002	0.004	0.018	<0.002	0.014	<0.046	0.002	0.05
pH	6.51	6.84	6.3	6.76	7.7	6.1	7.1	7.6	6.5	6 TO 9
ZINC	0.048	0.19	<0.005	0.046	0.15	0.011	0.05	0.17	0.02	10
Total Toxic Organics		0.014	U		U	U		0.34	U	NA
Ra 226&228 (pCi/L)	3.09	10.38	<ldl	6.39	11.7	<ldl	4.75	8.4	<ldl	30 pCi/L
TKN	5.6	6.4	4.8	7.24	9.95	2.7	8.38	12.27	3	NA
NH3-N	5.8	12	0.6	4.8	7.9	0.55	6.18	9.26	0.95	NA
NO3-N	41.7	90	23	34	58.3	13	131.3	239	32.3	10

Notes

TTO=Total Toxic Organics: See Appendix B for complete listing of compounds

U=No compounds detected above the laboratory's quantitation limit

ldl=laboratory detection limit

All units, excluding pH and Ra 226&228, are in mg/L

Table 1.1

NPDES Monitoring Data for Outfall 051
January, 1994 -- May, 1996

CONSTITUENT	1993 AVERAGE	1993 MAX	1993 MIN	1994 AVERAGE	1994 MAX	1994 MIN	1995 AVERAGE	1995 MAX	1995 MIN	WQCC 3103. STANDARDS
ALUMINUM				0.13	0.3	<ldl	0.11	0.4	<ldl	5.0
ARSENIC	0.002	0.0034	0.002	0.000	0.003	<ldl	0.001	0.0049	<ldl	0.1
BARIUM	0.016	0.054	0.005	0.013	0.018	0.009	0.023	0.065	0.007	1.0
BORON							0.17	0.29	0.11	0.75
CADMIUM	0.002	0.004	0.001	0.002	0.01	<ldl	<ldl	<ldl	<ldl	0.01
CHLORIDE	62	148	35	33	48	3	49	75	24	250
CHROMIUM	0.012	0.04	0.001	0.008	0.03	<ldl	0.007	0.04	<ldl	0.05
COBALT				0.002	0.01	<ldl	0.001	0.005	<ldl	0.05
COPPER	0.2	0.4	0.1	0.1	0.2	0.1	0.1	0.2	0.1	1.0
CYANIDE	0.2	0.4	0.03	0.1	0.1	0.02	0.1	0.25	0.01	0.2
FLUORIDE	2.9	4.9	1.3	1.9	3.3	1.1	2.6	6.7	1.7	1.6
IRON	0.3	0.7	0.1	0.2	0.6	0.04	0.2	0.4	<ldl	1.0
LEAD	0.04	0.37	0.001	0.004	0.024	<ldl	<ldl	<ldl	<ldl	0.05
MERCURY	0.0002	0.0004	0.0002	0.0002	0.0003	<ldl	0.0003	0.0004	<ldl	0.002
NICKEL	0.061	0.36	0.001	0.048	0.085	0.025	0.035	0.069	0.01	0.20
AMMONIA-N	6.07	8.6	4.87	5.50	9.2	2.2	5.284	7.8	2.05	NA
NITRATE-N	359.8	726.6	45.0	45.5	87.0	24.0	81.6	307.0	2.1	10.0
NITRITE-N	0.86	5.6	0.02	1.17	4.7	<ldl	0.63	1.84	0.11	NA
pH	7.2	7.6	6.81	7.2	7.4	6.7	7.2	8.5	6.8	6 TO 9
SELENIUM	0.002	0.0037	0.002	0.001	0.003	<ldl	0.0007	0.006	<ldl	0.05
SILVER	0.002	0.007	0.001	0.000	0.01	<ldl	0.003	0.028	<ldl	0.05
SULFATE	64	108	41	47	71	4	60	104	38	600
TDS	2659	4990	1100	842	1424	630	872	2692	290	1000
URANIUM	0.005	0.014	0.001	0.007	0.035	<ldl	0.005	0.008	<ldl	5.0
ZINC	0.137	0.2657	0.049	0.068	0.109	0.028	0.025	0.07	<ldl	10.0

Notes

All units, excluding pH, are in mg/L

ldl= Laboratory Detection Limit

Data Source: 1993,1994, and 1995 Annual Reports for the RLWTF at TA-50: by CST-13

Table 1.2

RLWTF Operational Monitoring of Treated Effluent
1993-1995

Table 2.0. Latitude/Longitude and Elevations for Monitor Wells in Mortandad Canyon

Observation Wells	Location		Elevation (ft)
	Longitude	Latitude	
MCO-3	106° 17' 38"	35° 51' 55"	7053
MCO-4	106° 16' 51"	35° 51' 50"	6900
MCO-5	106° 16' 36"	35° 51' 48"	6876
MCO6	106° 16' 22"	35° 51' 42"	6849
MCO-7	106° 16' 11"	35° 51' 38"	6827
MCO-7.5	106° 16' 00"	35° 51' 37"	6809

Reference: Purtymun, 1995

Table 2.1. Well Characteristics of Mortandad Canyon Observation Wells.

Well Name	Date Drilled	Date Completed	Depth Drilled (ft)	Depth Completed(ft)
MCO-3	3/67	3/67	18	12
MCO-4	10/63	10/63	24	19
MCO-5	10/60	10/60	47	46
MCO-6	10/60	3/74	82	47
MCO-7	10/60	10/60	77	69
MCO-7.5	11/61	4/74	60	60

Reference: Purtymun, 1995.

11. Ground Water Conditions.

a. Depth to Ground Water at the Discharge Site:

(1) The depth to the perched alluvial ground water in Mortandad Canyon varies temporally and with distance down the canyon. Depths to saturation typically are:

- Less than 1 ft. at the RLWTF Outfall, which is located at the confluence of Mortandad and Effluent Canyons;
- From 5 ft. to 22 ft. at MCO-4 in the upper reach of the canyon;
- From 30 ft. to 33 ft. at MCO-6 in the middle reach of the canyon and
- From 50 ft. to 60 ft. at MCO-8 in the lower reach of the canyon.

(2) Depth to the main aquifer at Mortandad Canyon Test Well No. 8, located near the middle of the canyon, is 968 ft.

b. Flow Direction of Ground Water Below the Site: Southeast

c. **Gradient of Ground Water Below the Site:**
The gradient of the saturated alluvium between MCO-3 and MCO-4, in the upper reach of the canyon below the RLWTF Outfall, is approximately 300 ft. per mile.

d. **Reference or Source of Information for 10. a, b, c, Above:**
Stoker et al. 1991. Extent of Saturation in Mortandad Canyon.

e. **Total Dissolved Solids(TDS) Concentration (mg/L) of the Ground Water:**
The TDS concentration of the perched alluvial ground water in Mortandad Canyon is 300-600 mg/L.

f. **Reference or Source of Information:**
Los Alamos National Laboratory Environmental Surveillance Report for 1993.

See Appendix E for a detailed description of the hydrologic setting of Mortandad Canyon.

Quality of Mortandad Canyon Alluvial Ground Water

Table 2.2 presents nitrate concentrations in Mortandad Canyon alluvial ground water from 1981 to 1995. A comparison of this data to the WQCC nitrate standard of 10 mg/L (as nitrogen) shows that while high concentrations of nitrates have been present as recently as 1994, the overall trend is downward. Purtymun (1977) determined that the loss of nitrates could be attributed to uptake by plants, adsorbtion onto alluvial material, and infiltration into underlying tuff (See Appendix E). In 1995, the average nitrate concentration among the seven wells sampled was 15 mg/L (as nitrogen). This downward trend is further illustrated in Figure 3.0. It is expected that this downward trend will become more pronounced once Phase II nitrate removal processes are operational.

Appendix F presents ground water quality data for six Mortandad Canyon alluvial monitoring wells from 1981 through 1995. Comparison of this data with the WQCC ground water standards shows that, beside nitrate, only one parameter, fluoride (F), has consistently exceeded ground water standards. Figure 3.1 illustrates the current downward trend in fluoride concentrations in the alluvial ground water. Once Phase I process upgrades are operational and the use of lime in the treatment process is reduced then more pronounced down-trending towards background conditions should be expected. Cyanide (CN) and TDS have been discharged by the RLWTF at concentrations greater than WQCC ground water standards but recent (1990-1995) monitoring data does not show elevated concentrations in the alluvial ground water.

STATION NAME	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	MAX	MIN	AVERAGE
MCO-3	217	59	29	25	15	4	42	9	111	13	5	23				217	4	46
MCO-4	145	60	75	104	56	90	38	123	107	52	35	58	66	17		145	17	73
MCO-4B															14			14
MCO-5	103	108	99	115	61	106	78	110	24	19	8	5	11	7	9	115	5	58
MCO-6B															17			17
MCO-6	497	555	440	650	54	102	56	19	81	38	29	19	54	48	18	650	18	177
MCO-7	27	19	68	25	110	74	54	111	82	7	26	16	60	61	18	111	7	51
MCO-7.5	16	13	108	77	111	74	55	109	82	77	27	28		57	15	111	13	61
MCO-7A															16			16

Data Source: Los Alamos National Laboratory's Water Quality & Hydrology Group (ESH-18)

Mortandad Canyon Alluvial Ground Water Monitoring Stations: 1981-1995
Nitrate Concentrations: NO3-N (mg/L)

Table 2.2

Figure 3.0. Nitrate (NO3-N) Concentrations in Six Mortandad Canyon Monitoring Wells from 1981 to 1995.

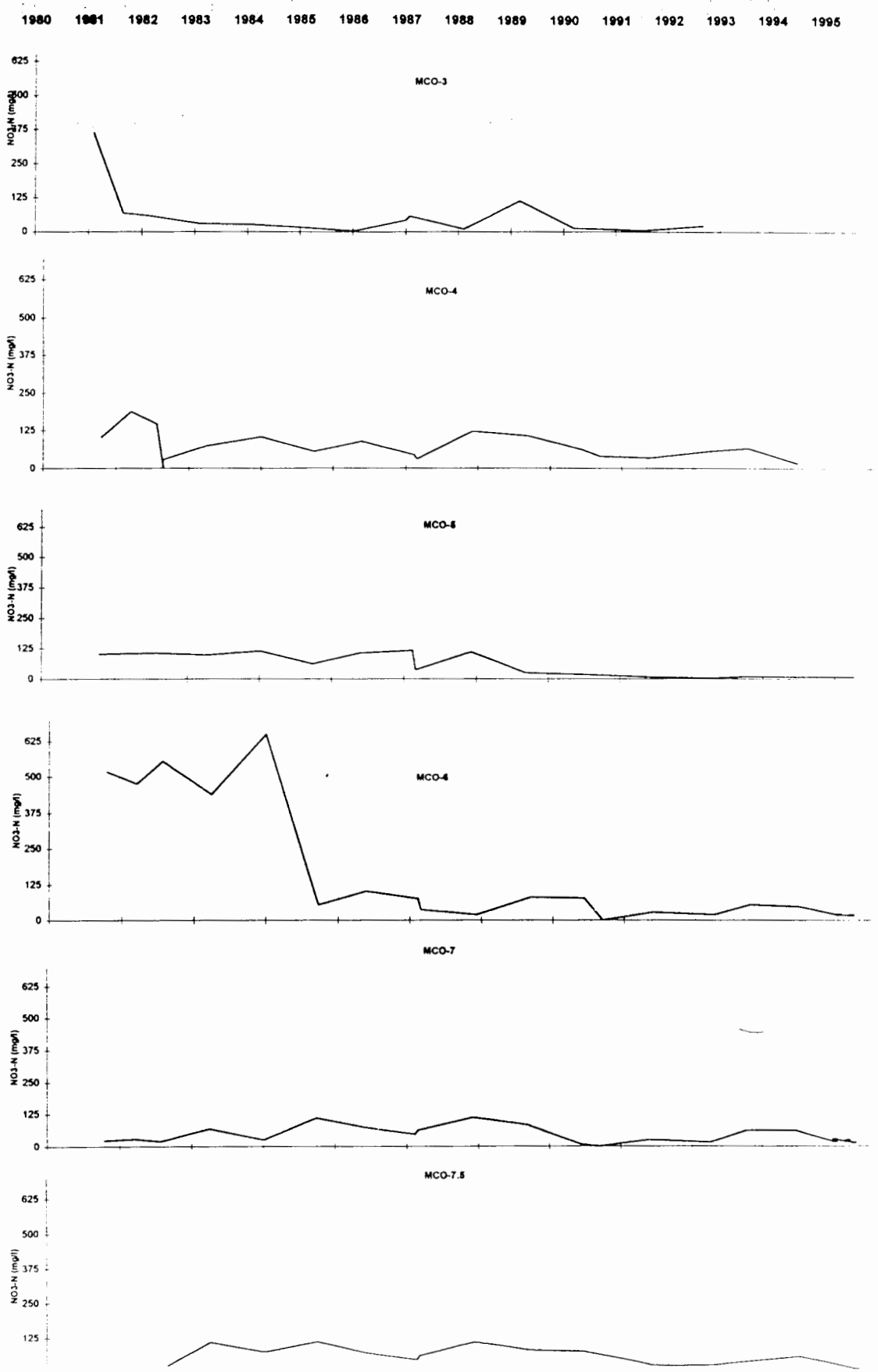
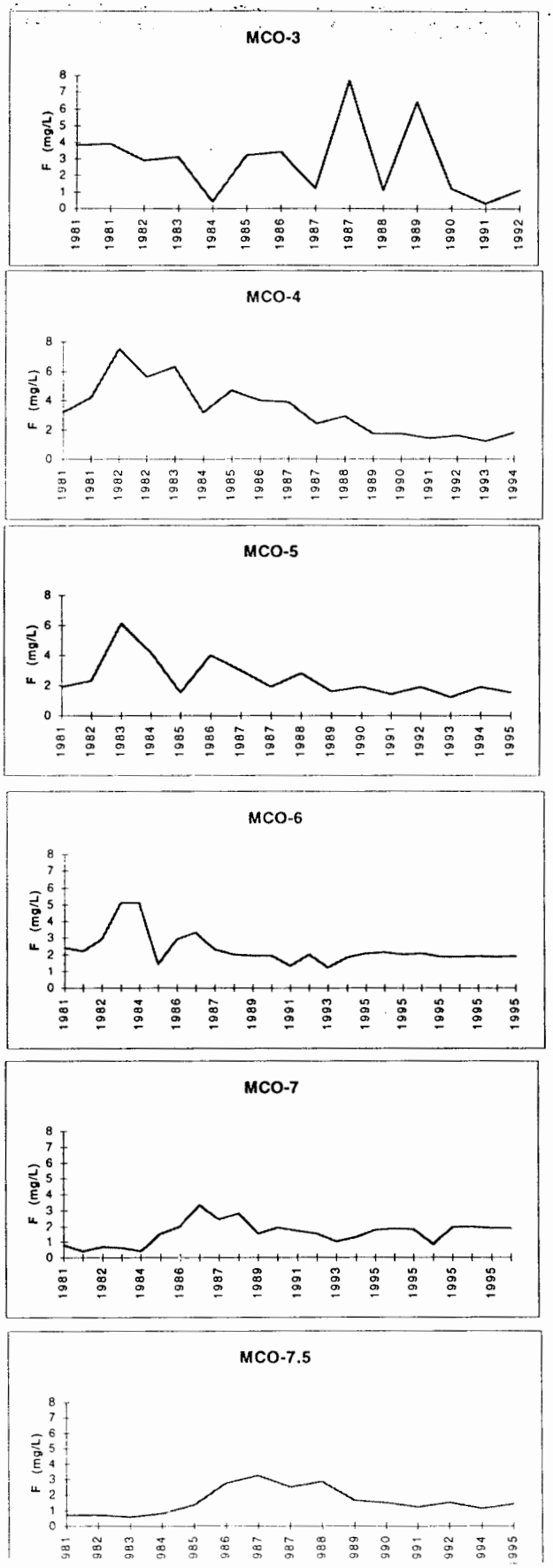


Figure 3.1. Fluoride (F) Concentrations in Six Mortandad Canyon Monitoring Wells from 1981 to 1995.



Mortandad Canyon Mass Balances

In 1977 Purtymun (Appendix E) evaluated the mass balance of water and chemicals (including nitrate) in the alluvial groundwater in Mortandad Canyon. With respect to water balance, water sources during the 1963-1974 study period were from industrial effluents from TA-50 and storm runoff and waste water from TA-48. The proportion of storm water and TA-48 discharge to TA-50 effluent ranged from about 0.6 to 1.7. The amount of water in storage (at the end of the year) in the alluvial groundwater during this time was about 20% of the surface water inflow. As the groundwater body does not extend beyond the Laboratory boundary, this implies large annual water losses from the system. Purtymun (1977) attributed these water losses to evapotranspiration and seepage into the underlying tuff.

Comparison of concentrations of chemicals in yearly effluent samples and groundwater samples shows that groundwater concentrations are about 30 to 50% of effluent concentrations. This holds true for sodium, chloride, nitrates, and total dissolved solids. Thus, dilution of the groundwater occurs continually. The amount of nitrate in storage in the Mortandad Canyon groundwater in 1974 was about 2.6% of the amount disposed of since 1963. The amount of chemicals unaccounted for in the inventory were taken up by plants, adsorbed onto alluvial material, or carried into the underlying tuff by infiltrating water. Purtymun (1977) concludes that "The rapid loss of water and its associated chemicals from the aquifer prevents chemical accumulation and indicates that cessation of effluent release to the canyon would rapidly improve the quality of water in the aquifer".

Related Ground Water Monitoring Projects

The Laboratory is currently preparing a site-wide Hydrogeologic Workplan pursuant to a request from NMED's Hazardous and Radioactive Materials Bureau. The Workplan is scheduled to be submitted to NMED during September, 1996. The Workplan will address both the Resource Conservation and Recovery Act (RCRA) regulatory ground water monitoring requirements, and the Hazardous and Solid Waste Amendments (HSWA) hydrogeologic permit requirements. The Workplan will describe proposed ground water characterization and monitoring activities Laboratory-wide, including their scheduled implementation, and specifically will include activities in and adjacent to Mortandad Canyon. Once the Hydrogeologic Workplan is approved by NMED, any proposed ground water activities relevant to Mortandad Canyon are expected to compliment this discharge plan, and may be included in a subsequent discharge plan modification, as appropriate.

The Laboratory has an on-going Environmental Restoration Project that is responsible for preparing RCRA Facility Investigation (RFI) task/site work plans that establish the technical approach and methodology for environmental investigations. An RFI work plan will be prepared for Mortandad Canyon, and at this writing, is currently scheduled for submittal to NMED in September 1997. The general purpose of the RFI investigation in Mortandad Canyon will be to:

- Determine the potential for contaminant transport into or within Mortandad Canyon watersheds;
- Evaluate human health risks and ecological impacts associated with the presence of contaminants;
- Refine conceptual models for contaminant transport;
- Assess the potential for interconnections between ground water in alluvium, perched intermediate zones, and the regional aquifer; and
- Assess the projected impact that contaminants may have on off-site receptors and the Rio Grande.

Once the RFI work plan for Mortandad Canyon is approved by NMED, any proposed ground water activities are expected to compliment this discharge plan, and may be included in a subsequent discharge plan modification, as appropriate.

12. Flooding Potential of the Site.

Map 5.0 , the 100-Year Floodplain, illustrates that the RLWTF at TA-50 is not within the boundaries of the 100-year flood plain.
Reference: McLin, 1992.

13. Description of Soils.

See Appendix E for a description of the soil distribution and characteristics of Mortandad Canyon.

14. Description of Geology.

See Appendix E for a description of the bedrock stratigraphy of Mortandad Canyon.

15. Operations and Maintenance Plan.

Detailed Operating Procedures (DOP) for the RLWTF at TA-50 Building 1 have been attached in Appendix G. These procedures ensure the quality of operations and the safety of personnel. Specifically, the DOP describes the procedures for:

- Routine treatment of liquid waste at the RLWTF;
- Routine rotary vacuum filter operations;
- Routine wastewater and sludge sampling; and
- Proper response to hard alarms.

16. Contingency Plan.

The RLWTF and LANL maintain three contingency plans to address actions that will be taken in the event of an emergency or spill at the facility:

1) Contingency Plan ;
2) Spill Prevention Control and Countermeasure Plan (SPCC); and
3) LANL Emergency Management Plan.

The Contingency Plan and the LANL Emergency Management Plan have been enclosed in Appendix G. Due to its size, the SPCC Plan has not been included in this discharge plan but is available upon request.

After January 31, 1998, as a contingency against discharging nitrates (N03-N) in excess of WQCC standards, each batch of treated effluent will be screened for nitrates prior to discharge. This will enable plant operators at the RLWTF to minimize their response time to sub-standard treatment process performance.

While the RLWTF has, and will continue to be, the most regular source of surface water entering Mortandad Canyon, storm water runoff and industrial discharges from NPDES permitted outfalls are additional sources. In order to quantify the ratio between RLWTF and other sources, the Laboratory will compare annual discharges from the RLWTF with discharge records from gaging station GS-1 (See Map 4.0) on an annual basis and report the results to the Ground Water Bureau as part of this discharge plan's reporting. Depending upon the results, the Laboratory will determine if there is a need for additional sampling locations upstream of the RLWTF's discharge point. These sampling locations would serve as control points for establishing the relative influence of other water sources in the drainage and how they affect ground water quality.

The Laboratory's approach in developing corrective actions for this ground water discharge plan is based upon Purtymun's research (1977) and the data record for Mortandad Canyon; both strongly indicate that after reducing the input of contaminants from RLWTF effluent the alluvial ground water will naturally attenuate to below WQCC ground standards. Following this position, the Laboratory is making a commitment to implement substantial process upgrades at the RLWTF, meet WQCC ground water standards in the treated effluent, and expand existing monitoring of the alluvial ground water. However, in the event that these corrective actions prove to be inadequate, the Laboratory is committed to revisiting its approach and evaluating alternative actions.

17. Monitoring Plan.

The Laboratory proposes to develop new data and use data from the following on-going monitoring programs to provide a comprehensive Monitoring Plan for the RLWTF Ground Water Discharge Plan Application:

(1) NPDES compliance sampling of treated effluent;

(2) RLWTF operational sampling of treated effluent;

(3) Groundwater Management Protection Program sampling of Mortandad Canyon's alluvial ground water; and

(4) NPDES Stormwater Program stream gaging of Mortandad Canyon.

Further information on NPDES compliance sampling and RLWTF operational sampling are presented in Appendix A. Table 3.0, presented on the following page, summarizes the sampling point locations, frequency, and sampling constituents of the Proposed Monitoring Plan.

Table 3.0. Proposed Monitoring Plan for the RLWTF Ground Water Discharge Plan Application

LOCATION	PARAMETER	NOTE	MONITORING FREQUENCY*
Discharge Point	Batch Volume, in gallons		Per batch
Discharge Point	pH		Per batch
Discharge Point	Nitrate Screening		Per batch
Discharge Point	Total Nitrogen	1	1/week
Discharge Point	Health Standards	3	1/month
Discharge Point	Total Toxic Organics	7	1/month
Discharge Point	Radium-226 & Radium-228		1/month
Discharge Point	Secondary & Irrigation Stds	4,5	1/month
Wells MCO-6	Nitrates (NO3-N)		Quarterly
Wells MCO-6	Health Stds	3	Quarterly
Wells MCO-6	Secondary Stds	4	Quarterly
Wells MCO-6	Irrigation Stds	5	Quarterly
Wells MCO-3,4,5,7,7.5	Nitrates (NO3-N)		Annual
Wells MCO-3,4,5,6,7,7.5	Radiochemistry	2	Annual
Wells MCO-3,4,5,7,7.5	Health Stds	3	Annual
Wells MCO-3,4,5,7,7.5	Secondary Stds	4	Annual
Wells MCO-3,4,5,7,7.5	Irrigation Stds	5	Annual
Wells MCO-3,4,5,6,7,7.5	Organics	6	1 per 3 Years
Mortandad Canyon Gaging Station	Surface Flows		Continuous

Notes

1. Total Nitrogen: TKN, Ammonia, NO2, NO3.
2. Radiochemistry: Uranium, Combined Ra-226 & Ra-228.
3. Health Standards (3103 A.): Ag, As, Ba, Cd, CN, Cr, F, Hg, NO3, Pb, Se.
4. Secondary Standards (3103 B.): Cl, Cu, Fe, Mn, SO4, Zn, TDS, and pH.
5. Irrigation Standards (3103 C): Al, B, Co, Mo, Ni
6. Volatile and Semivolatile Compounds, EPA SW 846 and Methods 8240 and 8270.
7. Total Toxic Organics (TTOs): See Appendix B for a listing of analytes in this method.

* Monitoring Plan data will be reported to the NMED annually.

Reporting

All RLWTF ground water discharge plan monitoring results will be submitted annually to the New Mexico Environment Department, Ground Water Protection and Remediation Bureau. The Laboratory's Environmental Surveillance Report is also submitted annually to NMED and presents extensive ground and surface water quality data for all water supply wells, monitor wells, and surface water stations in the Laboratory's network of sampling locations.

18. Closure Plan.

Currently, Los Alamos National Laboratory has no plans to discontinue RLWTF system components or abandon Mortandad Canyon ground water monitor wells during the term of the discharge permit. When the facility is ultimately closed it will be monitored, decontaminated, and decommissioned in accordance with applicable state and federal requirements.

I certify that I am familiar with the information contained in the application and that to the best of my knowledge and belief such information is true, complete, and accurate.

August 15, 1996

Mr. Dennis J. Erickson
Director, ESH Division
Los Alamos National Laboratory

Date

August 15, 1996

Mr. G. Tom Todd
Area Manager
U.S. Department of Energy
Los Alamos Area Office

Date

Discharge Plan Roles and Responsibilities

Successful implementation of the Ground Water Discharge Plan Application for the Radioactive Liquid Waste Treatment Facility at TA-50 requires a coordinated commitment by Laboratory management. The roles and responsibilities in accordance with the Laboratory management structure are defined as follows:

ESH Division Director--The ESH Division Director is the "owner" of the Laboratory's environmental permits and has overall responsibility and accountability for providing regulatory support and technical expertise for preparation of this Ground Water Discharge Plan Application.

EM Program Manager--The EM Program Manager is the primary point-of-contact with the Department of Energy (DOE) for environmental management and is responsible for securing funding for upgrades to the RLWTF.

CST Division Director--The CST Division Director is responsible for providing radioactive liquid waste treatment capabilities to the Environmental Management Program and is the institutional owner of the RLWTF.

APPROVED: **RLWTF GROUND WATER DISCHARGE PLAN APPLICATION**

ESH Division	Dennis Erickson, Division Director	August 15, 1996 Date
EM Program	for Thomas Baca, Program Manager	8-15-96 Date
CST Division	Alexander Gancarz, Division Director	August 15, 1996 Date

1993 TOTAL TA-50 DISCHARGES

1993 TA - 50 RADIOACTIVE LIQUID WASTE TREATMENT FACILITY EFFLUENT CONCENTRATIONS										
		1993 DISCHARGES	NEW MEXICO RADIATION	1993 TOTAL	1993 TOTAL	1993 TOTAL	1993 TOTAL			
RADIOISOTOPE	DCG	MEAN CONCENTRATION	PROTECTION REGULATIONS	DISCHARGE	CURIES					
	uCi/ml	uCi/ml	uCi/ml	in LITERS	DISCHARGED	uCi released	ml released	pCi	L	pCi/L
GROSS ALPHA		5.7079E-07		21,724,278	1.24E-02	12400	2.1724E+10	1.24E+10	21724278	570.79
GROSS BETA		1.06E-06		21,724,278	2.31E-02	23100	2.1724E+10	2.31E+10	21724278	1063.326
TRITIUM H 3	2.00E-03	1.22E-04	1.00E-03	21,724,278	2.66E+00	2660000	2.1724E+10	2.66E+12	21724278	122443.7
Sr 89	2.00E-05	1.21063E-07	8.00E-06	21,724,278	2.63E-03	2630	2.1724E+10	2.63E+09	21724278	121.0627
Sr 90	1.00E-06	1.57888E-07	5.00E-07	21,724,278	3.43E-03	3430	2.1724E+10	3.43E+09	21724278	157.8879
Cs 137	3.00E-06	3.76077E-07	1.00E-06	21,724,278	8.17E-03	8170	2.1724E+10	8.17E+09	21724278	376.0769
U 234	5.00E-07	4.87933E-09	3.00E-07	21,724,278	1.06E-04	106	2.1724E+10	1.06E+08	21724278	4.879334
Pu 238 **	4.00E-08	2.66522E-08	2.00E-08	21,724,278	5.79E-04	579	2.1724E+10	5.79E+08	21724278	26.65221
Pu 239 **	3.00E-08	2.26935E-08	2.00E-08	21,724,278	4.93E-04	493	2.1724E+10	4.93E+08	21724278	22.6935
Am 241	3.00E-08	5.15552E-07	2.00E-08	21,724,278	1.12E-02	11200	2.1724E+10	1.12E+10	21724278	515.5522
**	Indicates below DCG but above NMRPR limits									
	Indicates above DCG levels									

Hydrologic Setting of Mortandad Canyon

Mortandad Canyon is an east to southeast-trending canyon that heads on the western part of the plateau and is tributary to the Rio Grande to the east. The canyon is cut into the Bandelier Tuff. The canyon floor is narrow near the plant outfall and widens eastward. The canyon walls are steep, and in places are near vertical. The canyon contains a shallow body of ground water recharged by industrial effluent and runoff. The spatial extent of this saturation is within the Laboratory boundaries, extending from near the plant outfall on the west to near observation well MCO-8 (Figure 3.0). Transverse to the canyon axis, the saturation does not extend to the canyon walls.

The alluvium thickens eastward from less than 5 ft in the upper reach of the canyon to as much as 75 ft east of MCO-8. The shallow body of ground water in the alluvium occupies less than 10% of the volume of the alluvium. The greatest potential for the surface transport of contaminants from the area is with storm runoff, in solution or adsorbed on sediments. Due to the small drainage area and the large volume of unsaturated alluvium there has been no continuous surface runoff through the canyon extending off the Laboratory since hydrologic observations began in 1960. The largest runoff events have extended no further than a hundred or so meters past the sediment traps.

The canyon has been conceptually divided into three sections: Upper Canyon, Middle Canyon, and Lower Canyon. The hydrologic characteristics of each are slightly different: The upper canyon is narrow, and filled with underbrush, shrubs, pine, fir, box elder, and oak trees. The alluvium thickens eastward from less than 1 ft at the plant outfall to about 18 ft thick at MCO-4. The stream flow in this section is perennial from waste water and periodic releases of industrial effluents. The stream channel is entrenched. Major recharge to the shallow ground water occurs in the upper canyon. Large losses by evaporation occur in this section of the canyon due to the large amount of vegetation and to the water table being near the ground surface. The **middle canyon** widens and alluvium thickens from 18 ft at MCO-4 to 36 ft at MCO-6. The stream channel is well defined, but surface flow is intermittent.

The **lower canyon** becomes progressively wider and the alluvium continues to thicken to about 60 ft near MCO-8. The stream channel is discontinuous, braiding out on the canyon floor. The number of pines decrease eastward from the middle canyon with a transition to scattered pinion-juniper community. To prevent the transport of contaminants by storm

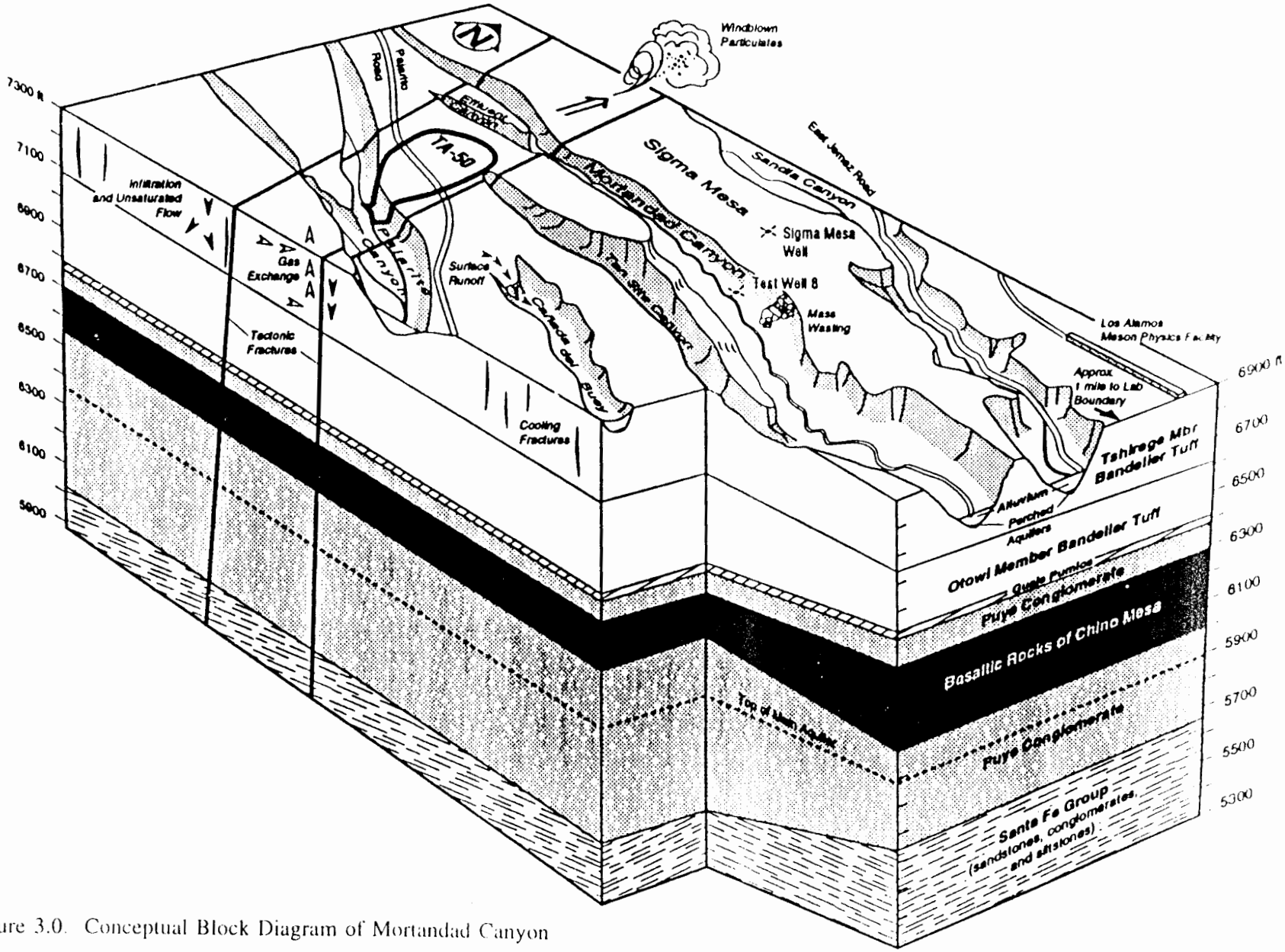


Figure 3.0. Conceptual Block Diagram of Mortandad Canyon

runoff out of the lower canyon, three sediment traps have been constructed between MCO-7 and MCO-7.5. These traps have a capacity of about 1.2 million gallons.

Recharge by industrial effluents and waste water to the shallow ground water occur in the upper canyon. Storm runoff recharges the upper canyon and, dependent on the volume, may extend to the lower canyon. Long periods of snow-melt runoff or wastewater discharge will override the saturated section in the upper canyon and infiltrate along the saturated front. When discharge ends, the stream flow will retreat up the canyon and the front will break off and move as a groundwater mound down the canyon. The volume of recharge since 1960 has not been sufficient to significantly change the volume of the shallow ground water.

Extent of Saturation in Mortandad Canyon

The saturated canyon alluvium is of limited extent as the recharge (effluents, waste water, and storm runoff) is sufficient only to maintain a saturated zone in the alluvium extending about 2.2 mi downstream from the outfall location (about the edge of the conceptual illustration in Figure 3.0, near observation hole MCO-8). The eastern extent of saturation is about 1 mi west of the Laboratory boundary as observed in test holes on the Laboratory and San Ildefonso lands. The saturated thickness of the shallow aquifer varies dependent upon the amount of recharge. A typical saturated thickness is 10 feet.

Test holes drilled or cored through the alluvium indicate that the underlying tuff, weathered to silts and clays immediately below the alluvium, is not saturated. The saturated portion of the alluvium is perched on the weathered-unweathered tuff. Moisture content generally declines to less than 50 percent of saturation conditions both transverse to canyon axis and at depth. Test holes completed in the weathered tuff below the saturated alluvium will not yield free water.

Groundwater Flow

The direction of groundwater flow in the alluvium is to the southeast, paralleling the canyon bottom. The rate of groundwater flow depends on the hydrologic characteristics of the two distinguishable units of the zone of saturation. Ground water west of MCO-5 is in a sand unit and is transitional into a silty clay unit near MCO-6. East of MCO-6, the aquifer is in a silty clay unit (Baltz 1963, Purtymaun 1974, Stoker 1991). Tracer tests indicate that the velocity of ground water in the transition from the sand unit to the silty clay unit is 65 ft/day and in the silty clay unit of 6 to 14 ft/day (Purtymun, 1974). Based on velocity, the transit

time from the plant outfall to the eastern end of the zone of saturation is about one year. The direction of groundwater flow in the underlying regional aquifer is also to the southeast towards the Rio Grande. The rate of groundwater flow in the regional, or main, aquifer is estimated to be about 95 ft/year (Purtymun, 1984).

Groundwater Quality

Routine environmental monitoring has been conducted in Mortandad Canyon since 1960. The routine monitoring program includes regular collection and analysis of water and sediment samples from the canyon. The 1993 and 1994 Environmental Surveillance Reports contain data on samples collected in Mortandad Canyon. As industrial effluents are released into the canyon and move down gradient, radionuclides (except tritium) and some inorganic chemicals are adsorbed or bound to the bed sediments, reducing the amount of radionuclides or chemicals in the water or effluents. A high build up of radiochemicals or chemicals does not occur in the alluvium at the effluent outfall since periodic storm runoff transports sediments and contaminants down the channel in the canyon. Adsorption of contaminants reduces the concentrations in the perched ground water.

Ground water in the perched alluvium contains inorganic constituents listed in the NMWQCC 3103 Groundwater Standards, as expected from analysis of effluent quality. Nitrate (as nitrogen) concentrations in the alluvial groundwater typically range between 40 to 60 mg/L, reflecting the significant influence of the TA-50 effluent quality on the groundwater (See Appendix F for a 10-year summary of nitrate monitoring in Mortandad Canyon). Total dissolved solids concentrations typically range between 300 and 600 mg/L.

No organic chemical constituents (listed in RCRA Appendix IX) have been identified in the alluvial ground water (Purtymun, 1988). Similarly, no cores taken in or beneath the alluvium to depths of about 100 feet showed any detectable organic chemical (volatiles, semivolatiles, herbicides, pesticides, or PCBs) contaminants (Stoker et al. 1991).

Generally, more than 99 percent of the radioactive residuals from the treatment plan effluents are associated with sediments in or immediately adjacent to the stream channel. A small fraction of the residuals, on the order of 1 percent or less, are present in the perched water in the alluvium. Recent data indicates variable movement of contaminants into the unsaturated tuff beneath the saturated portion of the alluvium. Except for tritium,

radioactive constituents have apparently moved less than about 10 feet in the unsaturated zone, based on analysis of cores from two on-site coreholes (Stoker et al. 1991). In contrast, the same boreholes showed migration of tritium, nitrate, and chloride to depths of at least 195 feet.

In 1993, trace levels (89 pCi/L) of tritium, as tritiated water, were detected in the main aquifer beneath Mortandad Canyon in Test Well 8. These levels are less than 1% of the EPA drinking water MCL of 20,000 pCi/L. The levels are significant nonetheless as they are indicative of recharge from the surface within the past four decades. Tritium is of great interest in evaluating the hydrologic process because tritium, the radioactive isotope of hydrogen, is chemically part of the water molecule and moves with water virtually unaffected by any geochemical processes such as ion exchange, chelation, or adsorption. Accordingly, it can be used as a fundamental conservative tracer to follow the movement of water.

A 1994 sampling of Test Well 8, a main aquifer well, showed a nitrate (as Nitrogen) value of 5.1 mg/L, while all other values since 1988 were 0.2 mg/L or less.

General Soil Distribution and Characteristics of Mortandad Canyon

Soils along Mortandad Canyon are spatially variable due in part to the steep and rugged topography of the canyon. Soils along this canyon have largely been mapped (Nyhan et al., 1978) as Rock outcrop, frigid (RF), Rock outcrop, steep (RS), and Typic Ustorthents-Rock outcrop complex (TS). The existing soils map for Mortandad Canyon should be considered only as a general estimation of soil cover; however, extreme variability in soil cover has been observed elsewhere within the Laboratory when more detailed soil surveys have been conducted. A more detailed and accurate determination of soil characteristics along this canyon will require additional mapping and description of soils.

Soils mapped by as RF largely consists of Bandelier Tuff rock outcrop. Soil cover in places may consist of either a (1) thin (<50 cm) covering of very shallow, poorly developed soils developed in sandy-gravely colluvium or (2) thin (<50 cm), moderately developed soils that have weakly developed Bt horizons (horizons that display an increase in silt and clay relative to the original parent material) and that may have silt loam to clay loam textures. Soils mapped as RS consist of slopes that exceed 30% and largely consists of Bandelier Tuff rock outcrop. Soils mapped as TS consist of rock outcrop and deep (>100 cm), poorly developed soils formed in sandy-gravely colluvium. TS soils generally have textures ranging from gravely loam to sand.

In places where soils have formed in colluvium that overlies the Bandelier Tuff along canyon walls, soil characteristics will also generally vary between north and south facing slopes. Soils on north facing slopes will generally have thicker A horizons (horizons where organic matter largely accumulates), including a greater accumulation of organic matter and forest litter, deeper soil profiles, and slightly finer textures (slight increase in silt and clay content) relative to soils formed on south facing slopes. In addition, soils will be generally be deeper along the lower footslopes of both north- and south-facing slopes relative to soil cover upslope.

Soils along canyon bottoms that have formed in young (Holocene, < ~10,000 years) alluvium are also be present although these soils were not specifically mapped by Nyhan et al. (1978). Soils formed in colluvium generally are deep (>100 cm), are poorly- to moderately-developed, have textures ranging from gravely loam to sand, and consists of simple A-Bw-C soil profiles (Bw horizons are weak B horizons where there is a slight increase in soil structure and/or accumulation of iron oxides relative to the parent material

(C horizon)). Soils formed in alluvium probably increase in abundance down canyon as width of the valley bottom increases.

Surface runoff will be extremely high for rock outcrop. Surface runoff will generally be poor to moderate, with moderate to high surface permeability for soils formed in colluvium along canyon walls depending on soil depth to bedrock. Permeability will be also generally be high for soils formed in alluvium along the canyon bottom. Soil cover along canyon walls will generally have a high potential for erosion due to steep slopes and generally thin soil depths and a variable cover of vegetation. Soils along canyon bottoms may be susceptible to erosion along active stream channels.

Bedrock Stratigraphy of Mortandad Canyon

The principal bedrock units in Mortandad Canyon consist of, in ascending order, 1) the Santa Fe Group (4 - 21 Ma, Manley, 1979), 2) the Puye Formation (1.7 - 4 Ma, Turbeville et al., 1989 and Spell et al., 1990) and interstratified basaltic rocks of the Cerros del Rio volcanic field (2-3 Ma, Gardner and Goff, 1984), 3) the Otowi Member of the Bandelier Tuff (1.613 ± 0.011 Ma, Izett and Obradovich, 1994), 4) epiclastic sediments and tephras of the Cerro Toledo interval, and 5) the Tshirege Member of the Bandelier Tuff (1.223 ± 0.018 Ma, Izett and Obradovich, 1994). The distribution of these geologic units is shown on several excellent geologic maps of the area (Baltz et al., 1963; Griggs, 1964; Rogers, 1995). Brief descriptions of the principal bedrock units are given below and illustrated in Figure 4.0.

Santa Fe Group

The Santa Fe Group consists of predominately fluvial slightly consolidated sedimentary rocks that crop out near the mouth of Mortandad Canyon in White Rock Canyon. Santa Fe Group sediments were penetrated in water supply well PM-5, located on the mesa south of Mortandad Canyon. The Santa Fe Group consists of, in ascending order, the Tesuque Formation, the Chamita Formation, and coarse-grained sedimentary rocks informally called the "Chaquehui Formation" by Purtymun (1995).

The Tesuque Formation consists of poorly consolidated buff, red, or gray arkosic sand, silt, clay, pebble beds, and thin, white or green ash beds derived primarily from Precambrian basement and Tertiary volcanic sources to the east and northeast of the Espanola basin. These clastic rocks range in age from about 21 to 7 Ma (Manley 1979; Cavazza, 1989). Cavazza (1989) states that the aggregate thickness of Tesuque Formation is >2000 m and shows the unit thickening to the west.

The Chamita Formation overlies and interfingers with Tesuque Formation. Chamita deposits are similar in appearance to Tesuque deposits, but the former reportedly contains a larger proportion of volcanic and granitic clasts in its gravel layers (Galusha and Blick, 1971) and Paleozoic limestone cobbles in its conglomerate layers (Dethier and Manley, 1985). The Chamita Formation contains lithologically distinct quartzitic gravels (Galusha and Blick, 1971). Upper layers of Chamita may contain cobbles of Jemez volcanic rocks, primarily andesites and dacites. However, because of similarities of appearance, obvious time overlaps, and interfingering relations, differentiation of Chamita from Tesuque

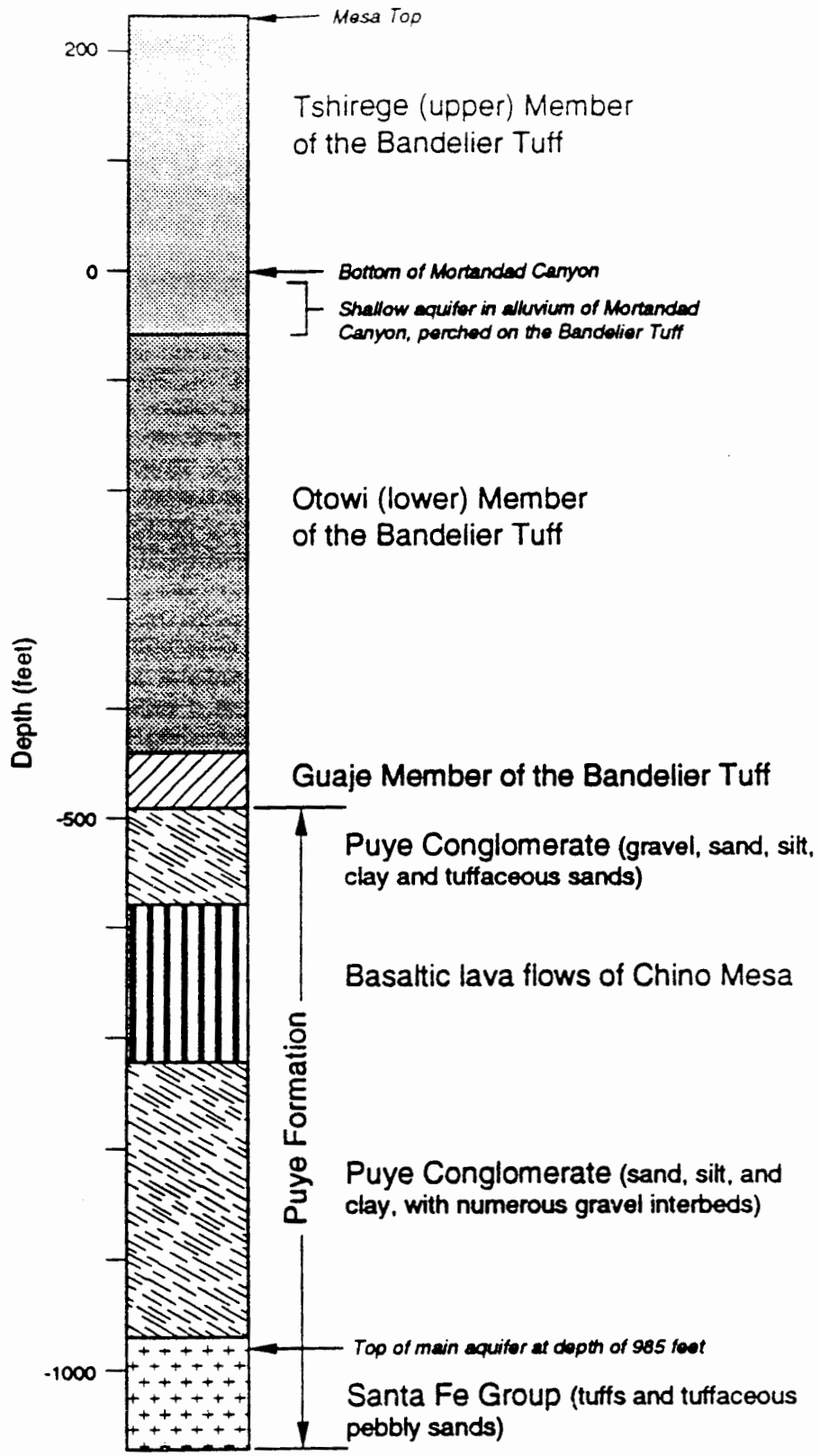


Figure 4.0. Simplified stratigraphy of Mortandad Canyon, based on cliff sections and Test Well 8 (from Baltz et al. 1963).

deposits is often difficult, particularly in borehole investigations. The Chamita Formation, if present, is less than 80 ft thick in the vicinity of well PM-5 (Purtymun, 1995).

Purtymun (1995) describes a trough of coarse-grained sediments at the top of the Santa Fe Group ("Chaquehui Formation") that would allow the development of high-yield, low-drawdown water supply wells. The trough is late Miocene in age (based on ca. 9 Ma basalts interlayered with the sediments in well Otowi-4 in Los Alamos Canyon; $^{39}Ar/^{40}Ar$ ages from A. W. Laughlin, unpubl. report for Los Alamos National Laboratory, 1993). This Miocene trough is about 4 km wide and extends at least 12 km from the northeast to the southwest, although subsurface data are not available to determine its full length. It is filled with coarse gravelly sediments, including volcanic, metamorphic, and sedimentary clasts which may have been derived from highlands to the north, east, and west. Approximately 1230 ft of this distinct coarse-grained facies of the upper Santa Fe Group was penetrated in well PM-5, and these deposits probably are present beneath the western half of Mortandad Canyon.

Basalt flows 50 to 480 ft thick were penetrated within the Santa Fe Group by water supply well PM-5 (Purtymun et al., 1995). Some of these basalt flows are probably present beneath Mortandad Canyon as well. Recent dating of these volcanic units shows that these basalt flows range in age from 9.8 to 11 Ma (WoldeGabriel et al., 1994).

Puye Formation

The Puye Formation is a fanglomerate deposit consisting of poorly sorted boulders, cobbles, and coarse sands made up of dacitic to latitic debris eroded from contemporaneous volcanism and erosion of the Tschicoma Formation. In the lower reaches of Mortandad Canyon and along the Rio Grande, the Puye Formation also contains basaltic debris derived from contemporaneous volcanism and erosion of the Cerros del Rio volcanic field. The Puye Formation contains numerous interbedded lapilli tuff beds and laharic deposits. Lacustrine deposits are volumetrically significant in the distal parts of the fan. The top of the main aquifer was encountered at a depth of 968 ft in fanglomerates of the Puye Formation in Test Well 8 in Mortandad Canyon (Baltz et al, 1963; Purtymun, 1995).

The lower part of the Puye Formation includes the Totavi Lentil, a deposit of well-round cobbles and boulders of Precambrian quartzites and crystalline rocks. The Totavi Lentil probably represents channel deposits of the ancestral Rio Grande, and it may interfinger with the fanglomerate facies of the Puye Formation beneath Mortandad Canyon.

Basaltic Rocks of the Cerros del Rio Volcanic Field

The basaltic rocks of the Cerros del Rio volcanic field (2.3-3.2 Ma; Manley, 1976 and 1979; Bachman and Mehnert, 1978; WoldeGabriel et al., 1994) include Pliocene olivine tholeiites, basaltic andesites, basanites, alkali olivine basalts, and hawaiites and erupted from vents east and west of the Rio Grande (Aubele, 1978, Baldridge, 1979; Dethier, in press). The main part of the volcanic field lies east of the Rio Grande, but outcrop and borehole data indicate that a major extension of the volcanic field lies buried beneath the Pajarito Plateau, including the area near Mortandad Canyon. Cerros del Rio basalts interfinger with fanglomerates of the Puye Formation in Test Well 8 and in well PM-5.

Otowi Member, Bandelier Tuff

The Otowi Member is a poorly consolidated ignimbrite penetrated by boreholes in Mortandad Canyon. The basal part of the Otowi Member includes the Guaje Pumice Bed, a thick series of well-stratified pumice-fall and ash fall-deposits that blanketed the pre-existing landscape before the overlying ignimbrites were erupted. Test Well 8 penetrated 430 ft of Otowi Member, including 45 ft of the basal Guaje Pumice Bed (Baltz et al, 1963).

The Otowi Member is made up of numerous stacked ash-flow tuffs, but it has a massive, homogenous appearance because of the lack of significant welding and because boundaries between individual flow units are often difficult to identify. The Otowi Member consists of light gray to orange pumice lapilli supported by a white to tan, ashy matrix. The matrix is made up of glass shards, broken pumice fragments, phenocrysts, and fragments of nonvesiculated perlite. Shards are glassy and show no evidence for either post-emplacement high-temperature devitrification or for subsequent low-temperature diagenetic alteration. Pumice lapilli typically make up 10 to 30% of the tuff and range from 0.5 cm to 6 cm in diameter. Pumices are larger (up to 20 cm) and more abundant (~40% of the rock) at the top of the unit which has a distinct a orange coloration due to the oxidation of iron by escaping vapors as the ash-flow sheet cooled or to incipient weathering of the top of the unit before deposition of overlying units.

Volcaniclastic Sediments and Tephras of the Cerro Toledo Interval

The Cerro Toledo interval is an informal name given to a sequence of epiclastic sediments and tephras of mixed provenance that lie between the two members of the Bandelier Tuff (Broxton and Reneau, 1995). Although not identified by earlier workers, the Cerro Toledo

interval is probably present beneath much of Mortandad Canyon. The Cerro Toledo interval normally contains well-stratified tuffaceous sandstones and siltstones and subordinate primary ash-fall and pumice-fall deposits. The Cerro Toledo interval also contains poorly-sorted sands, gravels, cobbles, and boulders derived from lava flows of the Tschicoma Formation. The Cerro Toledo interval is approximately 9 ft to 36 ft thick at TA-21 to the north of Mortandad Canyon and about 45 ft thick in upper Pueblo Canyon. In Mortandad Canyon, Cerro Toledo deposits were probably assigned to the lower part of the Tshirege Member by earlier workers.

Tshirege Member, Bandelier Tuff

The Tshirege Member is a multiple-flow ash-flow sheet that forms the prominent cliffs and flat mesa tops of the area around Mortandad Canyon. The Tshirege Member is a compound cooling unit whose physical properties vary vertically and laterally (Broxton et al, 1995). Variations in physical properties result from zonal patterns of welding and crystallization determined by emplacement temperature, thickness, gas content, and composition (Smith, 1960a,b). The Tshirege Member is approximately 300 ft thick in the vicinity of TA-50. The Tshirege Member can be divided into mappable subunits based on a combination of hydrologic properties and lithologic characteristics. These subunits are described below using the nomenclature of Broxton and Reneau (1995) which was adopted by the Environmental Restoration Project.

The Tsankawi Pumice Bed is the basal pumice fall of the Tshirege Member. This pumice bed is normally 1 to 2 ft thick. Pumices in the Tsankawi Pumice Bed are rhyolitic in composition and contain ~5 % phenocrysts, consisting of sanidine and quartz.

Unit 1g is the lowermost unit in the thick ignimbrite deposit of the Tshirege Member. This unit is poorly-indurated, but nonetheless forms steep cliffs because a resistant bench near the top of the unit forms a protective cap over the softer underlying tuffs. Qbt 1g is a porous, nonwelded, poorly sorted, vitric ignimbrite. A thin (10-25 cm) pumice-poor surge deposit is commonly found at the base of this unit.

Unit 1v forms a combination of cliff-like and sloping outcrops comprised of porous, nonwelded, devitrified ignimbrite. The base of unit 1v is thin, horizontal zone of preferential weathering that marks the abrupt transition from vitric tuffs below to devitrified tuffs above; this feature forms a widespread mappable marker horizon throughout Mortandad Canyon. The lower part of Qbt 1v is a resistant orange-brown

colonnade tuff that has distinctive columnar jointing. The colonnade tuff is overlain by a distinctive white band of slope-forming tuffs. The tuffs of Qbt 1v are commonly nonwelded and have an open, porous structure.

Qbt 2 forms a distinctive, medium-brown, vertical cliff that stands out in marked contrast to the slope-forming, lighter-colored tuffs above and below. This unit is the zone of greatest welding in the Tshirege Member with the degree of welding increasing up section through the unit. Because of its greater degree of welding, Qbt 2 is typically nonporous and probably has a low permeability relative to other units of the Tshirege Member. Vapor phase alteration is extensive in this unit.

Qbt 3 is a nonwelded to partially welded, vapor-phase altered ignimbrite. It consists of a basal, nonwelded tuff that forms a broad gently sloping bench on top of Qbt 2 and an upper partially welded tuff which forms the mesa top caprock.

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Chemical Quality of Effluents and Their Influence on Water Quality in a Shallow Aquifer[1]

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ABSTRACT

The chemical quality of liquid effluent released from an industrial waste treatment plant at the Los Alamos Scientific Laboratory controls the quality of water in a shallow aquifer in the alluvium of Mortandad Canyon. The dilution of the effluent with surface flow in the canyon reduces the concentrations of the chemicals as they move down gradient into the aquifer. Mass estimates of residual chemicals in solution in the aquifer average 1–6% of the total chemicals released to the canyon from 1963–1974. The average annual concentration of sodium, nitrate, chloride, and total dissolved solids in the aquifer through a 12-year period was directly correlated with annual average concentrations in the effluent. This relationship provides a means of predicting the impact of the chemical effluents on the quality of water in the aquifer.

Additional Index Words: dilution ratios, mass inventories, regression.

Industrial liquid wastes resulting from some of the scientific programs at the Los Alamos Scientific Laboratory (LASL) are collected and processed at a waste treatment plant at Technical Area (TA) 50 located adjacent to Mortandad Canyon. The plant, which became operational in June 1963, has been the sole source of treated effluents to Mortandad Canyon. Hydrologic studies which were initiated in 1960 have continued as a part of an overall evaluation of the impact of the effluents on the environment (1, 3, 4). The purpose of this study was to investigate annual changes in the chemical quality of water in the canyon resulting from the release of effluents through the period of 1963–1974. An annual mass inventory was made of chemical additions to the canyon and of the residual chemicals in storage in the aquifer; empirical data were used in developing a predictive model for estimating the concentrations of selected constituents in the aquifer.

METHODS AND MATERIALS

The stream in the upper reach of Mortandad Canyon is perennial due to the release of effluents from TA-50 and to additions of water from TA-48 which is located upstream from TA-50. The water from TA-48 (1.7×10^4 liters/day) results from a cooling pro-

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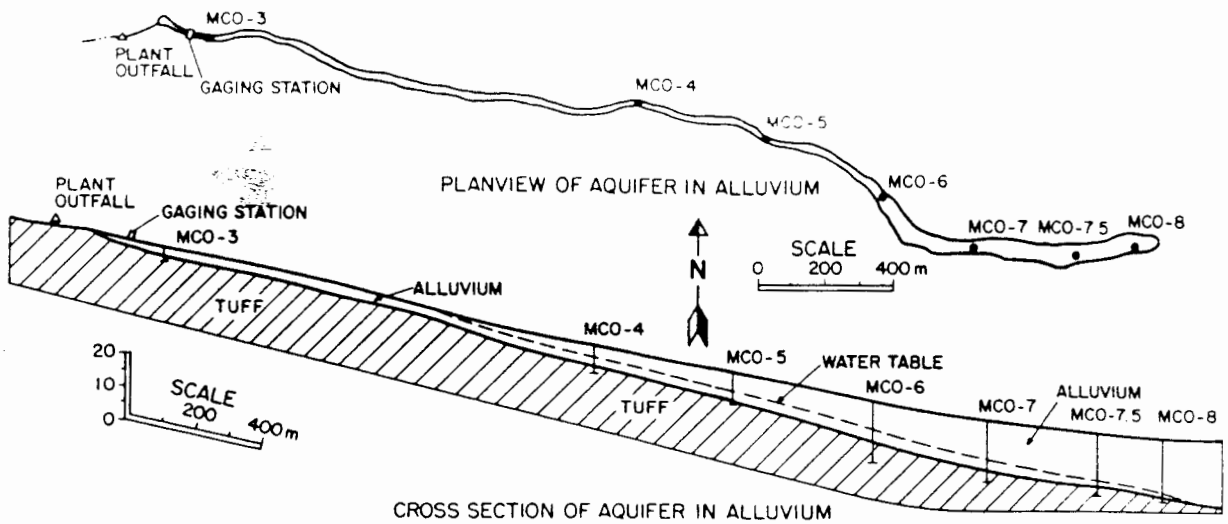

Fig. 1—Planview and cross section of aquifer in alluvium.

cess at this facility. Storm runoff adds to the surface flow in the canyon primarily during the spring and summer months. All of this water recharges a shallow aquifer that is perched in the alluvium on the underlying tuff (Fig. 1). Evapotranspiration and infiltration into the underlying tuff removes water from storage in the aquifer since the aquifer is not a part of the municipal or industrial water supply. The main aquifer which is the source of domestic and industrial water, lies at a depth of 293 m beneath the floor of the canyon. The two aquifers are separated by about 250 m of unsaturated strata.

The industrial liquid wastes collected at TA-50 contain varying amounts of chemical and radiochemical constituents. All of the influent wastes are subjected to a chemical-ion exchange treatment process. During treatment, various chemicals are added under controled conditions to enhance radionuclide decontamination factors. Some of the added chemicals remain in the effluent which is released when radioactivity is $< 10\%$ of the maximum permissible concentration (5). Records of volume of effluent released into the canyon are kept as part of the plant records.

The volume of surface water entering the canyon was determined from flow measurements obtained at a gaging station (Fig. 1). The station was equipped with a water-stage recorder on a 0.152-m (6-inch) modified Parshall flume (for low flow) overset with a 1.22-m (4-foot) wier (for large runoff events) and was rated using standard methods.

The volume of water in storage in the aquifer was determined from seven test holes across the canyon floor (Fig. 1). Water level measurements in the test holes were made in December to determine the volume of saturation at that time.

The chemical characteristics of TA-50 effluent were determined from composite samples of the wastes. Data from weekly composites were applied to release-volume and were averaged over the year. The chemical quality of water from the aquifer was determined 3-4 times annually and averaged for the year. Analytical methods used for various chemical constituents in the effluent and in the water from storage are outlined elsewhere (2).

RESULTS AND DISCUSSION

The volume of storm runoff and TA-48 water passing through the gaging station from 1962 through 1974 ranged from 25×10^3 m^3/year to 125×10^3 m^3/year for an average annual flow of about 58×10^3 m^3/year (Table 1). The volume of effluent released annually from TA-50 was less variable ranging from 40×10^3 m^3/year to 60×10^3 m^3/year. The dilution ratio (storm runoff and TA-48 water/TA-50 effluents) ranged from 0.6 to 1.7 from 1964-1974 and averaged about 1.0. The average annual volume of surface water (effluent and runoff) entering the canyon was about 105×10^3 m^3. There has been no surface flow out of the canyon during the period of study due to the rapid infiltration of surface water into the alluvium.

The volume of water in the aquifer in December was relatively constant from year to year (Table 1). Seasonal variations were observed with lowest volumes occurring during the winter and early spring and maximums occurring after spring snowmelt and storm runoff during the summer. The volume of water in storage at the end of each calendar year ranged from 19×10^3 m^3 to 30×10^3 m^3 during 1961-1974. Annual losses of water (i.e., added volume-storage volume) ranged from 65×10^3 m^3 to 146×10^3 m^3/year through a 13-year observation period and averaged 105×10^3 m^3 or about the same volume that entered the canyon each year. Water losses from the aquifer were attributed to infiltration and/or evapotranspiration. The losses attributed to evapotranspiration were estimated at about 15% based upon work described

Table 1—The estimated balance of water in the Mortandad Canyon watershed

Year	Effluent TA-50	Storm runoff and TA-48 water	Dilution ratio	Storage in aquifer†	Annual surface and ground water loss in canyon
	$\times 10^3$ m^3			$\times 10^3$ m^3	
1961	--	--	--	20	--
1962	--	70	--	20	70
1963	27‡	125	--	22	150
1964	51	59	1.2	24	108
1965	49	75	1.5	25	123
1966	53	35	0.7	20	93
1967	60	79	1.3	30	129
1968	60	52	0.9	24	118
1969	54	93	1.7	25	146
1970	53	50	0.9	20	108
1971	46	29	0.6	29	66
1972	57	26	0.5	23	89
1973	54	37	0.7	19	95
1974	40	25	0.6	19	65

† Storage as of December 31.
‡ Six months (July to December).

Table 2—Chemical quality of industrial effluent from TA-50; storm runoff and waste water from TA-48.

Effluent TA-50	Chemical constituents										Specific conductance at 25C	pH
	Calcium	Magnesium	Sodium	Carbonate	Bicarbonate	Chloride	Fluoride	Nitrate	Dissolved solids	Total hardness		
year	mg/liter										µmhos/cm	
1963†	52	1.4	188	302	376	28	1.7	63	830	135	1,730	11.6
1964	36	0.9	219	280	386	41	2.5	97	960	94	1,950	11.6
1965	40	0.8	196	278	367	30	2.2	131	860	109	2,070	10.9
1966	52	3.2	151	213	292	17	1.4	50	660	145	1,280	11.4
1967	110	3.1	120	226	306	21	2.3	55	570	289	1,520	11.2
1968	100	2.7	153	265	353	28	3.2	63	620	259	1,630	11.2
1969	91	2.3	286	300	428	34	2.7	131	940	235	1,990	11.2
1970	56	4.8	406	354	472	38	2.1	551	1,500	155	2,340	11.2
1971	42	3.9	433	218	641	169	2.7	372	1,590	120	2,450	9.2
1972	30	3.6	571	91	506	108	1.2	766	1,670	91	2,570	8.8
1973	33	5	310	52	331	60	1.5	310	1,150	105	1,530	9.0
1974	43	4	443	256	561	53	2.6	290	1,540	123	2,640	7.9
Storm runoff	29 (26)‡	3 (46)	22 (26)	0	102 (31)	9 (46)	0.3 (75)	0.5 (41)	174 (21)	103 (17)	192 (35)	8.7
Waste water TA-48	[illegible]	4.3 (77)	58 (49)	0	140 (34)	7.6 (45)	0.9 (33)	1.0 (53)	280 (47)	47 (43)	202 (44)	7.5

† Six months (July to December).
‡ Parenthetic values equal the coefficient of variation [(standard deviation/mean) X 100]; storm runoff means based on a sample size of 12, waste water (TA-48) on a sample size of 9.

elsewhere with infiltration accounting for the remainder (4).

The alluvium in Mortandad Canyon is derived from erosion and weathering of a rhyolite tuff. This alluvium is quite permeable; studies using tritium and chloride as tracers indicate water velocity in the aquifer ranges from 2 to 20 m/day with the higher velocity occurring in the upper reaches of the canyon. Total travel time from the effluent outfall to the eastern extent of the aquifer (about 3 km) is about 1 year (4).

The water from the cooling process at TA-48 originates from a supply which contains ambient levels of the various chemicals. Chemicals are not added during use of this water, thus, chemical quality has not changed significantly through the years (Table 2). Analysis of storm runoff indicates little chemical changes over a 12-year observation period as evidenced by the generally small coefficients of variation (Table 2).

Liquid effluents from TA-50 are the major source of chemicals entering Mortandad Canyon (Table 2). Most of the measured chemical concentrations generally averaged 2 to 20 times higher in TA-50 effluent than in the other two sources (TA-48 and runoff). One exception was magnesium, which averaged higher in storm runoff water. Many of the chemicals in the effluent from TA-50 have increased since 1963 although not in a consistent pattern. Parameters exhibiting increases include magnesium, sodium, bicarbonate, chloride, nitrate, dissolved solids, and conductivity. Relatively stable or decreasing values were observed for calcium, carbonate, fluoride, total hardness, and pH.

The release of industrial effluents into the canyon has changed the quality of the water in the aquifer (Table 3). The pH of the water has changed from 6 to 8 due to the alkaline nature of the liquid effluents. Most of the remaining chemical parameters have increased since 1962, although not consistently with time. The levels of fluoride and bicarbonate have approximately doubled, while for values for calcium, magnesium, sodium, chloride, nitrate, dissolved solids, and specific conductance have increased by factors of 3 to 7. Carbonates remained nondetectable in aquifer water through the entire observation period due to their conversion to HCO_3^- and CO_2 under the conditions in the aquifer.

Annual average concentrations of sodium, chloride, nitrate, and total dissolved solids in the effluent were compared with corresponding concentrations in solution in the aquifer to determine the relationship between

Table 3—Chemical quality of water in aquifer

Year	Chemical constituents										Specific conductance at 25C	pH
	Calcium	Magnesium	Sodium	Carbonate	Bicarbonate	Chloride	Fluoride	Nitrate	Dissolved solids	Total hardness		
	mg/liter										µmhos/cm	
1962	11	4	32	0	91	7	0.6	3.0	320	45	360	6.8
1963	14	5	53	0	90	9	0.5	16	310	67	360	7.2
1964	19	7	100	0	123	21	0.7	68	500	76	510	7.5
1965	16	5	99	0	143	13	0.7	40	400	59	440	7.6
1966	18	4	97	0	172	25	0.4	28	400	62	470	7.7
1967	21	7	140	0	147	16	0.7	15	340	82	400	7.7
1968	17	6	110	0	138	12	0.7	8	300	68	360	7.9
1969	23	5	140	0	129	11	0.5	25	370	81	410	8.2
1970	26	7	132	0	143	15	0.5	137	530	84	560	7.6
1971	44	11	228	0	176	54	0.9	366	990	153	1,130	7.7
1972	40	11	215	0	223	54	0.7	248	910	144	1,000	7.5
1973	33	7	164	0	221	34	1.0	204	786	112	910	7.7
1974	27	6	188	0	254	32	1.0	207	785	93	970	7.7

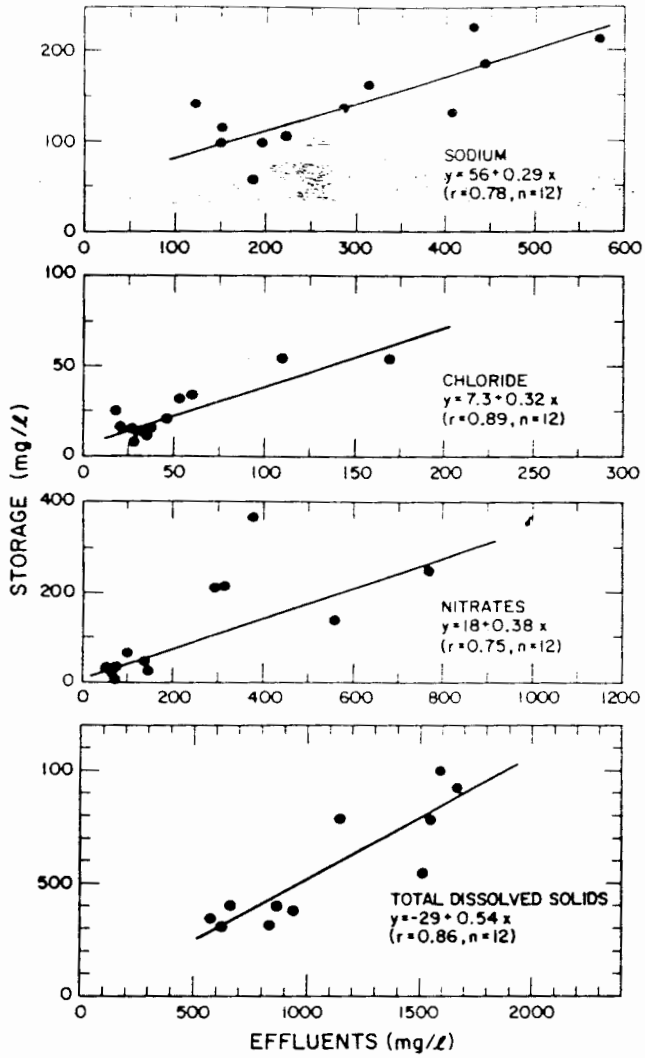

Fig. 2—The relationship of concentrations of sodium, chloride, nitrate, and total dissolved solids in treated effluent to corresponding concentrations in solution in the aquifer.

chemical release and levels appearing in the aquifer (Fig. 2). The linear least squares regressions were all highly significant ($P < 0.01$) with multiple correlation coefficients (r^2) ranging from 0.61 to 0.80.

The slopes of the four regression lines indicate that concentrations of the chemicals in solution in the aquifer averaged from 30–50% of those measured in the effluent when prerelease concentrations (i.e., intercept values) were taken into consideration. Recall that the chemical effluents from TA-50 are diluted with about equal volumes of storm runoff and TA-48 water. Thus, the reduction in chemical concentrations in the aquifer could be the result of dilution alone. The intercepts of the regression lines for sodium, chloride, and nitrate were not significantly different from pre-effluent release levels of chemicals in the aquifer indicating a rapid "turn-over" of

Table 4—Mass inventory of chemicals released and in storage

Constituents	Effluents, TA-50 1963–1974	In storage 1962	In storage 1974
	kg × 10³		
Calcium	35	0.2	0.5
Magnesium	1.8	0.08	0.1
Sodium	170	0.6	3.6
Carbonate	84	0	0.
Bicarbonate	150	1.8	4.8
Chloride	31	0.1	0.6
Fluoride	1.3	0.01	0.02
Nitrate	150	0.06	3.9
Total dissolved solids	640	6.4	15

the water in storage. This is supported by results of the tracer studies indicating water transit times of about 1 year (4).

The mass of chemicals added to Mortandad Canyon was estimated from the concentration and volume data in Tables 1 and 2. Corresponding estimates for aquifer water were made from data in Tables 1 and 3. About 625,000 kg of the eight chemicals listed in Table 4 were released into Mortandad Canyon from 1963–1974. Nearly 90% of this mass consisted of nitrates, bicarbonates, carbonates, and sodium with calcium, magnesium, chloride, and fluoride comprising the remainder.

Mass inventories of most of the chemicals in solution in the aquifer during 1974 were higher by factors of 2 to 65 over pre-effluent release inventories (Table 4) and averaged 1–6% of the total chemical releases. The largest increases over prerelease inventories were noted for sodium and nitrate, reflecting relatively larger concentrations of these chemicals in TA-50 effluent.

Chemical concentrations in solution in the aquifer have increased over prerelease levels, however, there has not been a steady accumulation of these materials in the water with time. The rapid loss of water and its associated chemicals from the aquifer prevents chemical accumulation and indicates that cessation of effluent release to the canyon would rapidly improve the quality of water in the aquifer.

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Mortandad Canyon Alluvial Wells

Mortandad Canyon Alluvial Wells (mg/L)

Location	Date	Code	Ag	Al	As	B	Ba	Cd	Cl	CN	Co	Cr	Cu	F	Fe	Hg	Mn	Mo	Ni	Pb	Se	SO_4	U	Zn	TDS[a]	pH[b]
MCO-3	4/2/81													3.8								128	0.0041		2632	9
MCO-3	10/26/81													3.9								36			732	10.2
MCO-3	4/21/82								33					2.9											1648	9.4
MCO-3	11/15/82																						0.0025			
MCO-3	3/30/83								17					3.1								14	0.001		468	7.9
MCO-3	10/31/83																						0.0206			
MCO-3	4/10/84								1					0.4								15	0.123		345	7.7
MCO-3	9/19/84																						0.123			
MCO-3	4/10/85								16					3.2								17	0.0054		322	8.7
MCO-3	9/23/85																						0.0026			
MCO-3	3/3/86								6					3.4								3	0.0002		175	8.6
MCO-3	9/15/86																						0.004			
MCO-3	3/1/87	no sample date							28					1.2								25			420	7.8
MCO-3	3/24/87								40					7.7								102	0.0038		963	7.9
MCO-3	11/6/87																						0.001			
MCO-3	4/7/88		< 0.001		0.003		0.031	< 0.001	17			0.014	0.01	1.1	0.46		0.104	0.003		0.002	0.002	12	0.001	0.009	247	7.7
MCO-3	4/26/89								294					6.4								102	0.004		1700	8
MCO-3	5/8/90		0.0002	0.456	0.001	0.14	0.0308	0.0005	11			0.0014	0.011	1.2	0.45	0.0002	0.025		0.0062	0.0005	0.001	18	0.0012	0.0092	352	8.3
MCO-3	8/28/91		< 0.0005	1	0.002	0.03		< 0.0005	7	0.017	< 0.03	0.0064	0.006	0.3	0.89	< 0.0002	0.044	0.059	< 0.01	0.004	0.05	5		0.032	250	7.5
MCO-3	10/29/92		< 0.03	0.72	< 0.002	0.07	0.04	< 0.01	16		< 0.004	< 0.02	0.04	1.1	0.57	0.0002	< 0.002	0.94	0.01	< 0.008	< 0.002	21	0.0025	< 0.006	468	8.1
MCO-4	4/2/81													3.2								73	0.0084		1100	8.2
MCO-4	10/26/81													4.2								78			1444	8.1
MCO-4	4/21/82								45					7.5								60	0.0036		1207	9.3
MCO-4	6/2/82					0.2		0.002	22			< 0.005	0.23	5.6		0.0001				0.031		60		0.437	1250	9.2
MCO-4	11/15/82																						0.0045			
MCO-4	1/1/83	no sample date				0.1		0.05				< 0.01	< 0.001			< 0.0001				0.01				0.07		
MCO-4	3/24/83								27					6.3								33	0.0023		788	7.5
MCO-4	10/31/83																			0.01			0.0371			
MCO-4	4/10/84								34					3.2								61	0.0115		1067	8.9
MCO-4	9/19/84																						0.0159			
MCO-4	4/11/85								31					4.7								27	0.0069		642	7.7
MCO-4	9/24/85																						0.0078			
MCO-4	3/3/86				< 0.002	0.18	0.08	< 0.001	29			< 0.005	0.093	4	0.428	< 0.0001	0.008			0.004	0.008	44	0.0097	0.05	944	7.7
MCO-4	9/15/86																						0.006			
MCO-4	3/1/87	no sample date							38					3.9								60			551	9.9
MCO-4	3/23/87								30					2.4								24	0.0024		601	8.4
MCO-4	11/6/87																						0.004			
MCO-4	4/11/88				0.003		0.218	< 0.001	38			0.002	0.01	2.9	0.23		0.018	0.006		0.002	0.001	50	0.006	0.014	1041	7.9
MCO-4	4/26/89								54					1.7								105	0.003		1060	7.5
MCO-4	5/8/90		0.0002	0.126	0.001	0.14	0.106	0.0005	29			0.051	0.0293	1.7	0.33	0.0002	0.0031		0.121	0.0036	0.001	53	0.0048	0.0866	910	7.8
MCO-4	8/28/91		< 0.0005	2.4	0.006	0.11		0.0006	29	0.034	< 0.03	0.0122	0.051	1.4	1.3	< 0.0008	0.268	0.01	< 0.01	0.016	0.09	30		0.07	500	7
MCO-4	11/6/92		< 0.03	1.07	< 0.002	0.096	0.16	< 0.01	15		< 0.004	< 0.02	< 0.03	1.6	0.7	0.0003	< 0.002	0.2	0.01	< 0.008	< 0.002	22	0.0038	0.03	614	7.5
MCO-4	7/19/93		< 0.01	9.6	0.002	0.1	0.22	< 0.003	19	0.03	< 0.004	0.02	0.035	1.2	6.8	0.0005	0.32	0.21	< 0.01	0.025	< 0.002	19	0.0052	0.06	724	7.4
MCO-4	6/23/94		< 0.02	2.2	0.002	0.053	0.076	< 0.003	12	< 0.01	< 0.004	0.028	0.02	1.8	1.4	0.0002	0.17	0.25	< 0.01	< 0.006	< 0.002	11	0.0018	0.043	396	7.8
MCO-5	4/2/81													1.9								72	0.0079		1066	8.3
MCO-5	4/21/82								34					2.3									0.0036		947	7.4
MCO-5	11/15/82																						0.0016			
MCO-5	3/29/83								28					6.1								42	0.0033		874	8.3
MCO-5	10/31/83																						0.0038			
MCO-5	4/10/84								39					4.2								79	0.0092		1190	7.7
MCO-5	9/19/84																						0.022			
MCO-5	4/11/85								37					1.5								36	0.0015		659	7.3
MCO-5	9/24/85																						0.0043			
MCO-5	3/3/86								29					4								53	0.0087		1071	7.7
MCO-5	9/15/86																						0.002			
MCO-5	3/1/87	no sample date							37					3								48			548	7.5
MCO-5	3/23/87								28					1.9								21	0.0017		1010	7.7
MCO-5	11/6/87																						0.004			
MCO-5	4/11/88				0.004		0.219	< 0.001	35			0.002	0.008	2.8	0.21		0.025	0.006		0.002	0.001	43	0.006	0.012	1086	7.6
MCO-5	4/26/89								66					1.6								100	0.003		1000	7.4

[a]TDS-Total Dissolved Solids
[b]Standard Units
Codes:D1-lab duplicate
R1-lab replicate
d-field duplicate
f-filtered; uf-unfiltered

Mortandad Canyon Alluvial Wells

Mortandad Canyon Alluvial Wells (mg/L)

Location	Date	Code	Ag	Al	As	B	Ba	Cd	Cl	CN	Co	Cr	Cu	F	Fe	Hg	Mn	Mo	Ni	Pb	Se	SO_4	U	Zn	TDS[a]	pH[b]
MCO-5	5/8/90		0.0002	1.1	0.001	0.14	0.18	0.0005	31			0.0125	0.0167	1.9	1.3	0.0002	0.0259		0.0085	0.0027	0.001	51	0.0029	0.041	982	7.5
MCO-5	8/28/91		< 0.0005	0.2	0.006	0.1		< 0.0005	31	0.033	< 0.03	0.0122	0.037	1.4	0.04	0.0009	0.309	0.011	< 0.01	0.02	0.08	31		0.063	488	7
MCO-5	11/6/92		< 0.03	1.08	< 0.002	0.089	0.1	< 0.01	13		< 0.004	< 0.02	< 0.03	1.9	0.24	0.0003	< 0.002	0.08	0.01	< 0.008	< 0.002	17	0.0021	0.007	400	8.1
MCO-5	7/19/93		< 0.01	7.3	0.002	0.07	0.21	< 0.003	17	0.02	< 0.004	0.013	0.031	1.2	5.7	< 0.0002	0.17	0.14	< 0.01	0.034	< 0.002	14	0.0027	0.13	574	7.2
MCO-5	6/23/94		< 0.02	2.9	< 0.002	0.05	0.12	< 0.003	16	< 0.01	< 0.004	< 0.004	0.013	1.9	1.8	0.0001	0.045	0.26	< 0.01	< 0.002	< 0.002	13	0.0021	0.034	506	7.6
MCO-5	8/1/95		< 0.01	0.38	0.006	0.054	0.078	< 0.004	18	< 0.01	< 0.004	< 0.004	< 0.004	1.5	0.25	< 0.0002	0.004	0.13	< 0.01	< 0.002	0.002	16	0.00144	< 0.02	406	7.27
MCO-6	4/2/81													2.4								69	0.0075		1192	7.8
MCO-6	10/26/81													2.2								72			1090	7.2
MCO-6	4/21/82								35					2.9									0.0042		1100	7.3
MCO-6	11/15/82																						0.0042			
MCO-6	3/29/83								25					5.1								44	0.0037		899	7.5
MCO-6	10/31/83																						0.007			
MCO-6	4/10/84								51					5.1								94	0.0212		1459	7.9
MCO-6	9/19/84																						0.013			
MCO-6	4/11/85								34					1.4								32	0.0031		618	7.4
MCO-6	9/24/85																						0.006			
MCO-6	3/3/86								29					2.9								52	0.0092		1037	7.8
MCO-6	9/15/86																						0.012			
MCO-6	3/1/87	no sample date							39					3.3								53			775	9
MCO-6	3/23/87								29					2.3								29	0.0027		751	7.6
MCO-6	11/6/87																						0.004			
MCO-6	4/12/88				0.004		0.206	< 0.001	30			0.001	0.014	2	1.1		0.145	0.006		0.006	< 0.001	20	0.003	0.025	338	6.8
MCO-6	4/26/89								27					1.9								38	0.004		782	7.3
MCO-6	5/8/90		< 0.0002	2.99	0.0019	0.14	0.184	0.0017	27			0.005	0.0114	1.9	2	0.0002	0.137		0.0109	0.0082	0.001	41	0.0059	0.045	1	7.4
MCO-6	8/28/91		< 0.0005	3.7	0.005	0.11		< 0.002	23	0.011	< 0.03	0.011	0.068	1.3	3.1	0.0009	0.293	0.015	0.03	0.016	0.07	30		0.089	584	2.2
MCO-6	11/5/92		< 0.03	0.1	< 0.002	0.083	0.1	< 0.01	16		< 0.004	< 0.02	< 0.03	2	0.05	0.0001	< 0.002	0.06	< 0.01	< 0.008	< 0.002	18	0.0022	0.009	378	8.3
MCO-6	7/19/93		< 0.01	12	< 0.002	0.08	0.29	< 0.003	19	0.02	0.006	0.011	0.026	1.2	8.1	< 0.0002	0.67	0.19	< 0.01	0.038	< 0.002	13	0.004	0.089	602	7.2
MCO-6	6/27/94		< 0.01	0.025	< 0.002	0.08	0.14	< 0.003	20	< 0.01	< 0.004	< 0.004	< 0.004	1.8	0.05	< 0.0001	< 0.002	0.25	< 0.01	< 0.002	< 0.002	16	0.0027	< 0.02	296	7.5
MCO-6	3/31/95	f	< 0.09	0.17	< 0.003	0.051	0.073	< 0.02	12.9	< 0.01	< 0.004	< 0.01	0.011	2.04	< 0.1	< 0.0002	< 0.003	0.19	< 0.01	< 0.002	< 0.002	15.7	0.00149	< 0.02	204	8.03
MCO-6	3/31/95	f d	< 0.09	1.3	< 0.003	0.05	0.074	< 0.004	13.1	< 0.01	< 0.004	< 0.009	< 0.01	2.12	< 0.1	< 0.0002	< 0.003	0.21	< 0.03	< 0.002	0.002	15.6	0.00146	< 0.02	370	7.78
MCO-6	3/31/95	uf	< 0.09	0.35	< 0.003	0.048	0.077	< 0.004	13.3	< 0.01	< 0.008	< 0.004	< 0.01	1.97	0.17	< 0.0002	< 0.02	0.21	< 0.02	< 0.002	0.003	15.7	0.00152	< 0.02	302	7.77
MCO-6	3/31/95	uf d	< 0.09	0.46	< 0.003	0.052	0.077	< 0.015	13.4	< 0.01	< 0.01	< 0.006	< 0.07	2.06	0.3	< 0.0002	0.033	0.2	< 0.01	< 0.002	0.002	15.7	0.00149	0.18	372	7.74
MCO-6	6/27/95	f	< 0.0111	0.267	< 0.0022	0.0589	< 0.0833	< 0.0033		< 0.00001	< 0.0044	< 0.0044	< 0.0044	1.86	0.133	< 0.0002	< 0.0033	0.144	< 0.0111	< 0.0022	< 0.0012	18.8	0.00203	< 0.0222		
MCO-6	6/27/95	f d	< 0.0111	0.256	< 0.0022	0.0589	< 0.0822	< 0.0033		< 0.00001	< 0.0044	< 0.0056	< 0.0044	1.86	0.111	< 0.0002	< 0.0033	0.156	< 0.0111	< 0.0022	< 0.0011	18.8	0.00187	< 0.0222		
MCO-6	6/27/95	f d	D1							0.00001				1.876												
MCO-6	6/27/95	uf	< 0.0111	0.444	< 0.0022	0.0589	< 0.0822	< 0.0033		< 0.00001	< 0.0044	< 0.0067	< 0.0044	1.86	0.2	< 0.0002	< 0.0033	0.156	< 0.0111	< 0.0022	< 0.0011	18.8	0.00184	< 0.0222		
MCO-6	6/27/95	uf d	< 0.0111	0.389	< 0.0022	0.0589	< 0.0844	< 0.0033		< 0.00001	< 0.0044	< 0.0044	< 0.0044	1.88	0.189	< 0.0002	< 0.0033	0.156	< 0.0111	< 0.0022	< 0.0011	18.8	0.00183	< 0.0222		
MCO-7	4/2/81													0.8								38	0.0021		354	7.1
MCO-7	10/26/81													0.4								40			406	6.7
MCO-7	4/21/82								22					0.7									0.0016		383	7
MCO-7	11/15/82																						0.0011			
MCO-7	3/29/83								30					0.6								39	0.0022		688	7.5
MCO-7	10/31/83																						0.0032			
MCO-7	4/10/84								44					0.4								42	0.0011		422	6.8
MCO-7	9/19/84																						0.0025			
MCO-7	4/11/85								46					1.5								63	0.0058		1040	7.4
MCO-7	9/23/85																						0.0081			
MCO-7	3/3/86				< 0.002	0.13	0.12	< 0.001	32			< 0.005	0.063	2	0.02	< 0.0001	0.022			0.001	0.005	41	0.0047	0.08	854	7.4
MCO-7	9/15/86																						0.003			
MCO-7	3/1/87	no sample date							35					3.3								40			777	7.6
MCO-7	3/23/87								30					2.4								37	0.0056		622	8.3
MCO-7	11/6/87																						0.003			
MCO-7	4/11/88				0.003		0.195	< 0.001	36			0.002	0.004	2.8	0.27		0.116	0.02		0.004	0.001	41	0.002	0.025	968	7.5
MCO-7	4/26/89								33					1.5								39	0.004		762	7.8
MCO-7	5/8/90		0.0002	7.4	0.0031	0.2	0.115	0.0005	28			0.0052	0.0306	1.9	3.9	0.0002	0.214		0.0082	0.0115	0.001	21	0.0013	0.047	1	7.1
MCO-7	8/28/91		0.001	3.2	0.006	0.11		< 0.002	23	0.011	< 0.03	0.0184	0.041	1.7	2.6	0.0019	0.687	0.015	0.03	0.029	0.07	30		0.078	444	6.9
MCO-7	11/4/92		< 0.03	0.16	0.0024	0.089	0.18	< 0.01	27		< 0.004	< 0.02	< 0.03	1.5	0.09	0.0003	< 0.002	< 0.03	< 0.01	< 0.008	< 0.002	38	0.0004	0.006	376	7.6
MCO-7	7/19/93		< 0.01	44	0.007	0.08	0.74	< 0.003	25	0.02	0.008	0.027	0.07	1	31	< 0.0002	0.65	0.031	0.03	0.041	< 0.002	17	0.0041	0.17	614	7.1
MCO-7	6/27/94		< 0.01	9.14	0.004	0.085	0.4	< 0.003	19	< 0.01	< 0.004	0.02	0.1	1.3	7.63	0.0001	0.187	0.05	< 0.01	0.027	< 0.002	19	0.0046	0.0525	509	7.2

[a]TDS-Total Dissolved Solids
[b]Standard Units
Codes:D1-lab duplicate
R1-lab replicate
d-field duplicate
f-filtered; uf-unfiltered

Mortandad Canyon Alluvial Wells

Mortandad Canyon Alluvial Wells (mg/L)

Location	Date	Code	Ag	Al	As	B	Ba	Cd	Cl	CN	Co	Cr	Cu	F	Fe	Hg	Mn	Mo	Ni	Pb	Se	SO_4	U	Zn	TDS[a]	pH[b]
MCO-7	3/30/95	f	< 0.08	0.42	0.004	0.056	0.16	< 0.004	11.7	< 0.01	0.006	0.006	< 0.007	1.76	0.2	< 0.0002	< 0.003	0.18	< 0.03	< 0.002	< 0.002	12.7	0.00126	< 0.02	324	7.69
MCO-7	3/30/95	f d	< 0.08	< 0.3	0.004	0.058	0.15	< 0.015	11.7	< 0.01	< 0.007	< 0.007	0.008	1.83	0.15	< 0.0002	< 0.003	0.16	< 0.03	< 0.002	< 0.002	12.6	0.0013	< 0.02	304	7.67
MCO-7	3/30/95	uf	< 0.07	1	0.003	0.061	0.17	< 0.004	11.7	< 0.01	< 0.004	< 0.009	< 0.012	1.79	0.58	< 0.0002	0.032	0.18	< 0.03	< 0.002	< 0.002	12.7	0.00134	< 0.02	312	7.68
MCO-7	3/30/95	uf d	< 0.07	3	0.008	0.073	0.2	< 0.004	11.9	< 0.01	< 0.004	0.015	0.013	0.82	1.4	< 0.0002	0.033	0.21	< 0.03	< 0.002	< 0.002	12.8	0.00122	< 0.02	164	7.47
MCO-7	3/30/95	uf d R1	< 0.07	3.1	0.004	0.06	0.17	< 0.004			< 0.004	0.006	0.02		1.4		0.029	0.19	< 0.03	< 0.002	< 0.002			< 0.02		
MCO-7	6/28/95	f	< 0.01	1.87	< 0.0034	0.0632	< 0.152	< 0.0033		< 0.01	< 0.0044	< 0.0049	< 0.0044	1.96	0.972	< 0.0002	< 0.007	0.18	< 0.0111	< 0.0022	< 0.0011	16.6	0.00178	< 0.0222		
MCO-7	6/28/95	uf	< 0.01	21.5	< 0.0073	0.0722	0.268	< 0.0033		< 0.01	< 0.0071	0.0232	0.0332	1.95	12	< 0.0002	0.209	0.188	< 0.0111	0.0156	< 0.0027	17.4	0.00223	0.0699		
MCO-7	8/10/95	f	< 0.01	0.1	0.004	0.07	0.15	< 0.003	16	< 0.01	< 0.004	< 0.004	0.005	1.89	0.1	0.0002	< 0.002	0.15	< 0.01	0.001	< 0.001	19	0.00182	0.02	440	7.45
MCO-7	8/10/95	uf	< 0.01	13	0.007	0.08	0.24	< 0.003	15	< 0.01	< 0.004	0.009	0.019	1.88	6.7	< 0.0002	0.15	0.15	0.01	0.01	0.001	19	0.0024	0.04	434	7.3
MCO-7.5	4/2/81													0.7								23	0.0012		268	7.1
MCO-7.5	10/26/81																						0.0011			
MCO-7.5	6/2/82					0.1		0.002	22			< 0.005	0.13	0.7		0.0005				0.08		76		0.168	938	6.8
MCO-7.5	11/15/82																						0.0023			
MCO-7.5	1/1/83	no sample date				0.09		0.09				< 0.01	0.007			< 0.0001				< 0.01				0.25		
MCO-7.5	3/29/83								30					0.6								51	0.0032		964	7.8
MCO-7.5	10/31/83																			< 0.01			0.0023			
MCO-7.5	4/10/84								42					0.8								42	0.0057		959	7.5
MCO-7.5	4/11/85								49					1.3								63	0.0077		1049	7.4
MCO-7.5	9/23/85																						0.0028			
MCO-7.5	3/3/86								32					2.7								41	0.0066		850	7.4
MCO-7.5	9/15/86																						0.005			
MCO-7.5	3/1/87	no sample date							35					3.2								40				7.7
MCO-7.5	3/23/87								30					2.5								38	0.0057		592	8.3
MCO-7.5	11/6/87																						0.003			
MCO-7.5	4/11/88				0.004		0.288	< 0.001	36			0.001	0.007	2.8	0.61		0.308	0.015		0.007	< 0.001	41	0.002	0.026	938	7.3
MCO-7.5	4/26/89								26					1.6								40	0.004		770	7
MCO-7.5	5/8/90		0.0002	4.5	0.001	0.17	0.245	0.0005	28			0.0047	0.0074	1.45	3.3	0.0002	0.156		0.0071	0.0063	0.001	41	0.0022	0.021	792	7.1
MCO-7.5	8/28/91		0.001	3	0.006	0.1		< 0.002	23	0.011	< 0.03	0.0177	0.025	1.2	2.4	0.001	0.29	0.014	0.03	0.017	0.08	29		0.058	446	7.1
MCO-7.5	11/4/92		< 0.03	0.13	< 0.002	0.1	0.16	< 0.01	24		< 0.004	< 0.02	< 0.03	1.5	0.08	0.0003	< 0.002	< 0.03	< 0.01	< 0.008	< 0.002	23	0.0015	< 0.006	492	8.4
MCO-7.5	6/27/94		< 0.01	15	0.002	0.08	0.54	< 0.003	22	< 0.01	0.005	0.017	0.022	1.1	13	0.0001	0.29	0.06	< 0.01	0.02	< 0.002	15	0.001	0.08	480	7.1
MCO-7.5	8/1/95		0.011	1	< 0.002	0.07	0.14	< 0.01	13.6	< 0.01	< 0.01	< 0.004	< 0.004	1.38	0.55	< 0.0002	0.016	0.04	< 0.01	< 0.002	0.001	14	0.00148	< 0.02	414	7.51

[a]TDS-Total Dissolved Solids
[b]Standard Units
Codes: D1-lab duplicate
R1-lab replicate
d-field duplicate
f-filtered; uf-unfiltered