PATHFINDER

A Cogema Resources Company

August 29, 2001

Mr. Melvyn Leach, Chief
Fuel Cycle Licensing Branch
Division of Fuel Cycle Safety and Safeguards
Office of Nuclear Material Safety and Safeguards
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555-0001

Ref: Source Material License No. SUA-442, Docket No. 40-6622

Dear Mr. Leach:

Enclosed please find five copies of a revision to the Shirley Basin Application for Alternate Concentration Limits that was prepared in response to NRC comments to Pathfinder in a letter dated July 20, 2001. Included are directions for the insertion of the pages, and a summary memorandum that indicates where in the revision to find the responses to the Request for Additional Information transmitted in the July 20, 2001 letter.

Item 12 in the request is not directly addressed in the enclosed revision. Pathfinder feels that it is premature to be required to produce evidence of Pathfinder ownership of all land that is anticipated for eventual transfer to the Department of Energy. The size of the area owned by a local rancher that we intend to acquire was based upon the modeling assumptions and conclusions that are integral to the ACL application. For all we know the ongoing NRC review process may lead Pathfinder to conclude that a different sized area must be acquired. We feel that it is more logical to complete the ACL review process, and if the NRC grants the requested ACLs, to do so conditioned upon Pathfinder acquiring the lands involved.

We fully understand that Pathfinder's exclusive control of the area of concern around Spring Creek is vitally important to the ACLs and final site transfer to the DOE. We have entered into discussions with the rancher concerning the purchase of the land, but such discussions often take considerable time before a deal is consummated. It does not make sense to hold up the ACL application review pending land acquisition. By conditionally approving ACLs, the burden will then be on Pathfinder to acquire the land. If we should fail to do so, we would then jeopardize the approved ACLs and final site transfer. In the interim Pathfinder has an exclusive lease on the relevant land which runs through 2005 with an option to extend the lease to 2015. As a result Pathfinder currently controls access to the area and will continue to do so until a final purchase is completed.

NMSS01 Public

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We trust that these revisions to the Shirley Basin ACL application adequately address the issues raised by the NRC staff. We look forward to approval of the application. Please call me if you have any questions.

Sincerely,

Tom Hardgrove

T. W. Hardgrove
Operations Manager

Enclosures

Cc: C. Cain, US NRC, Region IV
Gary Beach, Wyoming DEQ/LQD
D. L. Wichers
J. R. Blaise

Discussion of Changes in the ACL Application.

The changes in and additions to the Application for Alternate Concentration Limits for the Pathfinder Mines Corporation Shirley Basin site have been made to address concerns expressed by U.S.N.R.C. personnel. The following brief discussion indicates where particular comments or concerns were addressed in the revised ACL document.

Comment 1: Substitution of SDWA MCL for selenium.

Discussion: Selenium has been added as an ACL constituent with the site standard of 0.01 mg/l as the applicable standard. This change is included throughout the document.

Comment 2: Other hazardous constituents which exceed the site standards.

Discussion: Like selenium, radium-226 + radium-228 has been added as an ACL constituent. In section 1.3.6.1 of the revised document, a detailed discussion of additional constituents is included. Also, the recent annual Corrective Action Report (referenced in the ACL document) included mapping of site standard constituents. This annual report also includes water quality tabulations for the constituents. This information was used in considering additional constituents for ACL's.

Comment 3: Uranium toxicity.

Discussion: Section 2.3 and Appendices A, B and C of the report have been revised to consider new information on chemical toxicity of uranium.

Comment 4: NEPA constituents.

Discussion: Section 5.0 has been revised/added to include modeling and analysis of these additional non-hazardous constituents. In addition, potential health and environmental concerns of these constituents is addressed in Section 2.3.2.4 and Appendices A, B and C.

Comment 5: Sampling of the POE.

Discussion: Section 4.2.1 has been revised to include sampling of the POE as well as other wells and points along Spring Creek.

Comment 6: Table of input parameters.

Discussion: Table 2.2-1 was added to the report to present a summary of modeling inputs.

Comment 7: Model inputs for uranium.

Discussion: A more thorough discussion of the derivation of model inputs for uranium is included in Section 2.1.2.4 and provides details of some preliminary modeling.

Comment 8: Potential migration under Spring Creek.

Discussion: Additional wells were drilled on the northeast side of Spring Creek. A discussion of the water-level elevations and sampling results for these wells is included in Section 1.2.4.3. This discussion addresses the potential for migration under Spring Creek. The analysis indicates that the Spring Creek is functioning as a hydraulic boundary, and that seepage migration under Spring Creek is very unlikely.

Comment 9: Risk to aquatic organisms.

Discussion: Portions of Section 2.3 and Appendix C have been modified to address the risk to aquatic organisms.

Comment 10: POE location.

Discussion: As mentioned in the response to comment 5, the POE and 2 other points along Spring Creek are included in the monitoring program. Additionally, an analysis of the selection of the POE and the progressive loading of Spring Creek is included in Section 2.2.2.4.

Comment 11: Post-CAP monitoring.

Discussion: Section 4.2.1 has been revised to include a relatively high frequency sampling of additional points following termination of the CAP. This sampling will continue for one year, and will be followed by a semi-annual sampling of the POC wells and the POE through the year 2005.

Comment 12: Property ownership.

Discussion: Pathfinder Mines Corporation (PMC) is in the process of negotiating to acquire the relevant property. The premise of the ACL application is that the POE is the point at which there will be some access. By designating the POE, PMC has committed to controlling or preventing access prior to reaching the POE. Thus, the review can proceed under the assumption that land ownership or control issues will be resolved in accordance with the ACL application.

REPLACEMENT PAGES

The following pages have been revised and are included for replacement or addition to "Application For Alternate Concentration Limits, Pathfinder Mines Corporation, Shirley Basin Mine".

Page No.	Action
Cover	Replace current cover
Tabs	Replace Tab 5.0 and add Tab 6.0
Pgs. i thru vii	Replace Entire Table of Contents With Pgs. i thru x
Pg. P-1	Replace Preface (Pg. P-1)
Pgs. ES-1 thru ES-3	Replace Executive Summary (Pgs. ES-1 thru ES-3)
Pgs. 1.1-1 and 1.1-2	Replace Pgs. 1.1-1 and 1.1-2
Pgs. 1.2-1 thru 1.2-8	Replace Pgs. 1.2-1 thru 1.2-8 and add Pgs. 1.2-8a thru 1.2-8c
Pg. 1.2-13	Replace Pg. 1.2-13 and add Pgs. 1.2-14 and 1.2-15
Pgs. 1.3-1 thru 1.3-10	Replace Pgs. 1.3-1 thru 1.3-10 and add Pgs. 1.3-10a thru 1.3-10d and add Pgs. 1.3-17 thru 1.3-22
Pg. 1.4-1	Replace Pg. 1.4-1
Pgs. 1.5-1 and 1.5-2	Replace Pgs. 1.5-1 and 1.5-2
Pgs. 2.1-1 thru 2.1-11	Replace Pgs. 2.1-1 thru 2.1-11 and add Pgs. 2.1-11a thru 2.1-11c
Pgs. 2.1-15 and 2.1-16	Remove Pgs. 2.1-15 and 2.1-16
Pgs. 2.2-1 thru 2.2-7	Replace Pgs. 2.2-1 thru 2.2-7 and add Pgs. 2.2-8 thru 2.2-16
Pgs. 2.3-1 thru 2.3-7	Replace Pgs. 2.3-1 thru 2.3-7 and add Pgs. 2.3-8 thru 2.3-9
Pgs. 3.1-1 thru 3.1-6	Replace Pgs. 3.1-1 thru 3.1-6 and add Pgs. 3.1-7 thru 3.1-8
Pgs. 3.2-1 and 3.2-2	Replace Pgs. 3.2-1 and 3.2-2
Pgs. 3.3-1 and 3.3-2	Replace Pgs. 3.3-1 and 3.3-2
Pgs. 3.4-1 thru 3.4-4	Replace Pgs. 3.4-1 thru 3.4-4
Pgs. 3.5-1 thru 3.5-4	Replace Pgs. 3.5-1 thru 3.5-4
Pg. 4.1-1	Replace Pg. 4.1-1
Pg. 4.2-1	Replace Pg. 4.2-1
Pg. 5.1-1	Replace Pg. 5.1-1 and add Pgs. 5.1-2 thru 5.1-6
Pg. 5.2-1	Add Pg. 5.2-1
Pg. 6.1-1	Add Pgs. 6.1-1 and 6.1-2
Appendix A	Replace Appendix A
Appendix B	Replace Appendix B
Appendix C	Replace Appendix C

REPLACEMENT PAGES (CONTINUED)

Page No.	Action
Appendix E	Replace Cover
Pgs. E-i thru E-ii	Replace Table of Contents With Pgs. E-i thru E-iv
Pg. E.1-1	Replace Pg. E.1-1
Pgs. E.2-1 and E.2-2	Replace Pgs. E.2-1 and E.2-2
Pgs. E.2-45 thru E.2-92	Add Pgs. E.2-45 thru E.2-92
Pgs. E.3-1 thru E.3-3	Replace Pgs. E.3-1 and E.3-3
Pgs. E.3-12 thru E.3-19	Add Pgs. E.3-12 thru E.3-19
Pg. E.4-1	Replace Pg. E.4-1
Appendix G	Add Appendix G with Tab

APPLICATION FOR:

ALTERNATE CONCENTRATION LIMITS
PATHFINDER MINES CORPORATION
SHIRLEY BASIN MINE

PREPARED FOR:

PATHFINDER MINES CORPORATION
SHIRLEY BASIN MINE

LICENSE NO. SUA-442

DOCKET NO. 40-6622

MARCH 2000
REVISED 06/01/2000
REVISED 08/28/2001

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PREFACE

This report presents a summary of the hydrologic conditions at the Shirley Basin Site in support of Alternate Concentration Limits (ACLs) for uranium, selenium, radium-226 + radium 228 and thorium-230. The 1999 Annual Report (Hydro-Engineering L.L.C., 2000) presents an updated analysis of the ground-water monitoring results with time plots for all site standard constituents. The 2000 Annual Report (Hydro-Engineering L.L.C., 2001) presents updated constituent mapping. The 1999 and 2000 Annual Reports present a tabulation of all Surficial Aquifer water-quality data in Appendix A. Ground-water conditions have also been defined in previous documents (see Hydro-Engineering, 1982, Robertson-Pincock, 1980). Monitoring results for this site have been presented in numerous documents and are listed in the Annual Reports (Hydro-Engineering, 1984-1996, and Hydro-Engineering L.L.C., 1997-1999). This report is written to summarize hydrologic conditions at the Shirley Basin Site, and these previous reports should be referred to for details.

Appendices A, B and C in this ACL report present details of the exposure assessment for this site. Section 2.3 of this report presents a summary of the results from these appendices. Appendices A, B and C and Section 2.3 were prepared by Kenneth R. Baker, Ph.D. of Environmental Restoration Group, Inc. Appendices D and E present the water-flow modeling and transport modeling, respectively. Appendix F presents summary water quality graphs and statistics. Page, figure, and table numbers are sequenced by the subsection number. Tables are located after their initial reference while all figures follow all text in their respective subsection.

With this revision (August, 2001) of the application for ACLs, the timeframe of the modeling in support of the ACLs has been obviated by the passage of time. The operation of the Corrective Action Program (CAP) is continuing beyond the proposed termination date of mid-2001. However, this continuation of the CAP beyond the planned termination date will only make initial predictions of seepage impacts more conservative, and will not adversely affect the protection of public health and safety or the environment in any way. Therefore, the modeling was not updated.

EXECUTIVE SUMMARY

This document is an application for alternate concentration limits (ACLs) for Pathfinder Mines Corporation (PMC), Shirley Basin Site and follows the Nuclear Regulatory Commission (NRC) guidelines (NRC, 1996). The NRC has set the following site standards for the ground water at the site:

TABLE E-1. PMC SHIRLEY BASIN NRC SITE STANDARDS.

CONSTITUENTS	NRC
ARSENIC	0.05
BARIUM	1.0
BERYLLIUM	0.02
CADMIUM	0.01
CHROMIUM	0.05
GROSS ALPHA	15
LEAD	0.05
MOLYBDENUM	0.1
NICKEL	0.05
RADIUM-226 + RADIUM-228	5.0
SELENIUM	0.01
THORIUM-230	0.3
URANIUM	0.07

NOTE: All concentrations are in mg/l except: Radium-226 + Radium-228, Gross Alpha and Thorium-230 are in pCi/l.

The NRC site standards for uranium, selenium, radium-226 + radium-228 and thorium-230 will be exceeded at the two points of compliance (POC) after the completion of restoration efforts. The ground-water concentrations for arsenic, barium, beryllium, cadmium, chromium, lead, molybdenum, and nickel are presently low, and alternate concentration limits (ACL's) will not be required for these site standards. The site standard for selenium of 0.01 mg/l is lower than the current EPA drinking water standard of 0.05 mg/l, but the ACL is based on the present site standard. This document provides support for and proposes ACLs for uranium, selenium, radium-226 + radium-228 and thorium-230 at the POC's that will prevent the exceedence of the concentrations stated in Table E-2 at the proposed point of exposure (POE). The following POE and POC concentrations are proposed:

TABLE E-2. PROPOSED CONCENTRATIONS.

CONSTITUENTS	POE Concentrations	Range of POC Concentrations
URANIUM	0.15	4.40 – 4.45
SELENIUM	0.0056	0.158 - 0.163
RADIUM-226 + RADIUM-228	1.5	12.7 - 13.76
THORIUM-230	0.30	5.53 – 5.76

NOTE: Uranium concentration and selenium concentration are in mg/l, radium-226 + radium-228 activity and thorium-230 activity are in pCi/l.

Based on historic data for well MC-14, background water-quality concentrations or activities at this site are above the site standards for uranium, thorium-230, gross alpha, and radium-226 + radium-228. However, the occurrences of elevated gross alpha, and radium-226 + radium-228 activities in MC-14 are infrequent and systematic in nature. As such, they are considered analytical or sampling errors that correspond with specific sampling cycles. South and west of the tailings impoundments, radium-226 + radium-228 activity is elevated and the selenium concentration exceeds the drinking water standard of 0.05 mg/l in a significant number of samples. The greater selenium concentration in this area occurs in some wells that are hydraulically isolated from tailings and is thought to be natural or the result of water table fluctuations that mobilize the constituents at the water table.

The recharge to the Surficial Aquifer is local, and there is not a contiguous regional Surficial aquifer system in the tailings area. The Surficial aquifer in the tailings area is bounded roughly on the northeast by Spring Creek and on the west by the Area 2 reclaimed mine pit. There is also a zero-saturation boundary southeast of the tailings where the Surficial sands are absent or are too shallow to be saturated. Northwest and southwest of the tailings the piezometric surface is maintained by local recharge. Seepage from the tailings impoundments mixes with local recharge directly beneath the tailings.

Detailed hydrologic conditions have been defined for the quantity of water and drainage from the tailings area. A dewatering program has been designed to remove a substantial portion of the drainable water from the tailings. The long-term average drainage rate of the water that is not removed by dewatering has been estimated and presented in Section 2.1. The mixture of seepage from the tailings with the un-impacted Surficial ground water will require ACL's for this site.

Parameters developed from observed site ground-water conditions were used to predict the ion migration of the ACL constituents during post restoration conditions. These simulations, which represent as low as reasonably achievable (ALARA) conditions, were used to establish the ACL concentrations.

Exposure assessments were used to develop the proposed POE concentrations. This analysis shows that these concentrations are safe for down-gradient surface and ground-water users. A risk assessment was also conducted for the major non-hazardous constituents of chloride, sulfate and TDS. Concentrations of these constituents are shown to be within their State use standards.

The corrective action program consists of aggressive dewatering of the tailings until mid 2001 in conjunction with continued operation of the Surficial aquifer collection and injection system until January 2001 or after. The analysis of the corrective action demonstrates that ALARA conditions can be met with this restoration program.

1.0 GENERAL INFORMATION

1.1 INTRODUCTION

This Alternate Concentration Limit (ACL) application is being submitted in accordance with 10 CFR, Part 40, Appendix A, Criterion 5B(6). Site-specific ACL's may be established by the United States Nuclear Regulatory Commission (NRC) if it can be shown that the constituents will not pose a substantial present or potential hazard to human health or the environment as long as the ACL's are not exceeded. It must also be demonstrated that the proposed ACL's are as low as reasonably achievable (ALARA). This application and the attachments provide sufficient evidence that these requirements have been met.

The groundwater restoration program at the Shirley Basin tailings facility has been operating since 1984, in compliance with a corrective action plan (CAP) approved by the NRC in 1989. The site is regulated by the NRC under radioactive materials license SUA-442.

A collection and injection system was designed to contain the seepage from the solid tailings storage area and restore the Surficial ground-water quality. The CAP consists of collecting contaminated water in the Surficial aquifer near the tailings impoundments and injecting non-contaminated fresh water into the aquifer down-gradient of this area to reverse the water flow toward the collection wells. A series of injection wells are also used to establish a hydraulic barrier in the Surficial aquifer along the east and northeast side of the No. 5 tailings impoundment. In addition, dewatering of the tailings impoundments is on-going. The contaminated water collected from the wells (collection water) has been evaporated or discharged to the Area 2/8 reclamation reservoir if it met specific water quality standards.

In 1989, the NRC established site standards for arsenic, barium, beryllium, cadmium, chromium, gross alpha, lead, molybdenum, radium-226 + radium-228, selenium, thorium-230, and uranium based on the average of a small number of samples taken from an up-gradient background well or based on EPA drinking water concentration levels at the time. The operation of the CAP for over 16 years has resulted in the restoration of ground-water quality in the identified north and south plumes in the Mine Creek area. However, even after the tailings have been dewatered to the extent practicable, the concentrations of uranium, selenium, radium-226 + radium-228 and thorium-230 at the point of compliance (POC) wells will not remain below the site standards. The background concentrations of uranium and thorium-230 at well MC-14 also routinely exceed the site standards. For uranium, selenium, radium-226 + radium-228 and thorium-230, small quantities of seepage from the tailings are predicted to produce measurable elevations above background at the POC wells for a few decades. The seepage from the tailings after the planned dewatering until mid 2001 will be at a small rate that limits the concentrations at the POC wells, but also extends the duration of the elevated concentrations for a relatively long period of time. Continued restoration efforts beyond the planned dewatering until mid 2001 will be shown to be impractical. While ACLs will be required for these constituents, the calculations show that the concentrations at the point of exposure (POE) will be within acceptable limits.

1.2 FACILITY DESCRIPTION

PMC's Shirley Basin Mine site is located in southeast Wyoming as shown in Figure 1.2-1. The former uranium mill and mine site is located approximately 5 miles northeast of the former Shirley Basin town site. The town of Shirley Basin functioned primarily as a mining camp and has been entirely abandoned for more than 10 years. The nearest residence is a ranch location approximately three miles east of the tailings area.

The uranium mining in this area was in the Shirley Basin Mining district. PMC's mine site is just north of Petrotomics' mine. Final reclamation is nearing completion for PMC's mine pits, which create two reclamation reservoirs.

1.2.1 URANIUM MILL FACILITIES

Uranium milling began at this site in 1971 and continued through 1992 when the last ore was processed. The mill has been decommissioned according to the decommissioning plan submitted to the NRC in June 1992. Figure 1.2-2 shows the former mill area. A total of 8,564,130 tons of ore were milled at the site. The mill utilized a conventional acid leaching process. The mill was demolished and placed in disposal trenches adjacent to the mill site and covered with uncontaminated soil.

The Tailings Reclamation Plan (TRP) specifies a cover system consisting of 2.5 feet of clay radon/infiltration barrier overlain by 0.5 feet of sandier material for the mill area. An erosion protection cover of topsoil or rock mulch and filter will overlay the barrier cover. Portions of the milling process equipment, including the dryer, were buried within the No. 4 Tailings Impoundment.

Figure 1.2-2 shows the location of the two solid tailings impoundments (the No. 4 and No. 5 Tailings impoundments) and the No. 3 Pond, which was used to contain tailings solution.

The No. 4 Tailings impoundment covers approximately 158 acres and appreciable (more than a few feet) depths of solid tailings were deposited over roughly 120 acres of the pond. The No. 5 Tailings impoundment covers approximately 135 acres with tailings thicknesses of more than a few feet over approximately 110 acres. No solid tailings were deposited in Pond No. 3, which covers roughly 30 acres, but the area is used for disposal of ISL waste materials. There is interim cover over the No. 5 Tailings impoundment and over the exposed portions of the No. 4 impoundment. The maximum tailings thickness is approximately 63 feet in the No. 5 Tailings and the maximum thickness in the No. 4 Tailings is approaching 60 feet.

1.2.2 OFF-SITE POPULATIONS

There are currently no downstream or down-gradient residences within six miles of the tailings area. The nearest ranch residence is approximately three miles east of the tailings area and is located upgradient of the tailings in the flood plain of the Little Medicine Bow River. The confluence of Spring Creek, which bounds the Surficial Aquifer east of the tailings, and the Little Medicine Bow River is downstream of both the tailings area and the ranch site. This precludes any potential hydraulic communication in surface water or Surficial ground water between the tailings and the ranch home site.

1.2.3 GROUND-WATER RESTORATION FACILITIES

Pumping from five Surficial Aquifer collection wells installed downgradient (5A1, P3, P4, P6, and P7), began in November of 1984 (see Figure 1.2-3 for location of wells). Collection from well P4 ceased on November 28, 1984 because of very low yield. This left four collection wells operating to capture tailings seepage in the Surficial aquifer in the Mine Creek area. The initial monitoring program indicated that containment of seepage, or gradient reversal, was successful only in the permeable portions of the Surficial aquifer. It was determined that a water recharge system in conjunction with more pumping wells would be needed to insure continuous gradient reversal in the Mine Creek seepage areas of the Surficial aquifer. Consequently, a fresh water recharge system was constructed during the summer of 1986, and three more collection wells were added to the pumpback system.

Pumping from the three new wells, P1, P8A, and P9, began on October 6, 1986. Further monitoring, from late 1986 through August 7, 1987, indicated the need for two more pumping wells and better distribution of water in the North recharge line. Consequently, collection wells P10 and P11 and a permanent re-distribution water line from WW23 were added. Pumping of collection wells P1 and P7 was discontinued on August 9, 1990 because of low yields.

A series of injection, collection, and monitor wells were added to the ground-water restoration system in 1994. Twelve Surficial injection wells were installed on the interior of the northern edge of the No. 5 tailings dam (see Figure 1.2-3) with operation beginning on 5/2/94. The wells were placed 100 to 200 feet apart to produce a ground-water "ridge" as a barrier to seepage. The initial injection rate was approximately 25 gpm, but has declined to approximately 9 gpm with development of a ground-water mound. The source of the injection water is well WW20. With the exception of brief periods of down time for maintenance of individual wells, the system has operated continuously. Additional Surficial collection wells are distributed throughout the tailings area. Five additional Surficial monitoring wells were also installed on the northeast side of the No. 5 Tailings Dam to analyze the effectiveness of the injection/collection system.

In 1995, additional collection and injection wells were installed. Extraction from newly installed collection wells P12 through P21 began in 1996. The original common suction line pumping system was later converted to individual pumps. Extraction from the Surficial aquifer is supplemented with 16 collection wells within the tailings area. Injection wells TWI-12 through TWI-20 and TWI-22 extended the injection system along the No. 5 Dam to the south. Figure 1.2-3 presents the location of the injection and collection systems in the Surficial aquifer.

1.2.4 SURFACE WATER

Surface waters in the vicinity of the tailings include Mine Creek, the perennial streams Spring Creek and Fox Creek, the Area 3 and Area 2/8 reclamation reservoirs, and the Industrial Pond. The current continuous flow in Mine Creek results almost entirely from fresh-water recharge. Fox Creek is tributary to Spring Creek on the east side of Spring Creek (see Figure 1.2-4 for location). Fox Creek is only incised a few feet and flows into Spring Creek at an elevation that is a few feet above the elevation of the Mine Creek confluence, so there is no question that Fox Creek is hydraulically upgradient of seepage from the tailings. Indications are that the Surficial aquifer is intercepted and hydraulically bounded on the northeast side of the tailings by Spring Creek. Four additional wells were installed in April 2001 on the northeast side of Spring Creek, and in conjunction with well RPI-32, were used to evaluate the gradient and potential for seepage migration underneath the creek. Lithologic logs for these wells are presented in Appendix G. The Wyoming Department of Environmental Quality/Water Quality Division lists Spring Creek as a Class 2C surface water classification. A subcategory of Class 2, Class 2C (non-drinking water) is known to support only non-game fish populations.

Both reclamation reservoirs penetrate the White River and Main Wind River aquifers, and the Area 2/8 reservoir also penetrates the Lower Wind River aquifer. The original mine pits removed the White River and Wind River aquifer materials. The reclamation of the mine pits has resulted in backfill of the pits to a point that is below the original White River aquifer. The slopes on the pit walls were graded to a 4H:1V or flatter. With this reclamation configuration, there is likely some convergent flow to the pit, but this is subject to the degree of hydraulic communication with the backfill.

The Industrial Pond is a constructed pond that provides water for construction uses and serves as a holding pond for the Area 2/8 discharge. The supply to the pond is a combination of runoff, discharge from the mine area supply well, WW20, and from the Surficial Aquifer discharge system. The water level in the pond is above the water level in the Surficial aquifer or the water level in the tailings. Thus, it is not vulnerable to contamination by seepage from the tailings. The final reclamation configuration will utilize the Industrial Pond as a surge pond for surface drainage with a partial breaching of the pond. Storage in the pond and the pond water level will be reduced dramatically, but the pond will still be hydraulically upgradient of the tailings and Surficial aquifer.

1.2.4.1 IMPACTS ON SURFACE WATER

Spring Creek serves as the receiver and hydraulic boundary for the Surficial aquifer on the east side of the tailings area. With the exception of Spring Creek and the remnant of Mine Creek, there are no measurable impacts on surface water. At the release point from the restricted area or the Point of Exposure (POE), Spring Creek has intercepted the impacted Surficial ground water east of the tailings. Ground-water flow in this area is convergent to Spring Creek, which makes Spring Creek a gaining stream in this reach. Section 1.2.4.3 details the evaluation of gradients and other information that indicate Spring Creek is an effective hydraulic boundary for the Surficial aquifer. As the boundary for the seepage impacted area of the Surficial aquifer, the ground-water impacts are consolidated to the POE on Spring Creek through discharge to the surface water. There is no measurable discharge of seepage-impacted ground water to other surface waters surrounding the tailings area.

1.2.4.2 SURFACE WATER FLOW

Base flows in Spring Creek and tributaries were measured in 1982 (Hydro-Engineering, 1982) and 1999. The measurements were taken in the fall when the flow is typically smallest. The identification of a base flow in Spring Creek is important because as the rate of surface flow decreases, the constituent concentrations in the composite of surface flow and ground-water discharge increase.

Two tributaries combine with Spring Creek in the reach adjacent to the tailings. Flow from Fox Creek, a perennial stream extending to the north and east from Spring Creek enters Spring Creek upstream of the confluence with Mine Creek. The flow in Fox Creek was measured and is typically 15% to 25% of the base flow in Spring Creek. Currently, the discharge from Mine Creek to Spring Creek is supported by the fresh-water recharge. The modeling predicts that the flow will decrease to approximately 1-2 gpm following cessation of recharge.

The 1982 flow measurements gave a flow rate of 237 gpm at a point on Spring Creek approximately 800 feet downstream of the confluence with Murdock Creek (see Figure

1.2-2). The base flow in Spring Creek just upstream of the confluence with Fox Creek was measured at 248 gpm and the flow in Fox Creek was measured at 57 gpm. Flow in Mine Creek was measured at 4.9 gpm and flow at a point just upstream of the haul road crossing of Spring Creek, (see Figure 1.2-2), was measured at 318 gpm. Downstream of the haul road crossing, Spring Creek enters a diversion around the reclaimed Area 3 mine pit. There is likely some surface-water/ground-water exchange in the diversion channel, but the configuration of the channel prevents accurate measurement. Based on observation, there does not appear to be appreciable gain or loss within the diversion channel. The series of flow measurements indicates that there is approximately 24 gpm gain in Spring Creek through the measured reach when the Fox Creek flow is subtracted. The majority of this flow is believed to be ground-water discharge to Mine Creek and Spring Creek from the west side of Spring Creek. This is consistent with the modeling estimates of 20 gpm tailings area precipitation recharge, and 5 gpm of seepage from tailings.

During the fall and early winter of 1999, additional flow measurements were taken along Spring Creek, Fox Creek and Mine Creek. Three 90-degree sharp-crested triangle weirs were installed along Spring Creek during 1999 and a 2-inch Parshall flume was installed on Fox Creek. The approximate locations of the flow measurements are shown in Figure 1.2-4. In addition, a 6-inch Parshall flume was used to measure flow in Spring Creek at the entrance of the culvert at the haul road crossing. A 3-inch Parshall flume was also used to measure flow rate in Mine Creek. A temporary 60-degree sharp-crested triangle weir plate was constructed to calibrate the three weirs. This weir plate was placed within the semi-permanent weirs along Spring Creek, and after stabilization, the flow measurements with and without the weir plate in place were compared to allow calibration of the semi-permanent weirs. Based on typical accuracies of open channel flow measurements under similar circumstances, a 3% resolution under steady flow would represent a fairly optimal installation. There is significant storage in the Spring Creek channel behind the weirs and natural obstructions, so the accuracy will deteriorate under non-steady flow conditions.

Four measurement cycles of Spring Creek flow were used to determine the ground-water discharge to the creek. The first two series of measurements were taken on 9/9/99 and 9/10/99 and yielded precisely the same results at each location where the measurements were taken on successive days, so these are lumped together as a single measurement cycle. Multiple measurements were taken on some days. The results are included in Table 1.2-1. The various measurement locations are listed starting on the upstream end. Weir #2 is located just downstream of the confluence with Fox Creek, so the flow at Weir #2 represents the combination of Weir #1 flow, Fox Creek flow, and exchange with ground-water in the reach. Weir #3 is downstream of the confluence with Mine Creek, and thus represents the combination of Weir #2 flow, Mine Creek flow, and exchange with ground water in the reach. The 6-inch flume was temporarily installed at the entrance of the culvert for the haul road crossing and thus includes flow from Weir #3 and ground-water exchange in the reach downstream of Weir #3.

The sequence of measurements indicates the net flow gain between Weir #1 and Weir #3 for the first sampling cycle was 37.5 gpm when the Fox Creek flow is excluded. There was a measured net loss to ground water between Weir #1 and Weir #2 for this cycle, but this is thought to be an error resulting from the limits of flow measurement accuracy. The second sampling cycle of 10/6/99 showed a gain of 20.7 gpm between Weir #1 and Weir #2 when the Fox Creek flow is excluded. The gain between the Weir #2 and Weir #3 for this cycle was 46.9 gpm including a measured average of approximately 30 gpm flowing in Mine Creek. The last sampling cycle of 12/1/99 was intended primarily to determine ground-water discharge to the reach downstream of Weir #3. The comparison of the flow difference between Weir #3 and the 6-inch flume indicates that flow gain in the reach is between 9 gpm and 28 gpm. Unfortunately, there was snow on the ground at the time the measurements were taken, and by early afternoon the temperatures were high enough that there was some snowmelt. The first measurements were taken around noon when snowmelt was minimal. However, the flume installation was completed approximately an hour before the measurement was taken so the stabilization may not have been entirely complete. Shortly after the first measurement was taken, there was some evidence of snowmelt so the 28 gpm gain shown for the second measurement undoubtedly includes snowmelt runoff in the reach. Based on the range of measurements for this cycle, an estimated 10-12 gpm of ground water is discharging to Spring Creek in the reach between Weir #3 and the culvert. For the same cycle, the gain in flow between Weir #2 and Weir #3 was 41 gpm. Weir #1 was completely covered by a snowdrift during this cycle.

The smallest 1999 flow measurements for Spring Creek show nearly a 50% increase over the 1982 measurements. Based upon the Weir #1 and Fox Creek flows, all but the last measurement cycle appears to be representative of a late season base flow for a relatively wet recharge cycle. A comparison of the precipitation records for 1982 and 1998, the most recent available precipitation record, shows an increase from 10.13 inches to 14.71 inches of precipitation. It is likely that base flow is affected by the quantity and nature of precipitation for one or more years prior to the actual measurement. The 1982 measurements came at the end of a 3-year drought cycle, while precipitation in the two years prior to the 1999 measurements was above normal. For the purposes of transport modeling, the base flow in Spring Creek was assumed to be 290 gpm, or approximately the sum of the upstream base flow and the Fox Creek flow from 1982. The two flows were summed because Fox Creek contributes un-impacted flow upstream of the area of primary ground-water discharge to Spring Creek.

In addition to the base flow in Spring Creek, an "average" flow is necessary to assess certain aspects of the exposure analysis. A continuous USGS gaging station (Boles Spring) was present on the Little Medicine Bow River downstream of the confluence with Spring Creek. Monthly average flows for USGS station 006634620 at Boles Spring for water years 1985 through 1999 were tabulated and used in scaling to approximate the seasonal flow changes in Spring Creek. No continuous flow monitoring is available for Spring Creek. Figure 1.2-5 presents the monthly USGS flows in the Little Medicine Bow River based on the water year (starts in October). The projected monthly Spring Creek flow assumes a minimum base flow of 290 gpm (0.65 cfs) occurring in September. Flow rates in Spring Creek for the remainder of the year were scaled as

75% of the flow increase in the Little Medicine Bow River over the September flow. The fraction of 75% was selected to reflect the fact that the Little Medicine Bow drainage includes some more mountainous areas in addition to drainage area that is similar to the Spring Creek drainage and will likely show a higher peak flow from snowmelt.

The comparison of drainage area for Spring Creek to the POE and the drainage area of the Little Medicine Bow River at the confluence with Spring Creek allows an analysis of the combination of Spring Creek waters with other waters at the point of confluence. Figure 1.2-6 presents the drainage areas for the basins of Spring Creek to the POE and Little Medicine Bow River at the confluence with Spring Creek. The Spring Creek drainage area to the POE is approximately 17,150 acres, and the Little Medicine Bow River drainage area to the confluence with Spring Creek is approximately 98,720 acres. This gives a ratio of the areas of 5.76, which is used in estimating the ratio of flows between the Little Medicine Bow River and its tributary, Spring Creek.

1.2.4.3 SPRING CREEK BOUNDARY

The additional wells on the northeast side of Spring Creek were used to evaluate potential migration of seepage across the creek. Figure 1.2-7 presents water-level elevations for the Surficial Aquifer in the vicinity of the confluence of Mine Creek and Spring Creek. Also shown on Figure 1.2-7 are recent concentrations of uranium, chloride, TDS and sulfate. The lithology in the newly installed wells indicates a moderately permeable Surficial Aquifer adjacent to the Spring Creek, with no shallow sands in the WSC-2 area and sands that are higher in well WSC-5. With the absence of shallow sands in the vicinity of well WSC-2, and the very limited saturation in the vicinity of well WSC-5, the Surficial aquifer does not appear to be contiguous and may be absent while moving to the north and east from Wells WSC-5 and WSC-2. There is likely some local recharge through the reclaimed Area 7 overburden and the sediment pond at the toe of the overburden pile that supports the water levels in the limited Surficial aquifer north of Spring Creek.

The three water-level maps presented in Figure 1.2-7 indicate a gradient towards Spring Creek from both the northeast and southwest sides. The water-level elevation at three points along Spring Creek and the base of the drainage at two points on Mine Creek were surveyed in late June of 2001. The base of drainage points on Mine Creek approximate water levels for groundwater discharge to Mine Creek. Comparing the water-level elevation in Spring Creek and adjacent wells indicates that flow is convergent to Spring Creek. Well RPI-20A is located opposite of well RPI-32 near Spring Creek and the intermediate water level elevation of Spring Creek between the two wells is more than 0.47' lower than either well. The water level in wells WSC-4 and WSC-3 is also higher than adjacent points on Spring Creek, indicating that flow is towards Spring Creek. During periods of snowmelt or runoff, the increased stage may result in Spring Creek temporarily becoming a losing stream through this reach. Under these circumstances, the water recharging the Surficial aquifer will be characteristic of surface water.

The water quality in wells northeast of Spring Creek shows some elevated concentrations in comparison to typical background. Figure 1.2-7 presents concentrations of uranium, chloride, TDS and sulfate for wells RPI-20A, RPI-32, WSC-3, and WSC-4. Wells WSC-2 and WSC-5 could not be sampled because of low water levels. The uranium concentration in wells WSC-4, RPI-32 and WSC-3 is appreciably greater than that in well RPI-20A, which is located on the opposite side of Spring Creek. Well RPI-20A has shown severe seepage impacts in the past, but uranium concentrations have been less than 0.1 mg/l since mid-1992. Concentrations of chloride and TDS are similar for the previously mentioned wells, while the sulfate concentration for well RPI-20A is appreciably greater than wells north of the creek.

Given the demonstrated gradient towards Spring Creek, and the long record of lower uranium concentration in well RPI-20A, it is highly unlikely that ongoing seepage from the tailings area is causing the moderately elevated uranium concentrations in wells WSC-4, RPI-32 and WSC-3. The proximity to the reclaimed Area 7 overburden with its associated sediment pond makes recharge through the overburden and pond a plausible uranium source of and other constituents. Naturally occurring uranium is also present in the area as evidenced by the windblown cleanup survey and the fact that uranium is present in both the Fox Creek discharge and the upstream Spring Creek discharge. It is also possible that the modestly elevated uranium is a result of residual contamination by seepage. However, the uranium concentration at well RPI-20A has been restored to near background levels for nearly 10 years, so it is unlikely that residual contamination has endured for this period of time, particularly with the existing gradient towards the creek.

TABLE 1.2-1. SPRING CREEK FLOW SUMMARY FOR 1999

	Date	Time	Reading (feet)	Discharge (cfs)	Discharge (gpm)	Calibration Factor
Weir #1	09/09/1999	16:55	0.64	0.781	350.44	0.957
	09/10/1999	15:50	0.64	0.781	350.44	0.957
	10/06/1999	7:46	0.638	0.775	347.71	0.957
Weir #2	09/09/1999	16:49	0.675	0.929	417.07	0.997
	09/10/1999	12:31	0.675	0.929	417.07	0.997
	10/06/1999	8:13	0.69	0.982	440.63	0.997
	12/01/1999	14:16	0.745	1.189	533.75	0.997
Weir #3	09/09/1999	13:20	0.72	1.032	463.06	0.942
	10/06/1999	10:00	0.735	1.086	487.55	0.942
	12/01/1999	12:46	0.78	1.260	565.64	0.942
	12/01/1999	14:35	0.785	1.281	574.75	0.942
6" Flume	12/01/1999	12:46	0.74		574.5	
	12/01/1999	14:38	0.763		603	
Fox Creek Flume	09/09/1999	16:50	0.4		75.10	
	09/10/1999	12:58	0.4		75.10	
	10/06/1999	8:15	0.39		72.22	
	12/01/1999	14:17	0.4		75.10	
Mine Creek Flume	10/06/1999	10:40	0.175		31.36	
	10/06/1999	13:50	0.173		30.81	

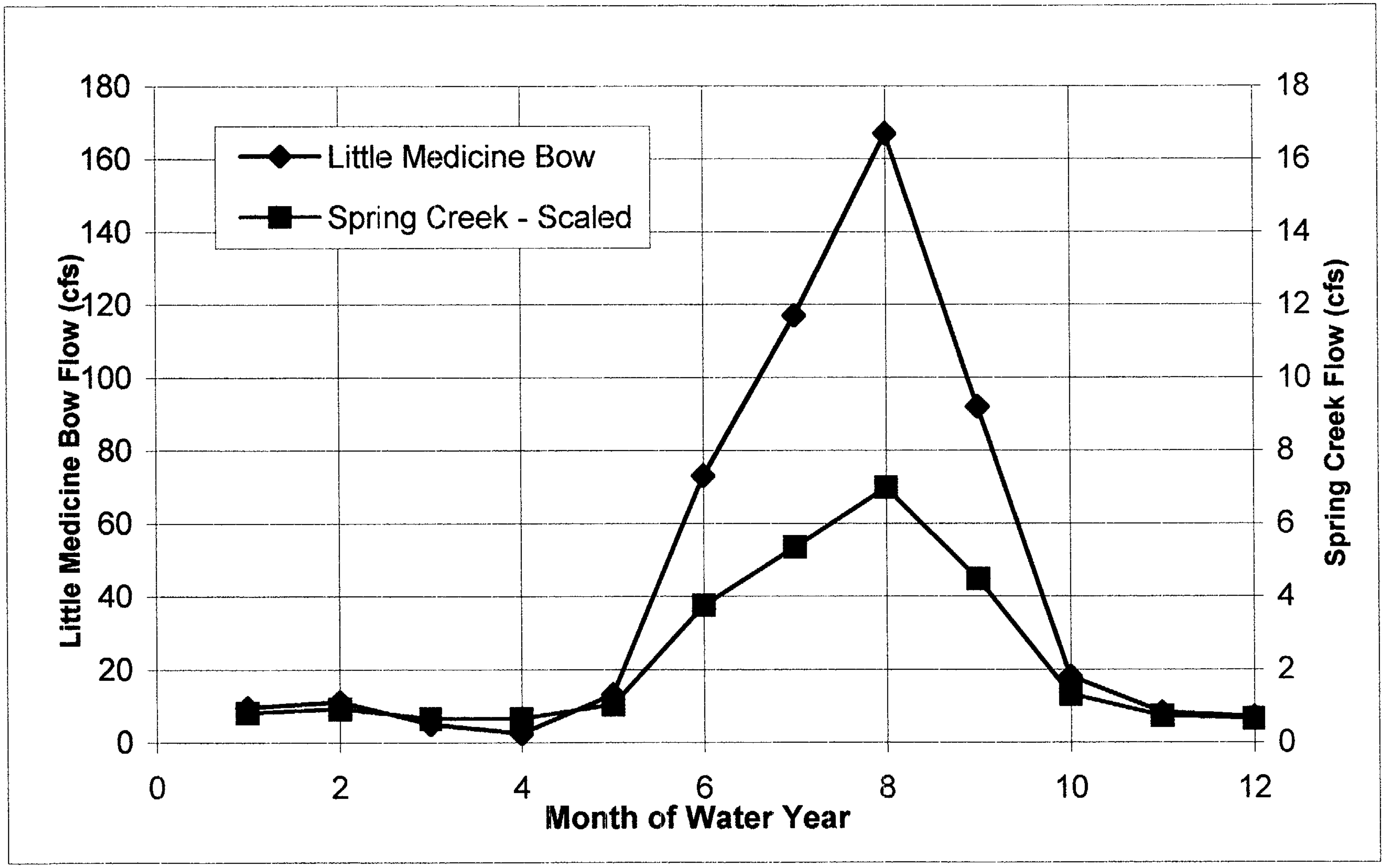


Figure 1.2-5. Little Medicine Bow River Flow and Projected Spring Creek Flow.

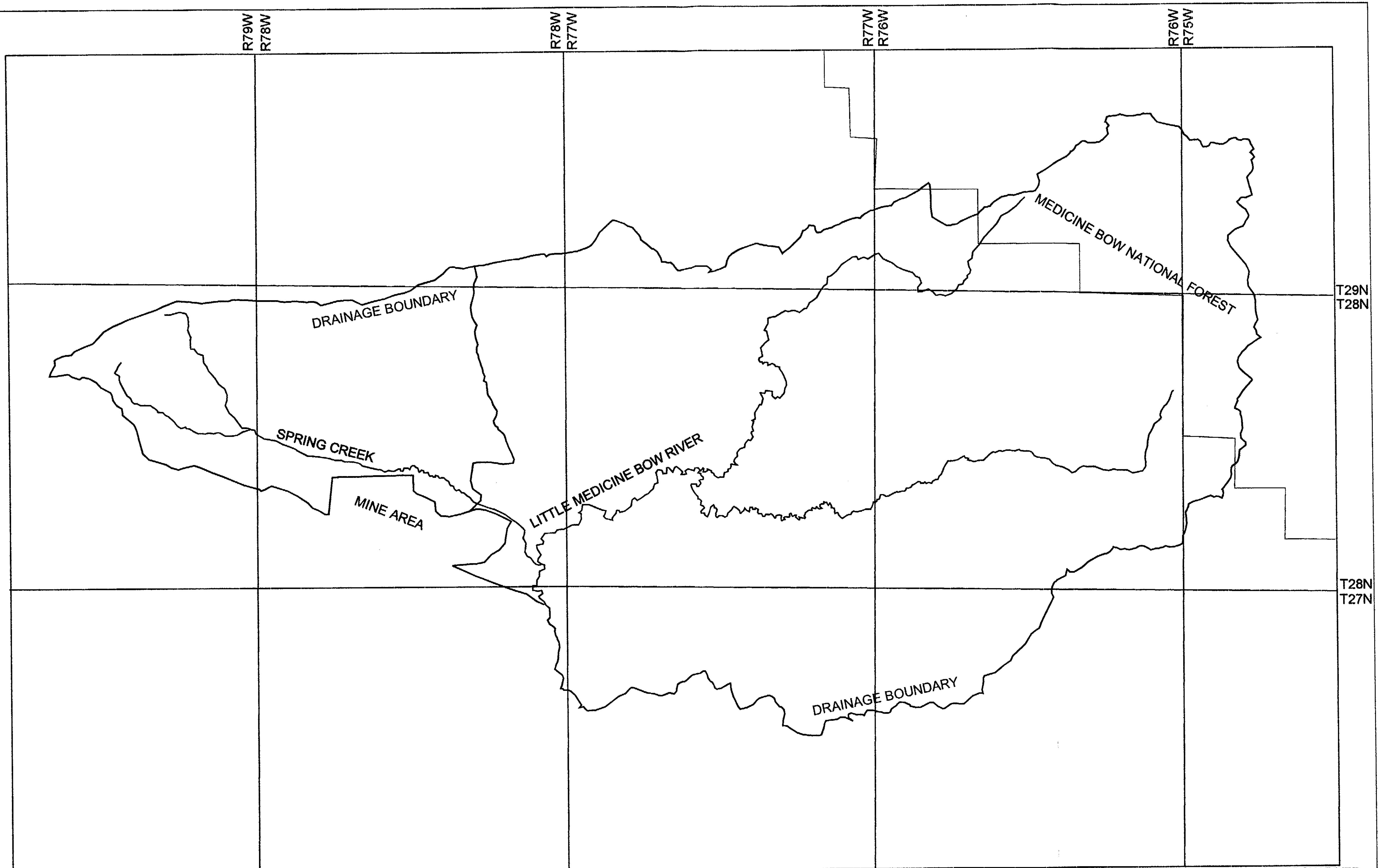
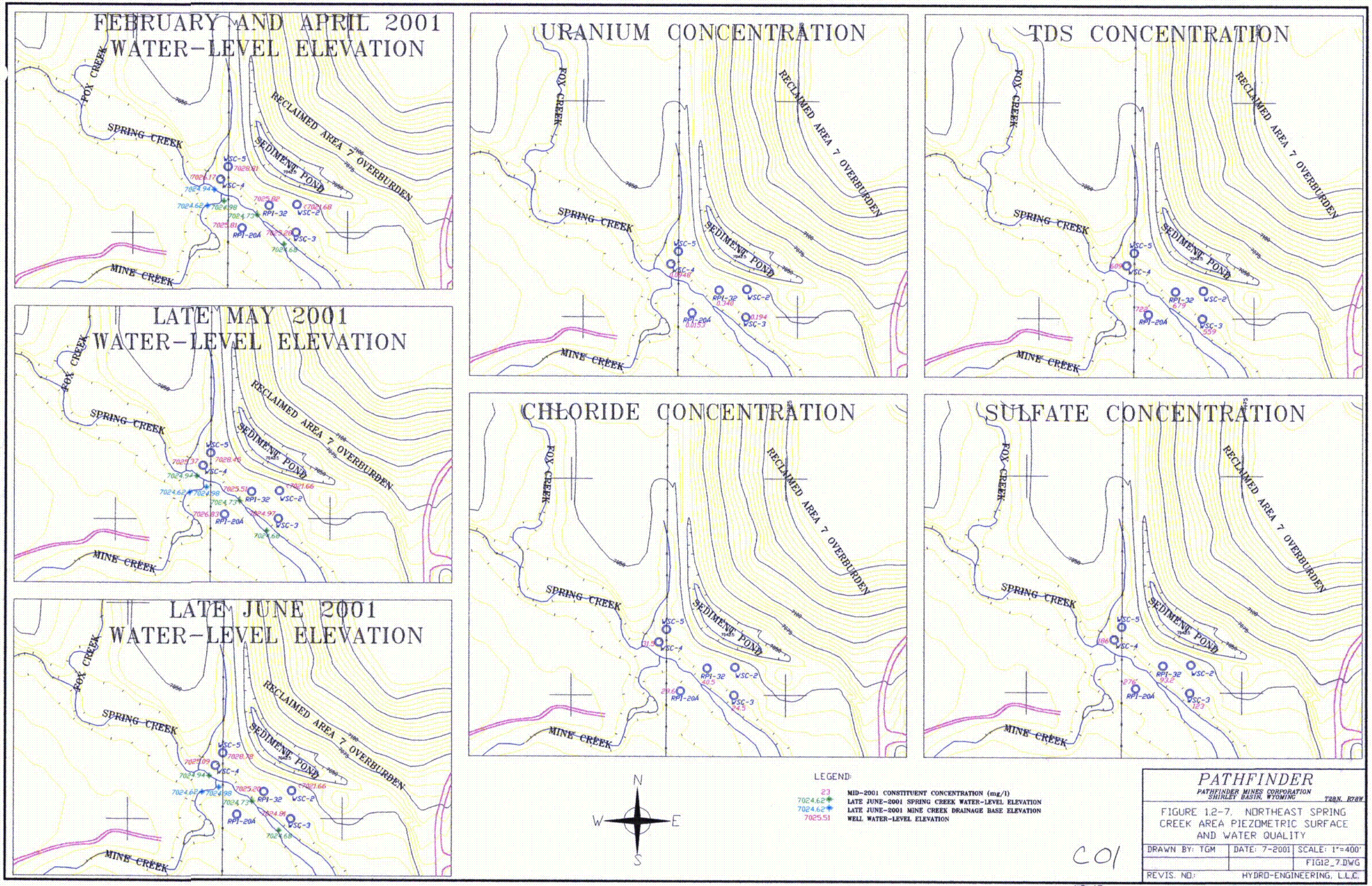


FIGURE 1.2-6. LITTLE MEDICINE BOW RIVER AND SPRING CREEK DRAINAGE BASINS


FEBRUARY AND APRIL 2001 WATER-LEVEL ELEVATION
LATE MAY 2001 WATER-LEVEL ELEVATION
LATE JUNE 2001 WATER-LEVEL ELEVATION
URANIUM CONCENTRATION
TDS CONCENTRATION
CHLORIDE CONCENTRATION
SULFATE CONCENTRATION
FOX CREEK
SPRING CREEK
MINE CREEK
RECLAIMED AREA 7 OVERBURDEN
SEDIMENT POND
N
S
E
W
LEGEND:
23 MID-2001 CONSTITUENT CONCENTRATION (mg/l)
7024.62 LATE JUNE-2001 SPRING CREEK WATER-LEVEL ELEVATION
7024.62 LATE JUNE-2001 MINE CREEK DRAINAGE BASE ELEVATION
7025.51 WELL WATER-LEVEL ELEVATION
PATHFINDER
PATHFINDER MINES CORPORATION
SHIRLEY BASIN, WYOMING
T28N, R78W
FIGURE 1.2-7. NORTHEAST SPRING CREEK AREA PIEZOMETRIC SURFACE AND WATER QUALITY
DRAWN BY: TGM
DATE: 7-2001
SCALE: 1"=400'
FIG12_7.DWG
REVIS. NO:
HYDRO-ENGINEERING, L.L.C.
C01

1.3 EXTENT OF GROUND WATER AND GROUND-WATER CONTAMINATION

This section describes the climatic conditions, ground-water systems, background water quality and current extent of ground-water contamination at PMC's Shirley Basin Mine site. The ground-water conditions and background water quality are presented because it is necessary to understand the ground-water systems and background concentrations before defining the degree and extent of contamination.

1.3.1 CLIMATIC CONDITIONS

The Shirley Basin site is at an elevation of 7100 feet above mean sea level (MSL). The climate is typical of high desert with average precipitation of 12 inches according to Martner (1986). A thirty-year record on site through 1998 gives an average of 11 inches/year. Annual lake evaporation is estimated by Martner (1986) at 47 inches. Precipitation is typically greatest in the months of May and June with high intensity thunderstorms a frequent occurrence. Figure 1.3-1 presents the total yearly precipitation for the Shirley Basin site from 1968 through 1998. Evaporation is typically greatest in the months of July and August.

1.3.2 GEOLOGIC AND HYDROLOGIC SETTING

The uranium-ore-bearing formation that has been mined in this area is the Wind River. There are two members of the Wind River formation in the mine area, and these members are designated the Lower and Main Wind River units. The Area 2/8 mine pit adjacent to the tailings area penetrated both units to mine ore sands in the Main and Lower Wind River units. In the tailings area, the Main Wind River exists throughout the area, while the Lower Wind River aquifer exists only in the western part of the No. 3 Pond. Overlying the Main Wind River aquifer is the White River Aquifer. This lower portion of sandstone is geologically a member of the Wind River formation, but is hydrologically distinct. The White River aquifer is present over the entire tailings area. Above the White River aquifer is a 10 to 60 feet thick siltstone and claystone that separates the White River aquifer from the Surficial aquifer. The Surficial aquifer consists of eroded and reworked White River material (see Figure 1.3-5).

1.3.3 SURFICIAL AQUIFER

Figure 1.3-2 shows the limits of the Surficial aquifer at the Shirley Basin site. The piezometric surface in the Surficial aquifer is supported by local recharge. In the tailings area, the Surficial aquifer discharges primarily to Spring Creek through more permeable materials in the vicinity of the Mine Creek channel. Spring Creek bounds the Surficial aquifer northeast and east of the tailings. West of the tailings, the Area 2 mine pit completely removed materials that could be hydraulically connected to the Surficial aquifer. Southeast of the tailings and Mine Creek area, the elevation of the Surficial sands rises above the piezometric surface resulting in a zero saturation boundary. The tailings dams were constructed across the Mine Creek channel, and the bulk of the seepage from tailings to the Surficial aquifer is likely occurring in close proximity to this channel. The original Mine Creek channel also terminated a few thousand feet northwest of the tailings ponds in an area now covered by an overburden pile.

1.3.3.1 SURFICIAL AQUIFER PROPERTIES

Data obtained from a large number of well logs has been used to define the base of the Surficial aquifer as shown in Figure 1.3-2. The combination of natural and artificial recharge maintains the piezometric surface. The difference between the water-level elevation and the base of the Surficial sands produces the saturated thickness of the Surficial aquifer. There is a relatively continuous clay at the surface in the tailings area that serves as a hydraulic barrier between the tailings and the Surficial aquifer. Directly beneath the tailings, the Surficial aquifer is largely confined. Outside of the immediate tailings area, the Surficial aquifer is typically unconfined.

The transmitting ability of an aquifer is defined by the transmissivity and the hydraulic conductivity (permeability). Transmissivity is the total transmitting ability of the aquifer, while permeability is the unit thickness transmitting ability of the aquifer. The specific yield is the primary storage property for the unconfined Surficial aquifer, while the storage coefficient is the important storage parameter for the confined underlying aquifers. Transmissivities for the Surficial aquifer near the Shirley Basin tailings aquifer range from just a few gal/day/ft to 8000 gal/day/ft. The area of greatest transmissivity or hydraulic conductivity is near the Mine Creek channel.

Figure 1.3-3 presents the contours of hydraulic conductivity for the Surficial aquifer. These contours were developed using pumping test results from area wells, and from calibration of the modeling. As indicated above, the hydraulic conductivity is greatest near the original Mine Creek channel. Directly beneath Tailings Pond #5 and the east side of Tailings Pond #4, the pre-pumping piezometric surface was relatively flat, indicating the hydraulic conductivity in this area is relatively large. Between the crest and toe of the Pond #5 dam, there is a very steep gradient in the piezometric surface, indicating very small hydraulic conductivity. The small hydraulic conductivity in this area is attributed to chemical precipitation resulting from neutralization of the tailings seepage.

To the west and southwest of the tailings area, the gradient steepens substantially, indicating a decrease in hydraulic conductivity. Slug tests on the WWL series of wells by Water, Waste and Land (1983) also indicated small hydraulic conductivity in this area. A pumping test of well TW5S-1 also indicated a dramatic decrease in hydraulic conductivity while moving to the west. The reduced hydraulic conductivity in this area results in a situation where rates of movement for seepage plumes are very slow. The small quantities of seepage that have encroached in this area are essentially stagnant.

1.3.3.2 SURFICIAL AQUIFER GROUND-WATER FLOW

Water-level elevations define the gradient and direction of ground-water flow in the Surficial aquifer. Figure 1.3-4 presents the details of the water-level elevation of the Surficial aquifer in the tailings area. Because the majority of Surficial wells within the actual tailings area have been converted to injection or collection wells, the contours in the immediate vicinity of these wells represent expected water-level elevations outside of the immediate cone of depression or water level mound around each active well.

The general shape of the piezometric surface indicates the complexity of the containment and restoration systems, as well as past artificial and natural recharge. Collection and injection operations in the middle of the tailings area have created a depression in the potentiometric surface in the middle of the tailings, with a hydraulic ridge along the line of injection wells.

The ground-water velocity equation is presented on pages 70 and 71 of Freeze and Cherry (1979). Hydraulic gradient times the horizontal permeability divided by the effective porosity yields the groundwater velocity. The recharge lines are a constructed fresh-water injection system consisting of buried and gravel-packed perforated piping with a distributed supply system. Injection through the recharge lines creates ground-water mounds that have a significant impact of gradients and the direction of ground-water flow. The ground water east of the south Mine Creek recharge line is presently moving downgradient toward Spring Creek at a rate of 3.75 ft/day based on the present hydraulic gradient and aquifer properties. An average permeability of 25 ft/day, gradient of 0.015 ft/ft and effective porosity of 0.1 were used in this estimate. The gradient on the west side of the south recharge line ranges from approximately 0.003 to 0.007 ft/ft, giving an apparent seepage velocity ranging from 0.75 ft/day to 1.75 ft/day.

The gradient in the north Mine Creek recharge area between wells MC-7 and MC-8 (northeast of the north recharge line) is 0.0065 ft/ft. The piezometric surface between these two wells is very flat and appears to steepen near Spring Creek.

The quantity of water moving in the Surficial aquifer is governed by Darcy's Law, where the rate is equal to the product of the transmissivity, gradient and the width of the aquifer. With the complexity of the piezometric surface and ongoing discharge to Mine Creek and Spring Creek, numerical modeling was used to predict discharge of ground water to Spring Creek.

The volume of water contained in the Surficial Aquifer with the area bounded by Spring Creek and the No. 5 Tailings dam is estimated at 165 Mgal using a specific yield of 0.10, the base of the Surficial aquifer and 1999 water-level elevations. A similar volume is likely present directly beneath the tailings and in the recharge area to the south of the tailings. The water-level elevation from the No. 5 dam outward to Spring Creek is artificially supported by fresh water recharge, and the volume will be reduced when recharge is discontinued.

The current usage of Surficial aquifer water within the area impacted by tailings seepage is limited to seepage containment measures including collection. There will be no post-reclamation usage of Surficial aquifer ground water within the area impacted by the tailings. There are springs and small stock reservoirs north and west of the tailings that are fed by surface water and ground-water discharge from shallow sands. It is likely that this shallow ground water will be further exploited for livestock watering in the future. The elevation of the springs and the channel base for Spring Creek and its tributaries place this ground-water discharge many feet upgradient of the tailings area Surficial aquifer water levels. It is possible that there is some degree of hydraulic communication between the tailings area Surficial aquifer and upgradient springs, but the direction and magnitude of the gradient will prevent any migration of tailings seepage into this area.

1.3.4 UNDERLYING AQUIFERS

In the immediate vicinity of the tailings, the White River aquifer, Main Wind River aquifer and the Lower Wind River aquifer all have sufficient permeability, thickness and saturation to function as major aquifer systems. The Upper Wind River sand is thinner and less continuous than the overlying and underlying sands and is typically not considered a major aquifer in the tailings area. The Area 2/8 Reservoir and associated reclaimed mine pit penetrate all three aquifers, and these aquifers are currently discharging to the reservoir. Figure 1.3-5 presents cross-sections for the Surficial and White River Aquifers in the tailings area. Current ground water uses in the immediate tailings area from the White River aquifer are limited to supply for fresh water recharge. There are two stock wells located more than two miles north of the tailings area and one stock well more than two miles west of the tailings that are believed to be completed in the White River aquifer. These wells are likely far upgradient of both the Surficial and White River aquifers in the tailings area. Current ground water uses from the Lower Wind River aquifer include mine area supply and supply for fresh water recharge. There were two Wind River aquifer wells located more than four miles south of the tailings that were used to supply the now abandoned townsite. The wells may be utilized for stock water, but are isolated from any potential tailings impacts by the Area 2/8 reservoir, which falls between the wells and the tailings. There will be no post-reclamation uses of ground water from any aquifer within the tailings seepage impacted area. There will be on-going ground water exchange between the Area 2/8 and Area 3 reservoirs and ground water. The White River aquifer and the Main Wind River aquifer are discharging to the reservoirs. The Lower Wind River aquifer is currently discharging to the Area 2/8 reservoir, but eventually the gradient will reverse when the reservoir approaches final stage.

1.3.4.1 WHITE RIVER AQUIFER

The White River aquifer is typically a 30-foot thick sandstone that is separated from the overlying Surficial aquifer by a 10 to 60-foot thick clay and siltstone. Fresh-water injection supply wells WW-22 and WW-23 are completed in the White River aquifer.

1.3.4.2 MAIN WIND RIVER AQUIFER

The Main Wind River aquifer is typically a 75-foot thick sandstone that is separated from the overlying White River aquifer by a 50-foot thick clay and siltstone and other thinner sandstone/claystone sequences.

1.3.4.3 LOWER WIND RIVER AQUIFER

The Lower Wind River aquifer is typically an 80-foot thick sandstone that is separated from the overlying Main Wind River aquifer by a 70-foot thick clay and siltstone. The Lower Wind River sands pinch out in the No. 3 Pond area and do not exist east of the pinch out.

1.3.4.4 UNDERLYING AQUIFER PROPERTIES

Transmissivity of the White River aquifer varies from a few hundred to 2,500 gal/day/foot in the mine area. Transmissivity of the Main Wind River aquifer varies from

2,500 to 25,000 gal/day/foot in the mine area with the exception of small local areas with dramatically reduced permeability. Transmissivity of the Lower Wind River aquifer varies from 1,080 to 22,400 gal/day/foot in the tailings area.

1.3.4.5 UNDERLYING AQUIFER GROUND-WATER FLOW

The present ground-water flow in the White River aquifer beneath the tailings is to the east under a relatively mild gradient. This gradient is believed to be increased slightly by the pumping of wells WW-22 and WW-23 to supply the fresh-water recharge systems. The general direction of ground-water flow in the Main Wind River is radially inward to the two recovering reclamation reservoirs in Area 2/8 and Area 3. There are no Main Wind River monitoring wells in the immediate tailings area, so the direction of ground-water flow directly beneath the tailings area is unknown. The general direction of ground-water flow in the Lower Wind River Aquifer is to the Area 2/8 Reservoir and to the WW-20 mine area supply well. There are no indications of hydraulic communication between the Surficial aquifer and any of the underlying formations.

1.3.5 BACKGROUND WATER QUALITY

The background water-quality conditions at this site have been monitored since 1979 using well MC-14, which is located north of the tailings. Based on the piezometric surface, the general ground-water flow in the Surficial aquifer is currently radially outward to the east, north and west of the center of the tailings area. However, there is no indication of movement of ground water from the tailings area north to the vicinity of well MC-14. The water quality in well MC-14 has remained relatively unchanged over the period of record. Prior to mining activity, the ground-water flow in the Surficial aquifer probably paralleled the Mine Creek channel with a tapering of saturated thickness while moving upstream.

Table 1.3-1 presents the average background water quality for Surficial aquifer well MC-14 over the period of record. One outlier was removed for uranium and thorium-230 prior to calculating the statistics.

(Revised 6/01/2000)
(Revised 8/28/2001)

TABLE 1.3-1. PMC SHIRLEY BASIN SUMMARY OF BACKGROUND WATER-QUALITY CONCENTRATIONS.						
Constituents	No. of Samples	Concentrations in Well MC-14				Range of Typical Values
		Minimum	Maximum	Median	Mean	
Uranium	61	0.01	0.13	0.08	0.083	0.05 – 0.13
Thorium-230	49	<0.2	3	0.2	0.404	<0.2 – 1.2
Ra-226+228	24*	0.2	19.5	1.475	2.99	----
Selenium	38*	<0.001	0.015	<0.001	0.0017	----
Gross Alpha	24	<1.0	25.6	2.2	5.33	----
Barium	25*	<0.02	0.5	<0.2	0.2	----
Chloride	79	<1	17.9	5.3	6.0	----
Sulfate	79	12.4	129	24	26	----
TDS	71	186	594	347	350	----

Note: All concentrations are in mg/l, except:
Ra-226+228, Gross Alpha and Thorium-230 which are in pCi/l
* - More than 50% non-detects. Statistical analysis is compromised.

This table lists the minimum, maximum, mean and median for each of the hazardous constituents with less than 77% non-detects at this site. The remainder of the site standard constituents have 95% or more non-detects, which renders statistical analysis meaningless. Statistics for chloride, sulfate and TDS are also presented because they are considered in the seepage analysis even though they are not site standard constituents. For ACL constituents uranium and thorium-230, Table 1.3-1 also presents a range of typical values where 90% or more of the samples are within the range. For the ACL constituents of radium-226 + radium-228 and selenium, the confidence interval ranges are not useful because of a high percentage of non-detects.

Background water quality as measured at well MC-14 has remained relatively consistent over the period of record. Hydro-Engineering L.L.C. (2000), presents the most recently tabulated water quality for the period of record.

1.3.5.1 INFLUENCE OF ORE-BEARING ZONES

The proximity of PMC's tailings and former mill area to the mining area raises the question of potential impacts of the presence of natural radionuclides in shallower aquifers. Unfortunately, the evidence for the presence of naturally occurring uranium and associated radionuclides is indirect. Soil sampling in conjunction with the windblown tailings cleanup has revealed that there are significant concentrations of radionuclides in Surficial sands adjacent to Spring Creek. These samples were taken from undisturbed areas at depths of more than five feet from the surface, which precludes contamination by windblown tailings. The WWL series of wells south and west of the tailings have shown erratic results with elevated concentrations of uranium, radium-226 + radium-228, gross alpha, and selenium. However, there are some anomalies that indicate that the elevated concentrations may be natural or a combination of natural variation and some seepage impacts. These anomalies include elevated concentrations of selenium and radium-226 + radium-228, which is not typical of tailings seepage impacts on the Surficial aquifer. This is further supported by the absence of proportionate increases in chloride concentration (see Hydro-Engineering L.L.C., 2000), which is generally the first and most prominent indication of impacts by seepage from tailings.

1.3.6 EXTENT OF CONCENTRATIONS

The extent of elevated concentrations for uranium for 1999 is presented in the figures in this subsection. Concentration maps for uranium were also presented in the Annual reports for 1997 and 1998. Elevated concentrations of selenium are local phenomena and there are no distinct plumes or paths of migration. Elevated radium-226 + radium-228 activity is also a local phenomenon. Other constituents are evaluated in terms of the site standards that are presented in Section 1.4.

1.3.6.1 SURFICIAL AQUIFER

URANIUM

Uranium concentrations in excess of the site standard have been documented at this site since 1979. However, the extent and magnitude of elevated concentrations were not well understood until the mid 1980's, when additional wells were installed and uranium concentration was measured more routinely in existing wells. The largest measured uranium concentration in well RPI-20A was 3.5 mg/l in August of 1983. This well is located near the confluence of Mine Creek and Spring Creek and represents the "heart" of the historic Mine Creek area plume. The uranium concentration in this well began to gradually decrease after the 1983 sampling and was down to roughly one-half of the maximum value in late 1985. This decline occurred prior to the implementation of corrective action measures, which may indicate that there were some geochemical or neutralization processes which were gradually reducing the mobility of uranium. Subsequent addition of recharge and collection systems has restored the water quality in this area to background conditions.

THORIUM-230

The occurrence of elevated thorium-230 activities is much more erratic than that of elevated uranium concentration. Like uranium, the first documented exceedances of the current site standard were in 1979, and ironically, the first measured thorium-230 activity in well MC-14 was twice the site standard of 0.3 pCi/l. Early samples for well RPI-20A rarely exceeded 0.3 pCi/l, while there was no question that the well was impacted by tailings seepage until the late 1980's, when the operation of recharge and collection systems began to have an effect. A typical scenario for elevated thorium-230 activity in a sampling record for an impacted well is 2 to 4 elevated analyses interspersed in 6 to 10 samples with activities below the detection level. For this reason, a thorium-230 activity contour map is not particularly useful. Sampling in 1999 yielded only two thorium-230 levels in excess of the proposed POE activity of 0.3 pCi/l and these were in at wells MC-14 and MC-6.

RADIUM-226 + RADIUM-228

Radium-226 + radium-228 has proven to be nearly immobile in the tailings area. A modest number of samples have shown activities in excess of the site standard of 5 pCi/l. However the distribution of elevated radium-226 + radium-228 activities in the known seepage area is characteristic of natural variation rather than a seepage front. Areas that are known to be profoundly affected by seepage from the tailings, (such as wells 5A-1 and P8A) have shown little or no elevated activity. On the other hand, areas where seepage impacts are milder or non-existent have shown occasional elevated activity.

SELENIUM

Selenium has proven to be relatively immobile in the tailings area. Concentrations in excess of the EPA drinking water standard of 0.05 mg/l occur in only a fraction of a percent of samples for wells in the known seepage area. However, exceedence of the site standard of 0.01 mg/l is fairly common, but there is no discernable plume.

ARSENIC

Elevated arsenic concentration has occurred in primarily one well, MC-6. Of 16 occasions when the site standard was exceeded in Surficial aquifer wells over the period of record, 14 occurred in well MC-6. This well is located in a less permeable clay knoll south of Mine Creek. There is no evidence of arsenic mobility within the Surficial aquifer, and the isolated occurrence of elevated arsenic concentrations in a single well is indicative of a natural occurrence. Well MC-6 is located within the proposed DOE boundary.

CADMIUM

The site standard of 0.01 mg/l has not been exceeded at the POC wells. Only three of the tailings well samples exceed the site standard, which indicates that tailings seepage is only a very limited potential source. The mobility of cadmium has also proven to be very limited. Occasions where the site standard has been exceeded in the Surficial aquifer are rare and most occurred prior to 1990.

CHROMIUM

The site standard of 0.05 mg/l has not been exceeded at the POC wells. Roughly half of tailings well samples exceed the site standard, which indicates that the seepage is a modest potential source. However the mobility of chromium has proved to be very limited. Occasions where the site standard has been exceeded in the Surficial aquifer are rare and most occurred prior to 1990.

BARIUM

The site standard of 1.0 mg/l has not been exceeded at any well in the tailings area, including the tailings wells. There are numerous detections of barium below the site standard, and these are as common in the background well as any well in the area. Any elevated barium concentration is attributed to a natural occurrence.

BERYLLIUM

The site standard of 0.02 mg/l has not been exceeded at the POC wells. Only one exceedence in the Surficial aquifer has occurred since 1995, and exceedence prior to that was very infrequent and was a single sample for a well. No repeat detections were observed in wells.

GROSS ALPHA

The site standard of 15 pCi/l has been exceeded at the POC wells a total of two times. These occurred in well RPI-19B, and as seen in Figure D-90 of Hydro-Engineering L.L.C. (2000), the elevated gross alpha activity occurred in the midst of a series of samples at or below the detection level. This has been the history of gross alpha measurement in the Surficial aquifer at this site. Elevated gross alpha activity is a rare and anomalous occurrence. There was only one Surficial aquifer exceedence of the site standard in 1999 (at well NP04) and there were no exceedences in 2000.

Therefore, mapping of gross alpha activity is not particularly useful. The exceedence in well NP04 was the only one in the sampling record for that well.

LEAD

The site standard for lead of 0.05 mg/l has been exceeded at the POC wells a total of three times. The majority of exceedences in all wells occurred prior to 1990. There has only been one exceedence of the site standard in tailings well samples. Without a significant source in the tailings, lead is not considered a site-derived constituent.

MOLYDENUM

The site standard of 0.1 mg/l has not been exceeded at the POC wells or in tailings well samples. There has only been one exceedence in the Surficial aquifer over the period of record. Without a significant source in the tailings, molydenum is not considered a site-derived constituent.

NICKEL

The site standard of 0.05 mg/l has not been exceeded at the POC wells. Occurrences of levels at or above the site standard are typically in severely impacted Surficial aquifer wells within the tailings. Exceedence of the site standard in wells RPI-5A and MC-9 occurred prior to 1990, but only one exceedence in well MC-9 has occurred since 1990.

1.3.6.2 WHITE RIVER AQUIFER

The White River aquifer is hydraulically separated from the Surficial aquifer by a thick clay and siltstone. There is no evidence that seepage from the tailings has impacted the water quality in the White River aquifer. Well WH-9 on the west side of the tailings has shown elevated TDS, chloride and uranium concentrations, but the well is located in close proximity to some historic underground mine workings and an early in-situ leaching test area. The gradient for the White River aquifer in this area is to the east to the pumping wells WW-22 and WW-23 and the first occurrence of noticeably elevated concentrations followed several years of pumping from the White River aquifer wells.

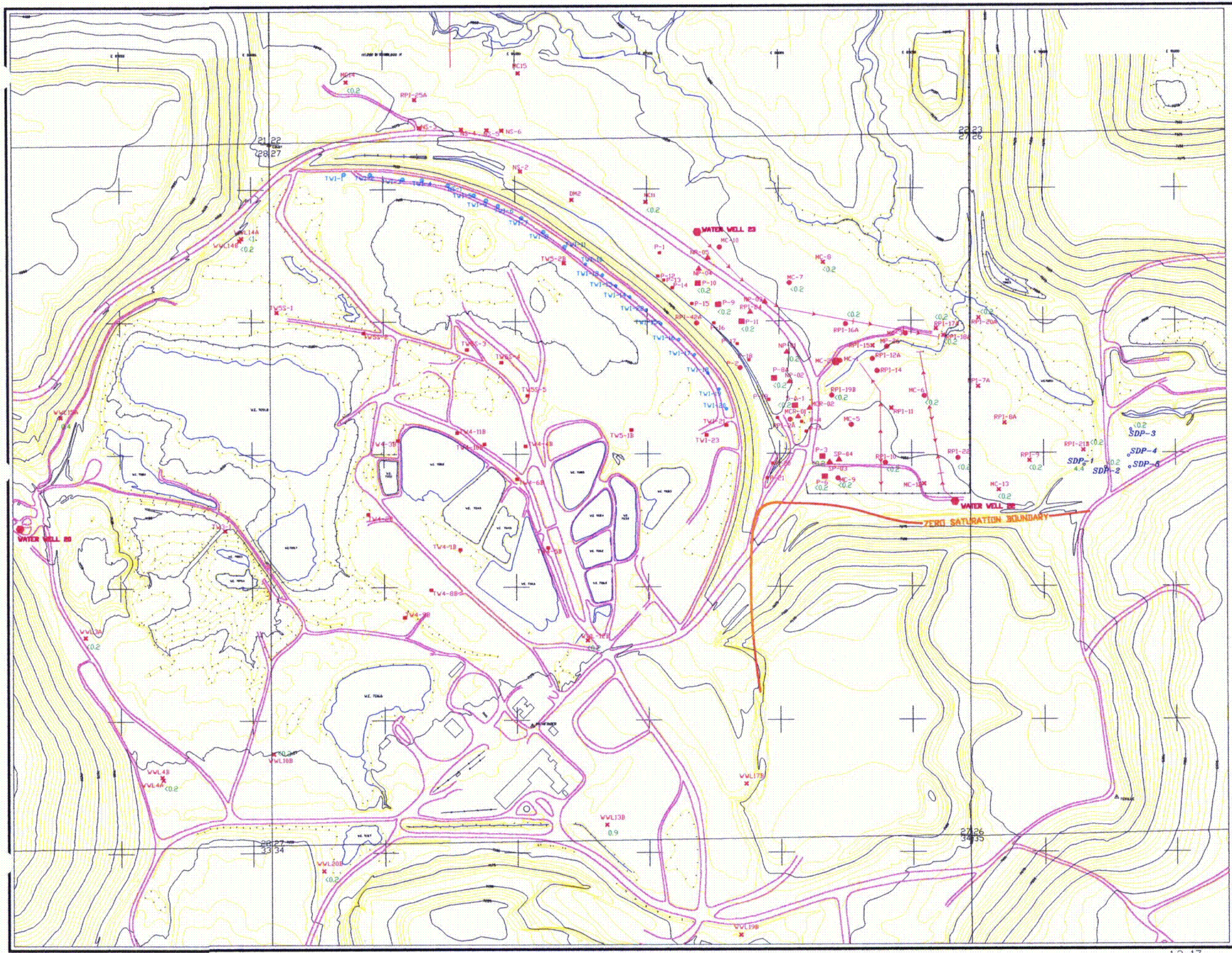
This combination of sequence of contamination and the gradient to the east indicates that the elevated concentrations at well WH-9 likely result from some mine-related remnant contamination to the west of the well.

1.3.6.3 MAIN WIND RIVER AQUIFER

With the additional separation provided by a substantial aquitard between the Main Wind River aquifer and the overlying White River aquifer, there is virtually no potential for impacts by tailings seepage. Any local contamination of the Main Wind River aquifer is a result of mining penetration of the formation.

1.3.6.4 LOWER WIND RIVER AQUIFER

With additional separation by a massive clay and siltstone, there is no potential for tailings area seepage impacts on the Lower Wind River aquifer.



LEGEND:

<0.2 THORIUM-230 ACTIVITY (pCi/l)

C02

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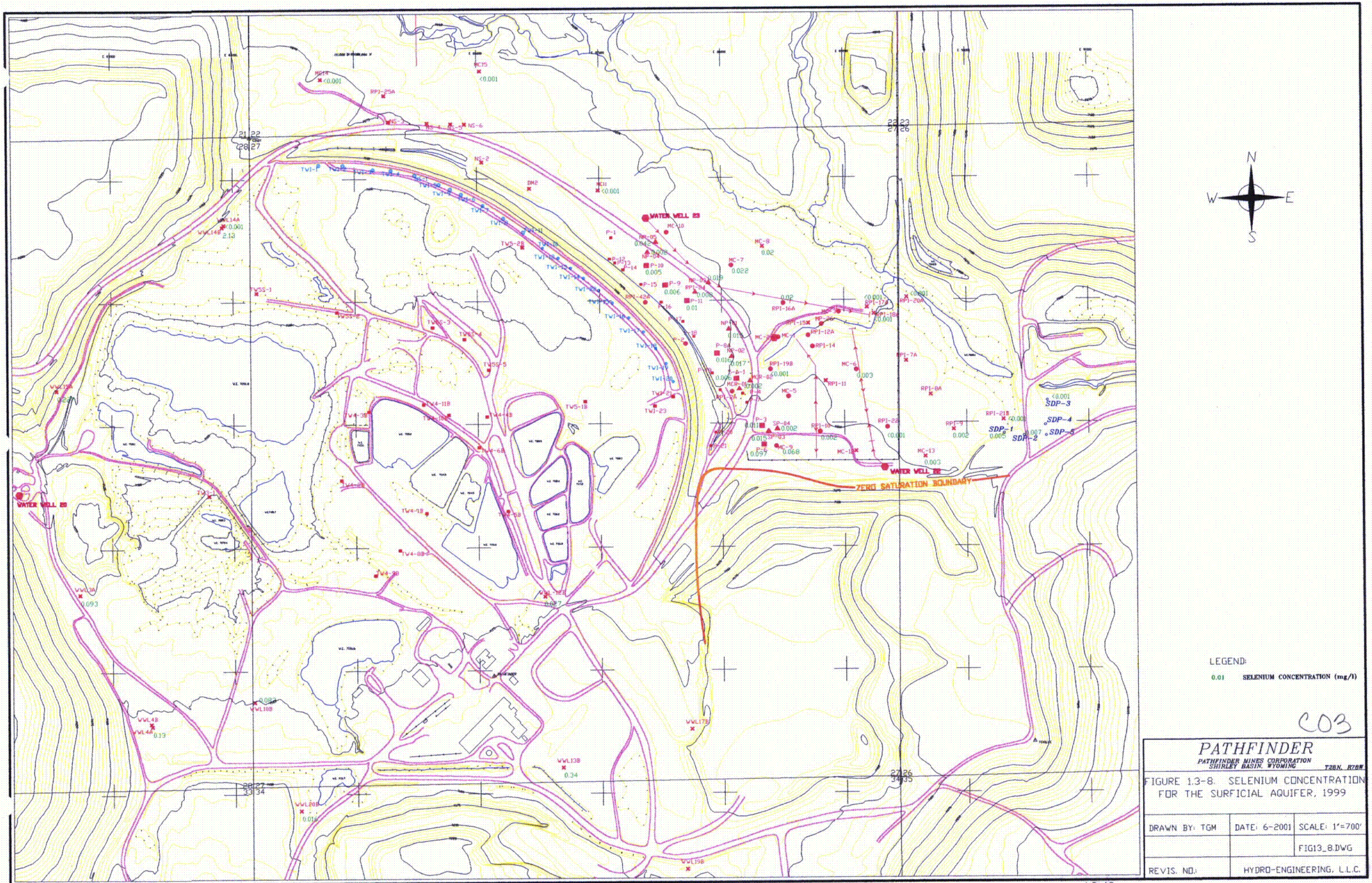
T28N, R78W

FIGURE 1.3-7. THORIUM-230 ACTIVITY FOR THE SURFICIAL AQUIFER, 1999

DRAWN BY: TGM	DATE: 6-2001	SCALE: 1"=700'
		FIG13_7.DWG
REVIS. NO.:	HYDRO-ENGINEERING, L.L.C.	



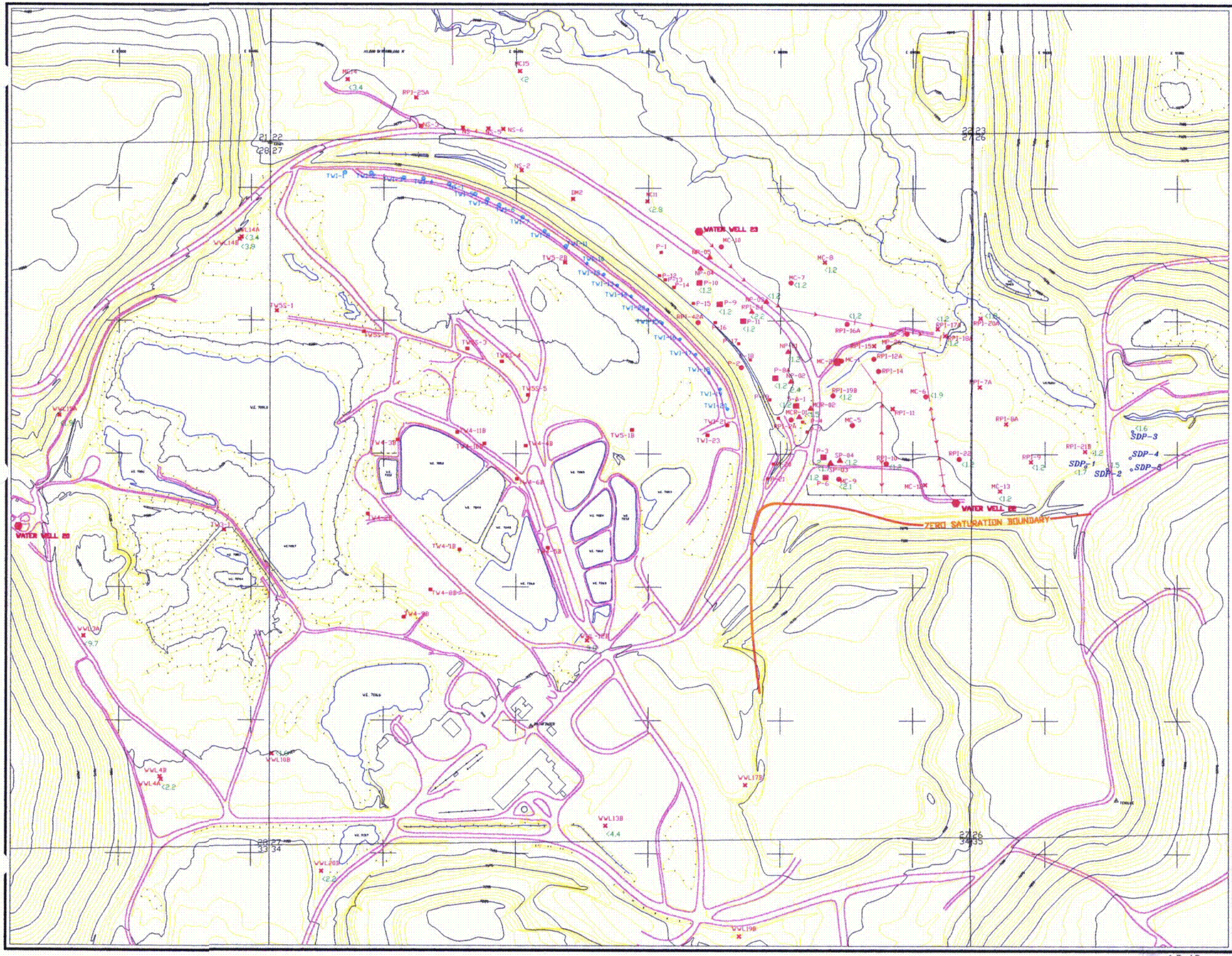
C03

PATHFINDER

PATHFINDER MINES CORPORATION
SHIRLEY BASIN, WYOMING

FIGURE 1.3-8. SELENIUM CONCENTRATION FOR THE SURFICIAL AQUIFER, 1999

DRAWN BY: TGM	DATE: 6-2001	SCALE: 1"=700'
		FIG13_8.DWG
REVIS. NO.:	HYDRO-ENGINEERING, L.L.C.	



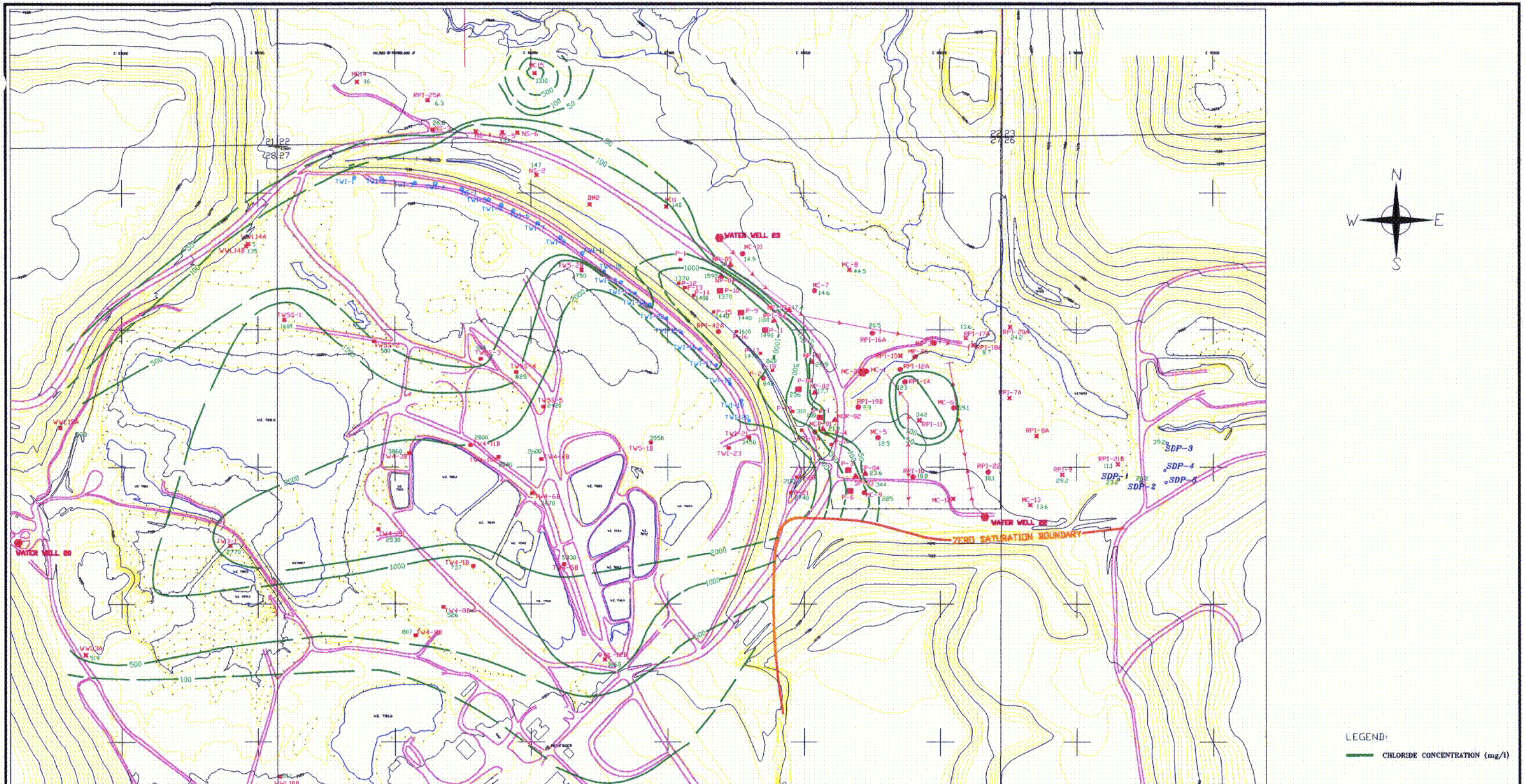
N
W E
S

LEGEND:

<1.2 RA-226+RA-228 ACTIVITY (pCi/l)

C04

PATHFINDER PATHFINDER MINES CORPORATION SHIRLEY BASIN, WYOMING T28N, R78W		
FIGURE 1.3-9. RADIUM-226 + RADIUM-228 ACTIVITY FOR THE SURFICIAL AQUIFER, 1999		
DRAWN BY: TGM	DATE: 6-2001	SCALE: 1"=700'
		FIG13_9.DWG
REVIS. NO:	HYDRO-ENGINEERING, L.L.C.	



C05

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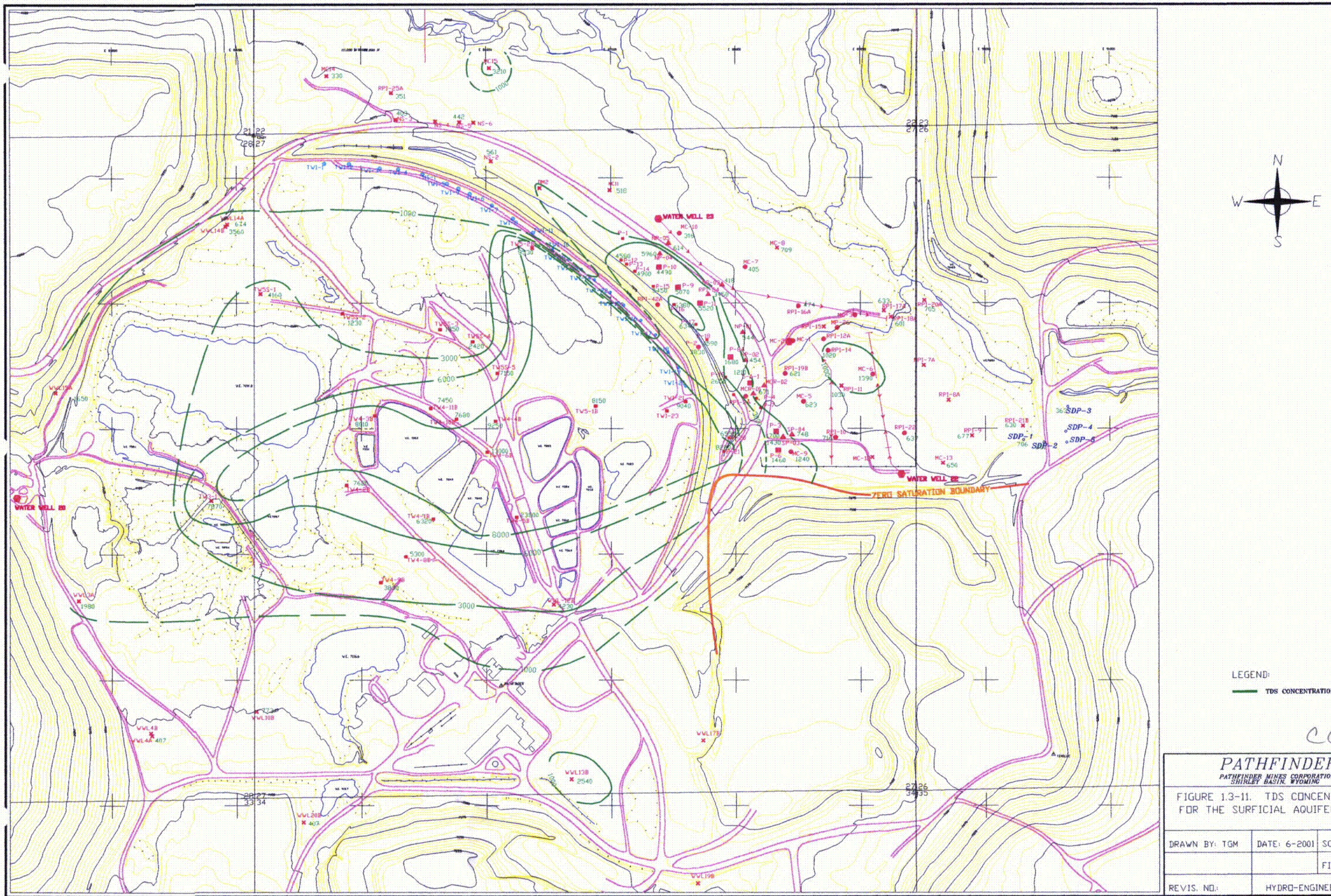
T28N, R78W

FIGURE 1.3-10. CHLORIDE CONCENTRATION FOR THE SURFICIAL AQUIFER, 1999

DRAWN BY: TGM	DATE: 6-2001	SCALE: 1"=700'
		FIG13_10.DWG
REVIS. NO:	HYDRO-ENGINEERING, L.L.C.	



LEGEND:

TDS CONCENTRATION (mg/l)

C06

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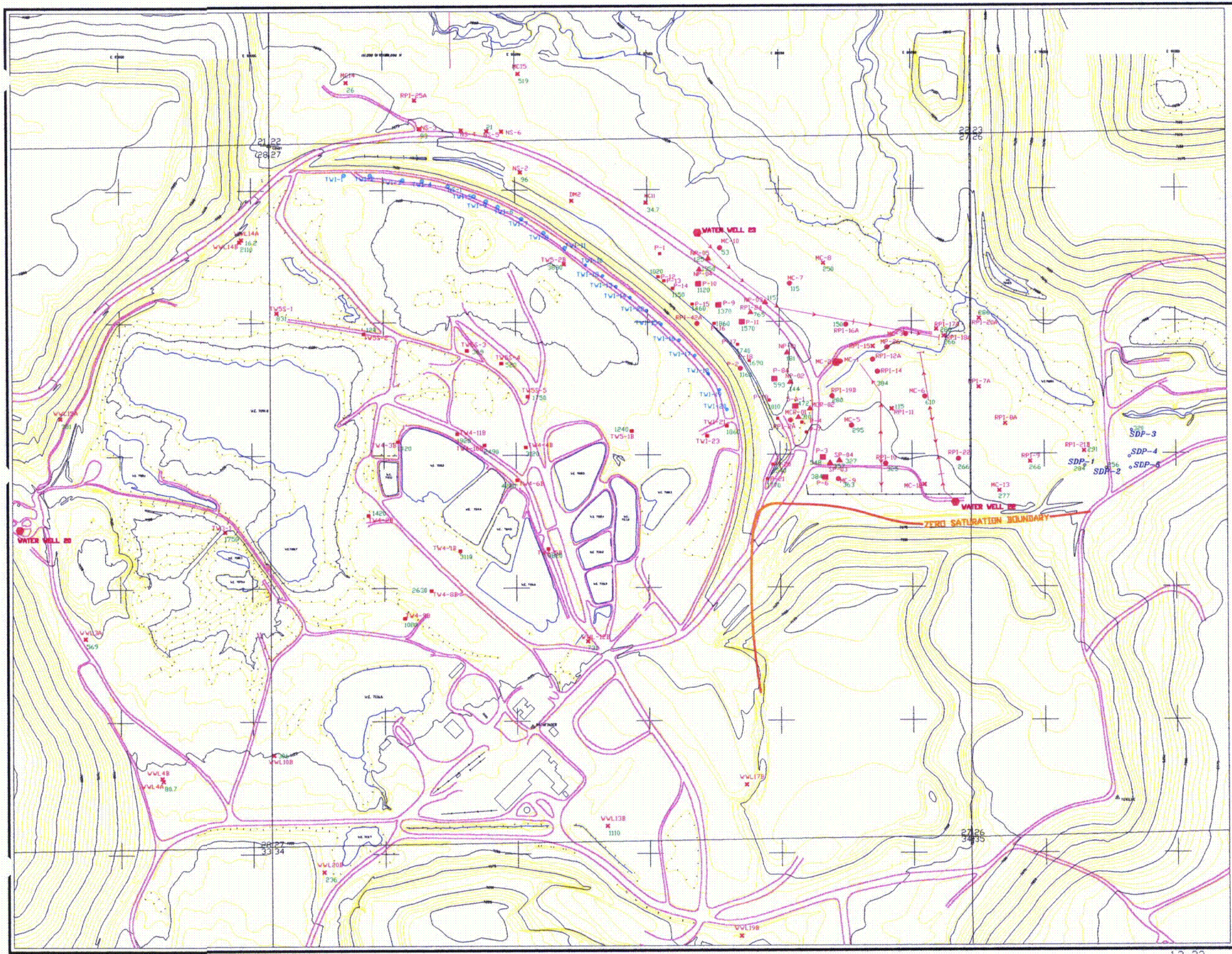
FIGURE 1.3-11. TDS CONCENTRATION FOR THE SURFICIAL AQUIFER, 1999

DRAWN BY: TGM	DATE: 6-2001	SCALE: 1"=700'
		FIG13_11.DWG
REVIS. NO.:	HYDRO-ENGINEERING, L.L.C.	



N
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LEGEND:

472 SULFATE CONCENTRATION (mg/l)

C07

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SHIRLEY BASIN, WYOMING

T28N, R78W

FIGURE 1.3-12. SULFATE CONCENTRATION FOR THE SURFICIAL AQUIFER, 1999

DRAWN BY: TGM	DATE: 6-2001	SCALE: 1"=700'
		FIG13_12.DWG
REVIS. NO.:	HYDRO-ENGINEERING, L.L.C.	

1.4 CURRENT GROUND-WATER PROTECTIONS STANDARDS

The PMC Shirley Basin site presently has ground-water protection standards established by the NRC to govern the points of compliance at this site. Section 1.5 presents the proposed alternate concentration limits. They are presented for comparison with the current standards. The following tabulation presents the thirteen site standards set by the NRC:

TABLE 1.4-1. PMC SHIRLEY BASIN NRC SITE STANDARDS.

CONSTITUENTS	NRC STANDARD
ARSENIC	0.05
BARIUM	1.0
BERYLLIUM	0.02
CADMIUM	0.01
CHROMIUM	0.05
GROSS ALPHA	15
LEAD	0.05
MOLYBDENUM	0.1
NICKEL	0.05
RA-226 + RA-228	5.0
SELENIUM	0.01
THORIUM-230	0.3
URANIUM	0.07

NOTE: All concentrations are in mg/l except: RA-226 + RA-228, Gross Alpha and Thorium-230 are in pCi/l

1.5 PROPOSED ALTERNATE CONCENTRATION LIMITS

Alternate concentration limits are needed for the Shirley Basin site because some background concentrations exceed the present site standards for uranium, thorium-230, selenium and radium-226 + radium-228, and seepage from the tailings has resulted in elevated concentrations in the Surficial aquifer. The long-term drainage of water from the tailings after the planned dewatering effort will result in Surficial aquifer concentrations greater than the present site standards at the Points of Compliance. These concentrations will be As Low As Reasonably Achievable (ALARA). Therefore, ACL's are needed for uranium, thorium-230, selenium and radium-226 + radium-228 at this site. Figure 1.5-1 presents the POC well locations, the proposed POE location, and the proposed DOE site boundary. No ground-water usage will be allowed within the eventual DOE site boundary.

A three-dimensional ground-water flow model, MODFLOW, (McDonald and Harbaugh, 1988) was used to simulate ground water flow in the Surficial aquifer and seepage from the tailings. The model used a grid covering the entire tailings and extending beyond Spring Creek in order to incorporate virtually all of the area involved with the tailings area Surficial aquifer flow system. The flow modeling was used to simulate the rates of ground-water discharge to Spring Creek and the rates of recharge water movement and seepage from the tailings. Results from the flow modeling were then used to predict the maximum concentration of the ACL constituents at the discharge point in Spring Creek and to predict the maximum concentration at the POC wells RPI19B and NP01. A three-dimensional numerical solute transport model, MT3D, (S.S. Papadopulos & Associates, 1992) was used to predict the concentrations with time at the POC wells, and an averaging technique was used to estimate the POE concentration at Spring Creek. This model uses the cell by cell flows produced by the MODFLOW model to predict the movement of the constituents from the tailings to the Surficial aquifer and eventually to the POC wells and beyond. The results from these simulations were used to determine the POC value for each of the POC wells for uranium, thorium-230 selenium and radium-226 + radium-228. Table 1.5-1 presents ACL values for the POC wells.

TABLE 1.5-1. PROPOSED ALTERNATE CONCENTRATION LIMITS.

CONSTITUENT	ALARA POC* WELLS	
	RPI –19B	NP01
Uranium	4.45	4.40
Thorium-230	5.76	5.53
Selenium	0.158	0.163
Ra-226 + Ra228	13.76	12.7

NOTE: Uranium and selenium concentrations are in mg/l
Thorium-230 and Ra226+Ra228 activity is in pCi/l

Pathfinder Mines Corporation has operated an extensive containment and restoration system for over 16 years that has been very successful in restoring water quality in the Mine Creek area. Restoration efforts beyond those currently in place are prohibitively expensive and result in incrementally smaller benefit. Discussions concerning ALARA values and the transport modeling are presented in Sections 3.5 and 2.2, respectively.

2.0 HAZARD ASSESSMENT

The proposed Alternate Concentration Limits for uranium, thorium-230, selenium and radium-226 + radium-228 are supported by the risk assessment described in this section. The source of the contamination is characterized and the transport of contaminants in ground water is described in the first two sub-sections. The potential pathways and rates of exposure are summarized in sub-section 2.3 and details are provided in Appendix A. The potential risk to human health is described in sub-section 2.3.2 and details are provided in Appendix B. The environmental risk is summarized in sub-section 2.3.3 and details are provided in Appendix C.

The source of ground-water contamination in PMC's Shirley Basin site is the tailings impoundments and the former mill site. The last mill tailings were hydraulically deposited in the tailings area in 1992. At the end of 1992, the tailings impoundments were essentially full of tailings solution. Since that time, enhanced evaporation and tailings dewatering have been used to reduce the quantity of tailings solution in ponds and stored within the saturated solid tailings. The tailings have been progressively covered and diversions have been constructed to reduce the runoff contribution.

2.1 SOURCE AND CONTAMINATION CHARACTERIZATION

The tailings impoundments have been the primary source of ground-water contamination at the Shirley Basin site. The hydraulic delivery of the tailings to the impoundments results in a segregation of material according to gradation at the point of discharge. Generally, the tailings were spigoted on the periphery of the impoundments resulting in a beach area made up of the coarser materials. The finer grained materials are typically carried to the pool area in the center of the ponds where they are deposited as slimes. The transition from coarse to fine grained materials is gradual and the process of advancing the spigot point radially inward resulted in stratification of the tailings by gradation. There are distinct sandy beach areas and slime pool areas, but much of the tailings area is made up of mixed gradation materials or layered sequences of sands and fine-grained materials.

The configuration of the tailings piles has some bearing on the concentrations reaching the Surficial aquifer. Sampling from tailings wells has indicated that there are measurable differences in the quality of tailings solution held in slime areas when compared to sandier beach areas. However, a more profound impact of the distinction between the slime areas and sandy areas is the dramatically different permeability between the two materials. The very low permeability slimes drain very slowly in both vertical and horizontal directions, and thus one of the more effective approaches to dewatering has been aggressive pumping of better yielding wells in more permeable areas to eventually draw the tailings solution from slime areas. Pumping of poor yielding wells in the slimes has been used to dewater the tailings, but based on relative pumping rates, lateral drainage to the cones of depression in sandier areas is the most effective dewatering mechanism.

The lateral redistribution of tailings solution has the effect of equilibrating water quality through the tailings. One of the more noticeable occurrences of this was the change in field water quality parameters for well TW5-3 over a four-year period. The first sample was taken shortly after the well was drilled, and the second sample was taken after roughly four years of aggressive dewatering. The field conductivity in this well nearly doubled over the period and is now similar to other tailings wells. Well TW5-4C exhibited similar behavior over a three-year period. It is plausible that early pumping from tailings wells yields a disproportionate fraction of solution that had been diluted by infiltrating precipitation, and this may explain the deterioration of tailings well water quality with time in some wells. However, regardless of the mechanism, the gradual equilibration of tailings water quality does lead to a "typical" tailings solution quality that can be used for uniform source term characterization. This uniform tailings solution quality uses slight weighting of the average to reduce the influence of wells or individual samples where the general water quality is appreciably better than typical tailings samples.

2.1.1 CONTAMINANT SOURCE TERM CHARACTERIZATION

Water-quality data for the tailings is tabulated in Table 2.1-1 where the major constituents are presented on the first page and the pH and minor constituents on the second page.

Uranium concentration for the tailings wells averaged 15.61 mg/l with the inclusion of all tailings well samples. When the three smallest uranium concentration values and the largest uranium concentration value are removed, the average becomes 16.08 mg/l. In this case, the largest uranium concentration was also removed to provide some balance in extreme value removal. The concentration of uranium in seepage from the tailings is dramatically reduced as evidenced by concentrations in Surficial aquifer wells within the tailings area that are typically less than one-half of the values that would occur with a simple dilution process. This reduction is attributed to adsorption or possibly a neutralization process that results in precipitation of uranium. The neutralization process was documented and described by Robertson-Pincock (1980) as a calcite dissolution – gypsum precipitation process, but the potential impacts on uranium mobility are not known. The estimated uranium concentration reaching the Surficial aquifer is 7 mg/l based on observed concentrations extending from the early 1980's through the present. Uranium concentrations in the more profoundly impacted wells in the Mine Creek area have approached roughly one-half of the 7 mg/l estimate.

The thorium-230 activity was not measured in the tailings well samples. However, the thorium-230 activity in many Surficial wells that have been affected by tailings seepage has been measured. Unfortunately, it appears from the tabulation of water quality in Hydro-Engineering L.L.C. (2000) that the sampling or analysis of thorium activity at these very low levels is considerably less reliable than uranium concentration analysis. There is strong evidence of systematic errors in the measurement of thorium-230 activity in the Surficial aquifer. The majority of samples for Mine Creek area Surficial aquifer wells have thorium-230 activities below detection, while most occurrences of elevated thorium-230 activities correspond with specific sampling cycles. As an example, the sampling cycle corresponding to the 3rd quarter of 1995 showed

TABLE 2.1-1. WATER-QUALITY ANALYSES FOR THE TAILINGS.

Well Name	Date	Cl (mg/l)	SO4 (mg/l)	pH (units)	TDS (mg/l)	Cond(f) (umhos/c	As (mg/l)	Se (mg/l)	Unat (mg/l)	Ra226 (pCi/l)
TW4-1C	4/29/1993	3008	10819	2.61	20835	16720	0.105	0.416	28.7	1173
	7/27/1995	---	---	---	---	20940	---	---	---	---
TW4-2C	7/27/1993	3921	11654	3.01	21776	15300	0.0580	0.395	6.71	320
TW4-3C	8/2/1993	5402	12000	2.75	25986	21070	0.892	0.399	29.6	530
TW4-4C	6/18/1993	2127	7696	3.04	1435	10750	0.0160	< 0.0010	4.09	447
TW4-4CA	8/1/1995	---	---	---	---	17410	---	---	---	---
TW4-5C	4/1/1993	4067	11106	2.89	22972	19370	0.0940	0.536	21.2	1249
TW4-6C	7/14/1995	5932	13574	2.53	27775	26310	0.255	< 0.0010	34.2	2366
	7/26/1995	---	---	---	---	22530	---	---	---	---
	7/26/1995	---	---	---	---	21490	---	---	---	---
TW4-6CA	7/12/1995	---	---	---	---	30310	---	---	---	---
TW4-6CB	7/14/1995	---	---	---	---	15880	---	---	---	---
TW4-7C	8/3/1995	5992	16030	2.85	31270	24960	0.336	0.582	52.4	1379
TW4-8C	7/7/1995	2539	8912	2.96	16455	14570	0.215	0.731	18.2	714
	7/14/1995	---	---	---	---	20210	---	---	---	---
TW4-8CA	7/27/1995	---	---	---	---	16140	---	---	---	---
TW4-8CB	7/27/1995	---	---	---	---	24180	---	---	---	---
TW4-8CC	3/22/1999	2000	15200	2.84	24900	20461	0.294	0.833	48.0	1470
TW4-9C	6/30/1995	339	3687	2.98	5338	5320	0.154	0.0750	2.02	235
	12/17/1997	---	---	---	---	5346	---	---	---	---
TW4-9CA	6/30/1995	167	3915	3.15	5703	5850	0.272	0.0290	0.593	377
TW4-10C	8/1/1995	5457	14461	3.26	27280	21920	0.0540	0.538	23.1	811
TW4-10CA	8/1/1995	---	---	---	---	21850	---	---	---	---
TW4-11C	7/10/1995	5200	13900	3.39	26324	22990	0.110	0.262	6.55	1062
TW4-11CA	8/1/1995	---	---	---	---	19730	---	---	---	---
TW4-11CB	7/25/1995	---	---	---	---	14040	---	---	---	---
TW4-11CC	7/12/1995	---	---	---	---	12330	---	---	---	---
TW5-1C	3/31/1993	1732	9342	4.50	16518	14780	0.0240	0.0050	1.27	212
TW5-2C	4/1/1993	4745	17822	3.68	35049	22480	0.0050	0.330	30.0	1578
	1/9/1998	2360	14100	---	28500	25036	---	---	8.28	---
TW5-3	3/24/1993	2542	3901	5.31	9439	10770	0.0360	0.0060	0.521	263
	12/17/1997	---	---	---	---	20461	---	---	---	---
TW5-4C	1/24/1994	1578	2943	5.94	7264	7490	0.0960	0.0020	1.07	198
	12/17/1997	---	---	---	---	20673	---	---	---	---
TW5-4CA	7/26/1995	---	---	---	---	20930	---	---	---	---
TW5-5C	3/2/1994	2097	5151	4.14	11584	8910	0.0400	0.0160	0.492	447
TW5-6C	3/2/1994	2194	7992	3.11	15152	9250	0.107	0.0490	4.38	532
TW5-7C	7/26/1995	4111	7372	2.99	18035	16000	0.101	0.286	9.62	306
TW5-8C	7/26/1995	3215	9840	9.74	18284	15300	0.0310	0.126	12.4	172
	7/26/1995	---	---	3.74	---	---	---	---	---	---
TW5-9C	7/26/1995	---	---	---	---	24950	---	---	---	---

TABLE 2.1-1. WATER-QUALITY ANALYSES FOR THE TAILINGS (cont'd).

Well Name	Date	Ba (mg/l)	Cd (mg/l)	Cr (mg/l)	NO3 (mg/l)	Fe (mg/l)	Pb (mg/l)	Mo (mg/l)	Ni (mg/l)
TW4-1C	4/29/1993	< 0.100	< 0.0100	< 0.0500	0.300	1770	< 0.0500	< 0.100	3.21
TW4-2C	7/27/1993	< 0.100	< 0.0100	< 0.0500	< 0.100	1740	< 0.0500	0.100	4.74
TW4-3C	8/2/1993	< 0.100	< 0.0100	< 0.0500	0.410	1635	< 0.0500	< 0.100	3.99
TW4-4C	6/18/1993	< 0.100	< 0.0100	< 0.0500	0.130	943	< 0.0500	< 0.100	2.14
TW4-5C	4/1/1993	< 0.100	< 0.0100	0.570	< 0.100	1338	< 0.0500	< 0.100	4.23
TW4-6C	7/14/1995	< 0.100	< 0.0100	0.970	0.360	1711	< 0.0500	< 0.100	0.490
TW4-7C	8/3/1995	< 0.100	0.140	1.35	< 0.100	2093	< 0.0500	< 0.100	5.00
TW4-8C	7/7/1995	< 0.100	< 0.0100	0.270	0.180	1177	< 0.0500	< 0.100	1.90
TW4-8CC	3/22/1999	0.100	0.0580	0.450	---	2500	0.350	0.100	3.60
TW4-9C	6/30/1995	< 0.100	< 0.0100	0.120	< 0.100	532	< 0.0500	< 0.100	0.500
TW4-9CA	6/30/1995	< 0.100	< 0.0100	0.0600	< 0.100	559	< 0.0500	< 0.100	0.640
TW4-10C	8/1/1995	< 0.100	< 0.0100	0.0800	< 0.100	1342	< 0.0500	< 0.100	4.70
TW4-11C	7/10/1995	< 0.100	< 0.0100	< 0.0500	< 0.100	1520	< 0.0500	< 0.100	4.00
TW5-1C	3/31/1993	< 0.100	< 0.0100	< 0.0500	< 0.100	1942	< 0.0500	< 0.100	4.17
TW5-2C	4/1/1993	0.510	< 0.0100	1.17	< 0.100	2136	< 0.0500	< 0.100	6.12
TW5-3	3/24/1993	< 0.100	< 0.0100	< 0.0500	< 0.100	705	< 0.0500	< 0.100	< 0.0500
TW5-4C	1/24/1994	< 0.100	< 0.0100	< 0.0500	< 0.100	178	< 0.0500	< 0.100	< 0.0500
TW5-5C	3/2/1994	< 0.100	< 0.0100	< 0.0500	0.400	800	< 0.0500	---	2.40
TW5-6C	3/2/1994	< 0.100	< 0.0100	< 0.0500	0.380	1403	< 0.0500	< 0.100	3.87
TW5-7C	7/26/1995	< 0.100	0.0900	0.0600	0.630	567	< 0.0500	< 0.100	2.01
TW5-8C	7/26/1995	< 0.100	< 0.0100	0.160	0.260	1226	< 0.0500	< 0.100	3.34

dramatically elevated thorium-230 activities in wells ranging from MC-14 to RPI-20A, which is located at the confluence of Mine Creek. Wells north and south of Mine Creek exhibited this same behavior for areas where hydraulic communication of the seepage plumes is virtually impossible. This makes the thorium-230 activities in this particular sampling cycle highly suspect. There are other less prominent examples where the correlation between elevated thorium 230 activity and a particular sampling cycle calls the values into question.

In the absence of measured tailings thorium-230 activities in the tailings well samples, the characterization of the thorium activity for the tailings seepage source requires some interpretation of the maximum mobile thorium-230 activity. With the elimination of thorium-230 values from unreliable sampling cycles, a maximum thorium activity of 1 to 3 pCi/l has been observed in areas of the Surficial aquifer where seepage impacts have been evident. With a 3 to 5 fold dilution factor indicated by the conservative chloride transport, this indicates an upper bound of approximately 7 pCi/l as the mobile thorium-230 activity. It is likely that thorium activities are much greater in the tailings, but due to pH buffering, precipitation, and other attenuating processes between the tailings and the Surficial aquifer, the thorium-230 does not appear to enter the Surficial aquifer at activities greater than 7 pCi/l.

The average arsenic concentration for the tailings wells including 1998 and 1999 samples is 0.157 mg/l. The average chromium concentration in the tailings wells is 0.262 mg/l. The average selenium concentration for the tailings wells is 0.267 mg/l. Radium-228 activity was not measured in tailings wells, but radium-226 activity ranged from 172 pCi/l to 2,366 pCi/l, and radium-226 + radium-228 activity would be equal to or greater than the radium-226 activity. The average nickel concentration for tailings wells is 2.91 mg/l. Like arsenic, chromium, selenium and radium-226 + radium-228, the movement of nickel to the Surficial aquifer has been very limited in spite of significant concentrations in the tailings solution. The concentrations of beryllium and gross alpha were not measured in tailings well samples, but like the previously mentioned constituents, they have not proven to be mobile in the seepage from the tailings to the

Surficial aquifer. The remaining site standard constituents of barium, lead, and molybdenum are not present in the tailings wells in measurable concentrations.

2.1.2 HYDROLOGIC SOURCE TERM CHARACTERIZATION

Sixty-five tailings wells have been drilled and are in place on the tailings (see Figure 2.1-1). The majority of the tailings wells are located close to the centerline of the Mine Creek channel and a tributary to the south. Fifty-two of the tailings wells were constructed in a manner to allow extraction for dewatering and the majority of these wells are currently being used for dewatering. The remaining wells are constructed with two-inch diameter or smaller casing and serve as water level monitoring wells.

The siting of many wells along the centerline of the original Mine Creek channel was done to capitalize on the larger tailings depths in this area. Those wells closest to the edge of the pond or the dams are typically better yielding wells due to deposition of coarser materials near the tailings spigot points. With increasing distance from the dam or the edge of the ponds, the tailings consist of finer silts and clays (slimes), and the tailings become less permeable. Wells completed entirely in slime tailings have very poor yields. In order to dewater slime areas, a number of wells were completed on the periphery of the slime pool on Tailings Pond No. 5 to induce lateral drainage to more permeable tailings adjacent to the slime pool.

2.1.2.1 TAILINGS DRAINABLE VOLUME

The drainable portion of the water in the tailings is a function of the saturated thickness of the tailings and the specific yield of the tailings. The base of the tailings is shown in Figure 2.1-2 and water-elevation of the tailings in late 1999 is shown in Figure 2.1-3. Information from these figures is combined to produce the saturated thickness of tailings.

A series of multi-well pump tests were conducted shortly after the first series of tailings wells were drilled in 1993. However, with a relatively high water level at the time of the testing, the results were dominated by one of two effects. The first of these was either a recharge boundary or no-flow boundary due to proximity to a dam or pond. The second effect was evidenced by dramatic increases in the slope of the drawdown response in areas where there was no evidence of potential boundaries. This effect was attributed to stratification in the tailings where recent advancement of the tailings discharge location had placed sandier tailings over less permeable tailings. Regardless of the cause, the result was an atypical drawdown response, which did not provide reliable measures of specific yield, and tailings specific yield was estimated based on experience with similar tailings materials.

The estimates of specific yield for the tailings range from 0.05 to 0.15. The larger specific yield is expected for sandier hydraulically emplaced tailings, while the smaller specific yield will reflect greater water retention in the finer slime materials. A typical specific yield of 0.12 was estimated for the modeling and for quantification of drainable water. The estimated drainable water in the tailings in late 1999 was 137 million gallons.

2.1.2.2 TAILINGS DEWATERING

Dewatering from tailings wells started in 1993 with pumping from well TW5-3. At that time, large volumes of ponded water in Pond #4 and #5 made an extensive pumping program futile. Pumping wells were progressively added in 1994 and 1995 with a total pumping rate of approximately 140 gpm in 1995. The maximum pumping rate of 250 gpm was reached for a short period in mid-1995. The current pumping rate from tailings wells is approximately 130 gpm, and with the exception of periods of interference by construction efforts and winter freeze up, has remained between 110 gpm and 140 gpm since 1995. The extraction rate has been maintained by addition of pumping wells and redevelopment of active wells. Vacuum enhancement of well yields was also used for a short period, but maintenance requirements were excessive for a relatively minor improvement in well yields.

There have been observed declines in tailings water levels with the dewatering program. With the reduction of quantities of water stored on the tailings surface and the placement of interim cover, the recharge to the tailings has been progressively reduced.

Infiltration into the tailings has slowed the dewatering process because it offsets much of the extraction by dewatering, and there have been periods where very little progress was made in lowering water levels in the tailings. Nearly all of the recently placed interim cover is a low permeability clay, but some of the earliest interim cover was coarser and more permeable. None of the interim cover has been placed as an engineered infiltration barrier, so there is potential for excessive infiltration over large portions of the interim cover area. Efforts are ongoing to capture and dispose of precipitation and runoff before it can infiltrate to the tailings. With the completion of the radon/infiltration barrier, the infiltration to the tailings will be reduced to a fraction of a gpm.

Tailings dewatering for the Shirley Basin site is a diminishing return process. As the saturated thickness of the tailings declines, the yield from individual wells naturally decreases. Unfortunately, this problem is also exacerbated by increased operation costs with declining yields. The equipment and energy costs for a 0.5 gpm well are virtually identical to those of a 3.0 gpm well and the lower yielding well will likely exhibit more precipitation problems and require more maintenance. Thus, the cost per unit volume of water extracted has been increasing since the start of the dewatering and will continue to increase at an accelerating rate. With the decreasing saturated thickness, the prospect for adding strong yielding wells also decreases. The presence of active dewatering systems on top of the tailings also interferes with other reclamation efforts. It is reasonable to assume that even preliminary grading for the final reclamation of the tailings will be delayed until the dewatering is terminated for that particular area.

2.1.2.3 TAILINGS SEEPAGE RATE

The active tailings dewatering program will extract tailings water to the point where further dewatering efforts add little or no benefit to the long-term water quality at the Spring Creek POE. It is not possible to completely evacuate water from the tails, so there will be a residual volume of tailings water that will discharge to the Surficial aquifer through gravity drainage. The rate of this drainage will gradually diminish over time as the water level in the tailings declines. The decline in head accounts for a portion of the reduction in seepage rate, and the trough shaped base of the tailings in each pond results in a diminishing footprint of the saturated tailings with declining water level.

Lithologic and geophysical logs for Surficial aquifer wells in the tailings area indicate that there is some barrier to seepage from the tailings over nearly all of the tailings area. The nature and thickness of this barrier varies from a 15 foot thick claystone and siltstone to a few feet of a sandy clay material. Lithology from well TW5-3 and well TW4-21C indicates that there are at least two locations where this barrier is absent or compromised. Based on the available lithology, the barrier appears to be thickest and the least permeable in the northern portion of Pond #5. The barrier appears to be thinner and more permeable near the original Mine Creek channel in the tailings area, and this is supported by the concentration of seepage impacts in the Mine Creek area.

The historic seepage rate from the tailings is estimated at 5 gpm. This estimate is based upon observed maximum concentrations of conservative constituents (chiefly chloride) in profoundly impacted Surficial wells. Wells that appeared to reach a steady-state chloride concentration with known seepage impacts approached an average concentration of 1,300 to 1,500 mg/l. Estimates of recharge to the Surficial aquifer that is passing beneath the tailings is 10 gpm. This gives a 2:1 dilution of local ground-water flow to tailings seepage. The average chloride concentration in tailings well samples is 3,214 mg/l, while the average with elimination of the seven lowest concentration samples is 4,046 mg/l. The lower concentration tailings samples were eliminated to reduce the effects of dilution of near surface water by precipitation or runoff. This combination of 5 gpm tailings seepage at a chloride concentration of more than 4,000 mg/l produces Surficial aquifer concentrations of 1,300 to 1,500 mg/l when combined with approximately 10 gpm of Surficial water with very little chloride.

With ongoing dewatering and the drainage of residual water in the tailings, the seepage rate is expected to gradually decline. With a distributed seepage footprint and dams that restrict lateral movement of tailings solution beyond the existing tailings boundaries, the water table in the tailings is expected to gradually flatten out following cessation of pumping. There may be slight depressions in the piezometric surface in areas where the hydraulic contact between tailings and the Surficial aquifer is greater. However, the general footprint of the area covered by saturated tailings will shrink towards the original Mine Creek channel following the base of the tailings surface. The model prediction of the seepage from the tailings drops to approximately 1.8 gpm 20 years after the cessation of pumping and will eventually drop to 1 gpm 50 years after the cessation of pumping. This eventual long-term seepage rate is difficult to predict because the footprint of the saturated tailings is gradually changing, and the available lithology information indicates that the vertical communication between the tailings and the Surficial aquifer is very heterogeneous. It is plausible that the seepage rate could drop dramatically if the saturation over an area of large vertical communication is thin. A smaller long-term seepage rate would reduce the concentrations at the POE, but would extend the duration of the seepage input to Spring Creek. Fortunately, the seepage rate over the next decade is more critical to seepage impacts than longer term seepage rates, and the extrapolation of current seepage rates to shorter periods of time is more reliable.

The dewatering of tailings reduces the volume of water that will eventually seep to the Surficial aquifer and eventually discharge to Spring Creek. Because the seepage rate is proportional to the remaining tailings water volume, reduction of that volume reduces the eventual seepage rate. However, the seepage rate is expected to exhibit an exponential decay type of curve with a long-term pseudo steady-state seepage rate. Extension of the dewatering program brings the maximum seepage rate closer to the long-term seepage rate, but the benefit of each additional increment of dewatering gets smaller. As the predicted maximum seepage rate approaches this long-term seepage rate, the benefit of dewatering approaches zero, while the cost of dewatering increases dramatically.

2.1.2.4 POC ALARA CONCENTRATION

The active dewatering effort will be continued until mid 2001 which meets the ALARA conditions with respect to reducing seepage impacts on Spring Creek water quality. At present, little or no tailings seepage is escaping the collection/recharge system. Seepage from the tailings is occurring, but the rate is likely reduced because excess fresh-water injection in the Surficial aquifer has reduced the gradient between the tailings and the Surficial aquifer. When collection and fresh-water injection ceases, the present ground-water mounds in the Mine Creek area and beneath the tailings area injection wells will decay to a nearly steady state condition. With this decay, the seepage rate from tailings is expected to increase slightly to reflect the increase in vertical gradient and then begin to slowly decline as the water level in the tailings drops and the more permeable contact area declines. The concentrations of constituents at the POC wells will be a result of the combination of the seepage from the tailings and the local ground water moving beneath the tailings.

For the transport modeling, the up-gradient and peripheral ground water concentrations were assumed to be equal to the average background concentrations measured at well MC-14. Recharge by precipitation was assumed to be at the background concentrations. The background uranium concentration for ground water was 0.083 mg/l, and the background thorium-230 activity was 0.4 pCi/l. The average uranium concentration in the Spring Creek base flow was calculated as 0.026 mg/l using available surface water data, and the average thorium-230 activity in Spring Creek was assumed to be 0.1 pCi/l, or one-half of the typical lower limit of detection level. The average background selenium concentration was 0.00176 mg/l, and the average Spring Creek concentration was 0.001 mg/l. The average background radium-226 + radium-228 activity was 3 pCi/l. There is limited radium-228 activity data for Spring Creek and typically both the radium-226 and radium-228 activities are below detection. An assumed Spring Creek activity of 1 pCi/l for radium-226 + radium-228 used in the modeling is very conservative in light of the limited number of detections in Spring Creek.

The uranium concentration in the tailings used in the transport modeling was 7.0 mg/l. This is roughly one-half of the average uranium concentration in water samples from tailings wells. The concentration was reduced because the observed concentrations are significantly lower than can be attributed to dilution and the adsorption and/or neutralization and precipitation process discussed earlier limits the uranium concentration reaching the Surficial aquifer. Once the uranium reaches the Surficial aquifer, the observed migration of the contaminant front indicates that the solubility of uranium doesn't change dramatically. When compared with the movement of conservative ions, there does appear to be some retardation by adsorption/desorption processes. However the reaction rates of chemical processes that result in permanent or semi-permanent removal of the uranium appear to be dramatically reduced. The modeled concentration of 7.0 mg/l produces peak concentrations in wells along the Mine Creek channel that closely match historic values. Preliminary modeling with a pre-1998 tailings uranium concentration of 14.57 mg/l produced concentrations in key wells that were dramatically larger than any measured concentrations. As an example, the modeling with a tailings uranium source of 14.57 mg/l produced a predicted maximum uranium concentration in well RPI-20A of 7.86 mg/l when the maximum measured concentration was 3.5 mg/l. The same comparison was made for a series of 10 key wells (including the POC wells) and in all cases the predicted concentration at the wells with a tailings source of 14.57 mg/l was more than twice the maximum observed concentration. This includes Surficial wells within the tailings area where there is no potential for restoration by the injection/collection systems.

The thorium-230 activity in the tailings used in the transport modeling was 7.0 pCi/l. As mentioned earlier, the measured thorium-230 activity in Surficial wells has been erratic, and the reliability of the analysis must be considered for the occasions where the site standard is exceeded. Although true mobility for thorium-230 appears to be much less than uranium, use of a value of 7.0 pCi/l for the tailings source produces model predictions of maximum thorium-230 activity in the Mine Creek area plume that are consistent with maximum measured values.

The average tailings selenium concentration used in the modeling was 0.258 mg/l (the measured average from tailings wells rounded up to the nearest 0.001 mg/l). Radium-228 activity was not measured in the tailings, but radium-226 activity in tailings wells ranged up to 2366 pCi/l. However, transport of radium-226 + radium-228 to the Surficial aquifer is very limited as indicated by observed levels in Surficial wells. Like uranium, preliminary modeling was used to determine an appropriate tailings source term. A tailings source of 20 pCi/l produced predicted concentrations that compared favorably with maximum observed activities in the 10 key wells.

The concentrations calculated above represent the projected mobile constituent concentrations for the tailings at present. The modeled scenario includes 1 ½ years of continued dewatering and collection/injection system operation with a modeled start time of January 2000. At the end of this period, the tailings dewatering and collection/injection are discontinued. This operational sequence and the constituent concentrations were used to determine the ALARA POC and projected POE concentrations. An alternate simulation with discontinuation of the Surficial aquifer injection and discontinuation of collection in the Mine Creek area at the end of year 2000 gave virtually no change in the POE concentrations from the original simulation which continued all system operations through mid-2001. Therefore, this alternate scenario with one year of continued injection/recharge system operation and one year of Surficial aquifer collection is considered equivalent to the original simulation with respect to POE concentrations.

2.2 TRANSPORT ASSESSMENT

The quantity of water moving in the Surficial aquifer in the tailings area is the sum of recharge from precipitation, seepage from tailings, and excess artificial recharge. When the collection/injection system operation is terminated, the ground-water mound that has developed will decay and the long-term ground-water flow will result almost exclusively from recharge and a small quantity of tailings seepage. In the area of concern, this water is moving to Spring Creek and is combining with the surface flow in the perennial stream. The transport of constituents from the tailings is primarily in the Mine Creek area where the transmissivity of the Surficial aquifer is greater. The movement rates of the constituents are governed by the seepage velocity and retarding processes such as adsorption/desorption. The seepage velocity is a function of hydraulic conductivity, ground-water gradient, and specific yield (effective porosity) of the aquifer.

The modeling of ground-water flow was done with MODFLOW (McDonald and Harbaugh, 1988), a three-dimensional finite-difference model. A two-layer model was used with the upper layer consisting of the tailings, and the Surficial aquifer represented by the lower layer. The details of the flow model construction are presented in Appendix D. The tailings aquifer was modeled as a bounded aquifer with the only means of discharge/recharge through exchange with the Surficial aquifer or through extraction by wells. The Surficial aquifer was modeled as a confined/unconfined aquifer with potential discharge/recharge by drains, river cells, wells, or precipitation recharge. Spring Creek was modeled as a river, and the remaining section of Mine Creek was modeled as a series of drain cells. This allowed separation of the ground-water discharge to Mine Creek from the discharge to Spring Creek in the tabulation of water balance provided by the model. Flow measurements have shown Spring Creek is a gaining stream in the reach adjacent to the tailings, and the modeling supported this. However, the ground-water discharge to Spring Creek will decline once the excess fresh-water injection ceases. The precipitation recharge over the area south of the tailings and between the tailings and Spring Creek was estimated as 0.96 inch/year.

The change in remaining volume of water in the tailings was calculated by summing the volume in each tailings cell at the end of each stress period. Stress periods were set to correspond with planned changes in system operation and to provide coverage of the entire model period. Up to 14 stress periods were used to provide up to 50 years of simulation. The changes in remaining volume for the tailings were used to calculate the rate of seepage from the tailings for each stress period. The model results also provided rates of ground-water discharge to the drain cells (Mine Creek) and to the river cells (Spring Creek). These rates then allowed a proportional comparison of various dewatering and collection/injection system scenarios. With a ratio of seepage rate from the tailings to total ground-water discharge to Spring Creek, the potential benefits of changing or extending remediation system operation could be evaluated. The alternate approaches are presented in Sections 3.2.1 and 3.2.2.

Current versions of the MODFLOW model can create a file of cell by cell flow terms for use by a transport model. The MT3D model (S.S. Papadopulos & Associates, 1992), can use the flow terms from the MODFLOW model in simulation of reactive solute transport, and was used to model the transport of uranium, thorium-230, selenium radium-226 + radium-228, chloride and TDS for the tailings area. The version of MT3D used in this modeling has been updated from an explicit finite difference solution to an implicit solution by the distributor. Table 2.2-1 summarizes inputs for the groundwater flow and transport modeling.

2.2.1 CONSTITUENT TRANSPORT

The transport of uranium and thorium-230 in the Surficial aquifer is radially outward from the tailings area. With the exception of the Mine Creek area, the rate of transport is extremely slow due to much smaller hydraulic conductivities outside of this area. The transport modeling included exchange of the uranium and thorium-230 between the tailings and the Surficial aquifer and eventual transport according to the ground-water velocities. A matrix of existing concentrations was established for the Surficial aquifer. This included a background concentration of 0.083 mg/l for uranium and a background thorium-230 activity of 0.4 pCi/l for all areas outside of the tailings. Directly beneath the

TABLE 2.2-1. GROUND-WATER FLOW AND CONTAMINANT TRANSPORT INPUT SUMMARY.

Property	Range of Values	Area
Base of Tailings Aquifer (feet above MSL) Table D.2-4	6950.22 to 7259.06	Entire modeled area - aquifer is only active on the interior of the tailings
Tailings Aquifer Hydraulic Conductivity (ft/day) Table D.2-3	0.24 to 18	Interior tailings area
Tailings Aquifer Specific Yield	0.12	Interior tailings area
Tailings Aquifer Initial Water-level Elevation (feet above MSL) Table D.2-5	6950.22 to 7259.06	Entire modeled area - aquifer is only active on the interior of the tailings
Base of Surficial Aquifer (feet above MSL) Table D.2-7	7010 to 7100	Entire modeled area
Top of Surficial Aquifer (feet above MSL) Table D.2-8	7035 to 7115	Entire modeled area
Surficial Aquifer Hydraulic Conductivity (ft/day) Figure 1.3-3 & Table D.2-6	0.1 to 10	Western side of the tailings area
	5 to 15	Central portion of interior tailings
	0.1 to 10	South central tailings area
	5 to 70	Mine Creek area
	0.1 to 5	Area between tailings and northern Spring Creek
Surficial Aquifer Specific Yield	0.1	Entire modeled area
Surficial Aquifer Storage Coefficient	0.0001	Entire modeled area
Surficial Aquifer Initial Water-level Elevation (feet above MSL) Table D.2-9	7020 to 7119.8	Entire modeled area - aquifer is only active on the interior of the tailings
Vertical Conductance Between Tailings and Surficial (1/day) Table D.2-10	0.00002 to 0.0001	Vertical communication is only possible in the active tailings area
Recharge to Surficial Aquifer (ft/day) Table D.3-7	0 to 0.00018	Entire modeled area
Individual Tailings Well Dewatering Rate (ft^3/day) Table D.3-6	0 to 1018.52	Interior tailings area
Individual Surficial Well Collection Rate (ft^3/day) Table D.3-3	25.45 to 1192.08	Mine Creek and immediate tailings areas
Individual Surficial Cell Injection Rate (ft^3/day) Table D.3-4 & Table D.3-5	110.3 to 550	Mine Creek and immediate tailings areas

(Revised 8/28/2001)

TABLE 2.2-1. GROUND-WATER FLOW AND CONTAMINANT TRANSPORT INPUT SUMMARY (continued).

Property	Range of Values	Area
Top of Tailings (feet above MSL) Table E.2-1	6950.22 to 7259.06	Entire modeled area - aquifer is only active on the interior of the tailings
Tailings Thickness (feet) Table E.2-2	0 to 61.02	Interior tailings area
Tailings Effective Porosity	0.12	Interior tailings area
Surficial Aquifer Thickness (feet) Table E.2-3	6.5 to 230.56	Entire modeled area
Surficial Aquifer Effective Porosity	0.1	Entire modeled area
Longitudinal Dispersivity (feet)	10	Entire modeled area
Transverse Dispersivity (feet)	2	Entire modeled area
Vertical Dispersivity (feet)	2	Entire modeled area
Initial Uranium Concentration in Tailings (mg/l) Table E.2-4	0 or 7	7 mg/l in active tailings area - 0 elsewhere
Initial Uranium Concentration in Surficial Aquifer (mg/l) Table E.2-6	0.083 to 0.83 0.083	Interior tailings area Outside of tailings area
Initial Thorium Activity in Tailings (pCi/l) Table E.2-5	0 or 7	7 mg/l in active tailings area - 0 elsewhere
Initial Thorium Activity in Surficial Aquifer (pCi/l) Table E.2-7	0.4 to 4.0 0.4	Interior tailings area Outside of tailings area

TABLE 2.2-1. GROUND-WATER FLOW AND CONTAMINANT TRANSPORT INPUT SUMMARY (continued).

Property	Range of Values	Area
Initial Selenium Concentration in Tailings (mg/l) Table E.2-8	0 or 0.268	0.268 mg/l in active tailings area - 0 elsewhere
Initial Selenium Concentration in Surficial Aquifer (mg/l) Table E.2-9	0.0005 to 0.336	Modeled Area
Initial Ra-226 + Ra-228 Activity in Tailings (pCi/l) Table E.2-10	0 or 20	20 mg/l in active tailings area - 0 elsewhere
Initial Ra-226 + Ra-228 Activity in Surficial Aquifer (pCi/l) Table E.2-11	0.005 to 47.9	Modeled Area
Initial Chloride Concentration in Tailings (mg/l) Table E.2-12	0 or 4320	4320 mg/l in active tailings area - 0 elsewhere
Initial Chloride Concentration in Surficial Aquifer (mg/l) Table E.2-13	6 to 4230	Modeled Area
Initial TDS Concentration in Tailings (mg/l) Table E.2-14	0 or 15000	15000 mg/l in active tailings area - 0 elsewhere
Initial TDS Concentration in Surficial Aquifer (mg/l) Table E.2-15	331 to 17845	Modeled Area

tailings, the range of estimated uranium concentrations was 0.083 mg/l to 0.83 mg/l. The larger concentrations were placed close to the original Mine Creek channel with a gradient to the general background concentration of 0.083 mg/l with increasing distance from the channel. The same approach was used for a thorium-230 with a range of 0.4 pCi/l to 4.0 pCi/l. The concentration in the tailings was assumed to be constant. All fresh-water injection was assumed to be at background concentrations.

2.2.1.1 DISPERSION

The dispersivity of the formation is unknown. Fortunately, the larger hydraulic conductivity in the Mine Creek area and the use of drains to simulate the Mine Creek surface flow makes the transport an advection dominated process with slight convergence toward the drains. This dramatically reduces the effects of dispersion and makes the modeling insensitive to dispersivity. The dispersivities used in the model were 10 feet for both layers, with a ratio of 0.2 for transverse/longitudinal dispersivity and a ratio of 0.2 for vertical/horizontal dispersivity. Diffusion was not used in the model.

2.2.1.2 RETARDATION

The retardation factor used in the model was one, giving no simulated retardation. Based on comparisons between observed chloride movement rates and uranium movement rates, it is apparent that there is some retardation of uranium transport. However, the retardation does appear to be inversely proportional to permeability of the aquifer with the least retardation in the immediate Mine Creek area. This is consistent with the expectation that a larger fraction of silts and clays in the aquifer would offer more adsorptive surface and reduce the permeability at the same time. The net effect of retardation in a situation where the source is slow leakage from a relatively large source volume, is a slowing of the movement rate and a modest reduction in peak concentrations at a given observation point. Hence, the use of no retardation in the modeling adds a measure of conservatism in the transport approach.

2.2.1.3 URANIUM

The predicted peak uranium concentration at POC wells RPI-19B and NP01 was 4.45 mg/l and 4.40 mg/l, respectively (see Figure 2.2-1). The modeling assumed no retardation and the two POC wells are located relatively close to the toe of the No. 5 Tailings dam, so retardation would not appreciably change the peak concentrations. The POE concentration at Spring Creek is discussed in Section 2.2.2.3.

2.2.1.4 THORIUM-230

The predicted peak thorium-230 activity at POC wells RPI-19B and NP01 was 5.76 pCi/l and 5.53 pCi/l, respectively. The modeling assumed no retardation and the two POC wells are located relatively close to the toe of the No. 5 Tailings dam, so retardation would not appreciably change the peak activity. The POE activity at Spring Creek is discussed in Section 2.2.2.3.

2.2.1.5 SELENIUM

The predicted peak selenium concentration at POC wells RPI-19B and NP01 was 0.158 mg/l and 0.163 mg/l, respectively. No retardation was considered in the modeling. The POE concentration at Spring Creek is discussed in Section 2.2.2.3.

2.2.1.6 RADIUM-226 + RADIUM-228

The predicted peak radium-226 + radium-228 activity at POC wells RPI-19B and NP01 was 13.76 pCi/l and 12.7 pCi/l, respectively. No retardation was considered in the modeling. The POE activity at Spring Creek is discussed in Section 2.2.2.3.

2.2.2 TRANSPORT TO SURFACE WATER

The seepage impacted ground-water discharges to Spring Creek. A large portion of the total ground-water discharge to Spring Creek occurs in the vicinity of Mine Creek because that precipitation recharge south of the tailings area is discharging through this area. Precipitation recharge to the area between Spring Creek and the tailings also discharges eventually to Spring Creek and is largely unaffected by tailings seepage. Discharge from the drain cells used in modeling the discharge to Mine Creek was assumed to be instantaneously combined with ground-water discharge to the river cells for Spring creek. The concentrations or activities in the ground-water discharge to surface water vary dramatically, so a proportional combination is required to determine the composite concentrations in the discharge.

2.2.2.1 FLOW RATES IN SPRING CREEK

Flow rates in Spring Creek and tributaries were measured in 1982 (Hydro-Engineering, 1982) and 1999. The measurements were taken in the fall when the flow is typically smallest. Section 1.2.4.2 describes the measurement of the flow rates. The resulting estimate of typical late season base flow is 290 gpm. The identification of a base flow in Spring Creek is important because as the rate of surface flow decreases, the concentration of the composite of surface flow and ground-water discharge increases. The use of this base flow represents a conservative approach because 290 gpm represents the smallest expected flow rate during the year for a year in the midst of a moderate drought cycle. The through flow in Spring Creek was not included in the flow model because it added complexity to the compositing of water and would not allow segregation of the Mine Creek discharge with drain cells.

2.2.2.2 GROUND-WATER DISCHARGE TO SPRING CREEK

Based on the measurements in the previous section, the current ground-water discharge to Spring Creek ranges from 47.5 gpm to approximately 80 gpm. Prior to the installation of the collection/recharge system, the ground-water discharge was approximately 24 gpm. There is undoubtedly some seasonal cycling of this discharge. The total predicted ground-water discharge to Spring Creek is tabulated by the MODFLOW model. The predicted rate of groundwater discharge during operation of the collection/injection system is 91 to 93 gpm. Following cessation of injection, the model predicts that the discharge rate will drop to 23 to 24 gpm after roughly 20 years. The predictions correspond reasonably well with measured values.

2.2.2.3 PROJECTED POE CONCENTRATIONS IN SPRING CREEK

A significant portion of the ground water entering Spring Creek has been impacted by seepage from the tailings. This water combines with the base flow in Spring Creek to produce composite surface water concentrations that are much lower than the typical ground-water concentrations. The MODFLOW model predictions of ground-water discharge to the river and drains cells representing Spring Creek and Mine Creek were extracted for each of 14 stress periods over a 50-year simulation period. The average concentrations for a series of drain and river cells was then multiplied by the discharge to each type of cell to give a constituent "load" to Spring Creek. The composite concentration of the ground-water discharge and the 290 gpm base flow in Spring Creek was then the POE concentration.

Mine Creek was represented by 20 drain cells, and the concentration of every other drain cell was averaged at regular intervals through the simulation period to represent the Mine Creek discharge. This quantity was then multiplied by the total drain discharge rate for each stress period. Since the drain cells are located roughly in a line perpendicular to the gradient from the tailings, the contaminant front reaches the cells sequentially. The maximum concentration in the Mine Creek discharge represented by the drain cells occurs long after the fresh-water mound from injection has decayed, and the contaminant has reached the last drain cell at the confluence of Mine Creek and Spring Creek.

A similar approach was used in determining the average concentration of ground water entering the river cells in Spring Creek over time. There were 143 river cells used for Spring Creek and the ground-water discharge to a cell was not uniform. For this reason, 12 indicator river cells along Spring Creek were used in this averaging. The indicator cells were selected to provide a distribution that would reflect the varying rates of discharge due to the larger conductivity near the Mine Creek confluence. Four cells were distributed upstream from the Fox Creek confluence. Seven cells were placed in the reach between the Fox Creek confluence and the haul road crossing. The remaining cell was placed just downstream of the haul road crossing. Over the simulation period, the concentrations in all but one cell did show an increase over background, although the magnitude of change was small for far upstream cells. Like the drain cells, the concentration across the 12 indicator cells was averaged at regular intervals and then multiplied by the rate of ground-water discharge for each stress period.

When the base flow in Spring Creek and the ground-water discharge to river cells and drain cells is combined at the end and middle of each stress period, a concentration curve for the POE is developed. This curve is somewhat bell shaped in nature and the maximum concentration represents the proposed ACL POE concentration. The predicted POE concentration for uranium is 0.15 mg/l and the predicted thorium-230 activity is 0.3 pCi/l. The predicted selenium concentration at the POE is 0.0056 mg/l and the predicted Ra-226 + Ra-228 activity is 1.5 pCi/l.

2.2.2.4 POE SELECTION AND SPRING CREEK LOADING

Ground-water discharge to Spring Creek is occurring along a reach extending along the eastern side of the tailings. The ground-water discharge is not uniformly distributed along Spring Creek and the majority of the discharge occurs in the vicinity of the Mine Creek confluence. The only significant influx of surface water along the reach is from Fox Creek, and the majority of ground-water discharge is downstream of the confluence with Fox Creek. Hence, the discharge of ground water downstream of the Fox Creek confluence is mixed with an assumed constant rate of baseline surface flow. Additional loading of constituents is thus progressive with full constituent load realized at a point downstream of all seepage-impacted discharge. The current location of the POE is selected as that point. Because the POE is located immediately downstream of the extent of seepage-impacted discharge, there is no significant influx of ground water that has a <u>lower</u> concentration (or activity) than the POE concentration (or activity) upstream of the POE, and the maximum concentration will occur at the POE.

Figure 2.2-7 presents the estimated sequential changes in uranium concentration while moving downstream along Spring Creek. The modeling assumptions are as detailed in previous sections and as discussed in Appendix E. The combination of contributing cells was added sequentially for four time periods to span the interval when the expected maximum concentrations will occur. This should approximate the worst-case scenario for compositing of the water even though the contribution of an individual cell may not be at its maximum concentration. The drain cells were assumed to contribute directly at the confluence of Mine Creek and Spring Creek. The remaining groundwater discharge rate was assumed to be uniformly distributed among the 12 cells used in compositing water quality in the transport modeling. The station along Spring Creek on the x-axis of Figure 2.2-6 was taken as an approximate straight line distance between individual cells used in compositing of the water. Thus the station reflects a generalized distance along Spring Creek without consideration of length in local meanders. The first point is located roughly due north of the center of the tailings, and the last point is at the approximate POE location.

The changes in uranium concentration for the four periods in Figure 2.2-7 illustrate the accumulation of seepage impacts while moving downstream on Spring Creek. The next to last data point (approximately station 6230) is located just upstream of the haul road crossing of Spring Creek. There is virtually no change in concentration between this point and the POE for the four time periods. Upstream of this point there is a measurable increase in concentration while moving downstream. Figure 2.2-8 illustrates the same accumulation of seepage impacts for TDS concentration. The accumulation leads to the observation that there is no measurable change in concentrations between the haul road crossing and the current POE location. The planned POE location is therefore appropriate and the POE could possibly be moved upstream to the haul road crossing with no discernable change in results. However, further Spring Creek sampling upstream of the haul road crossing is predicted to yield concentrations that are equal to or less than the concentration at the current POE. Thus, the single planned POE is appropriate.

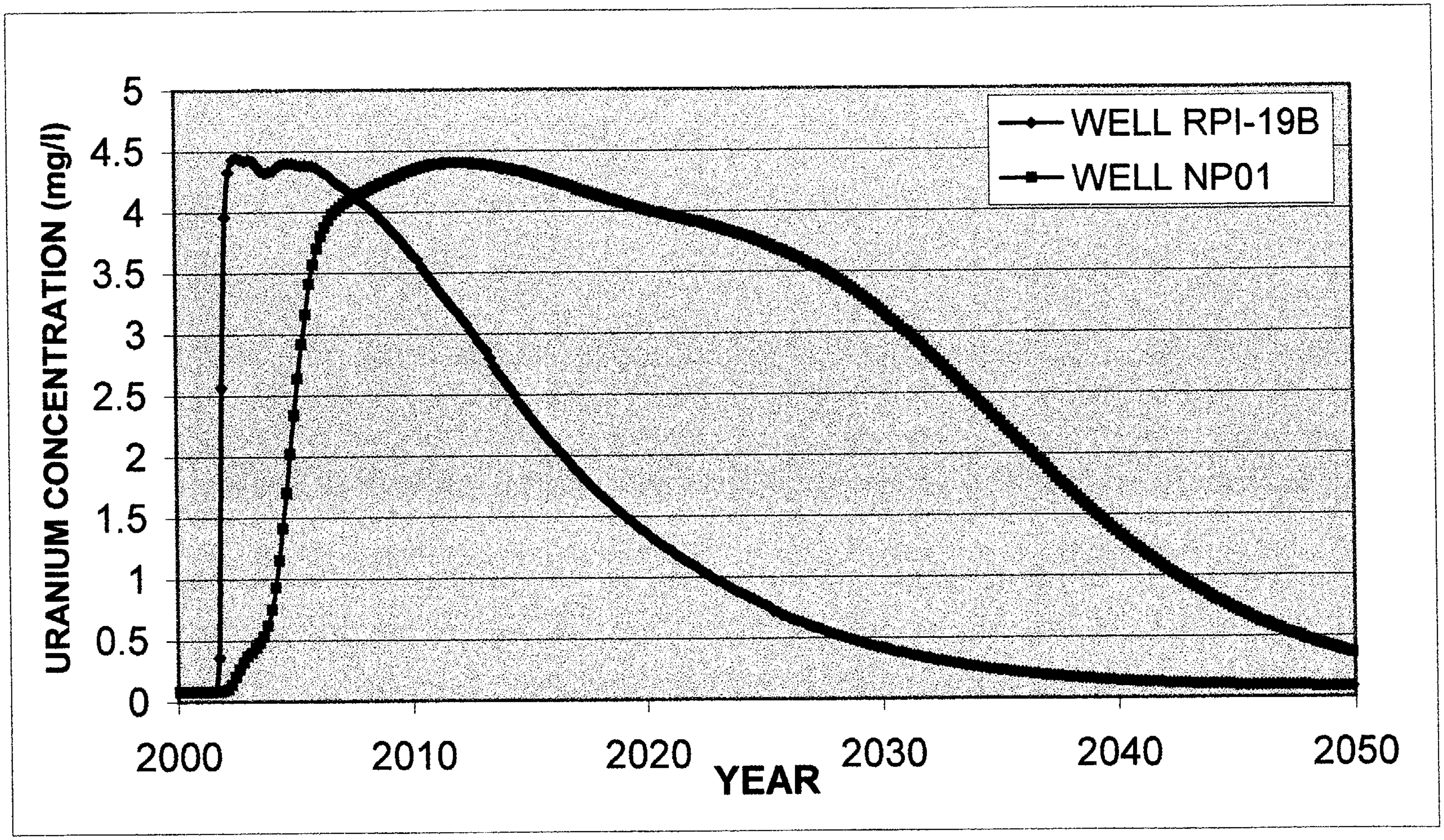

FIGURE 2.2-1. PREDICTED URANIUM CONCENTRATIONS AT THE POC WELLS

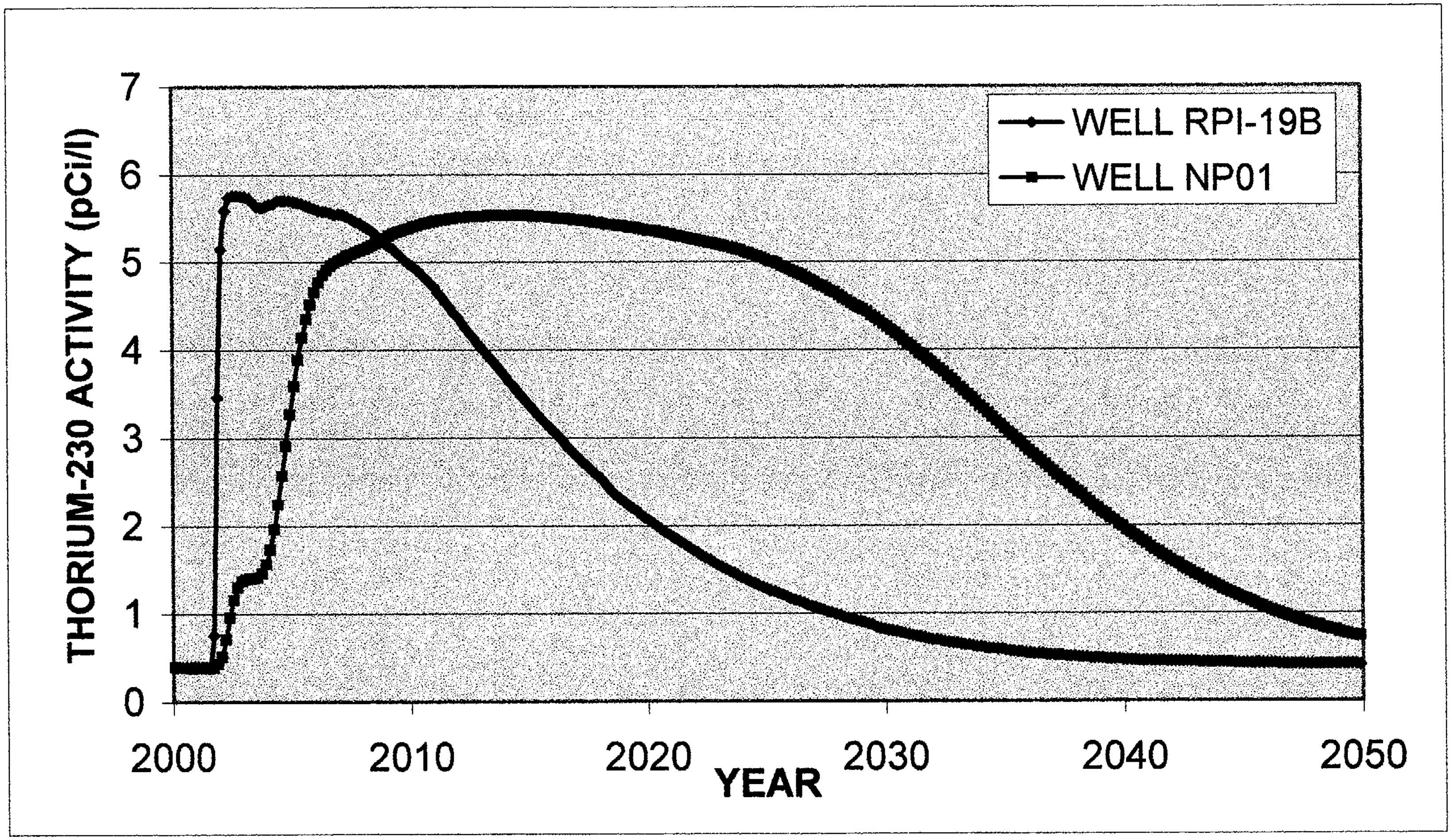

FIGURE 2.2-2. PREDICTED THORIUM-230 ACTIVITY AT THE POC WELLS

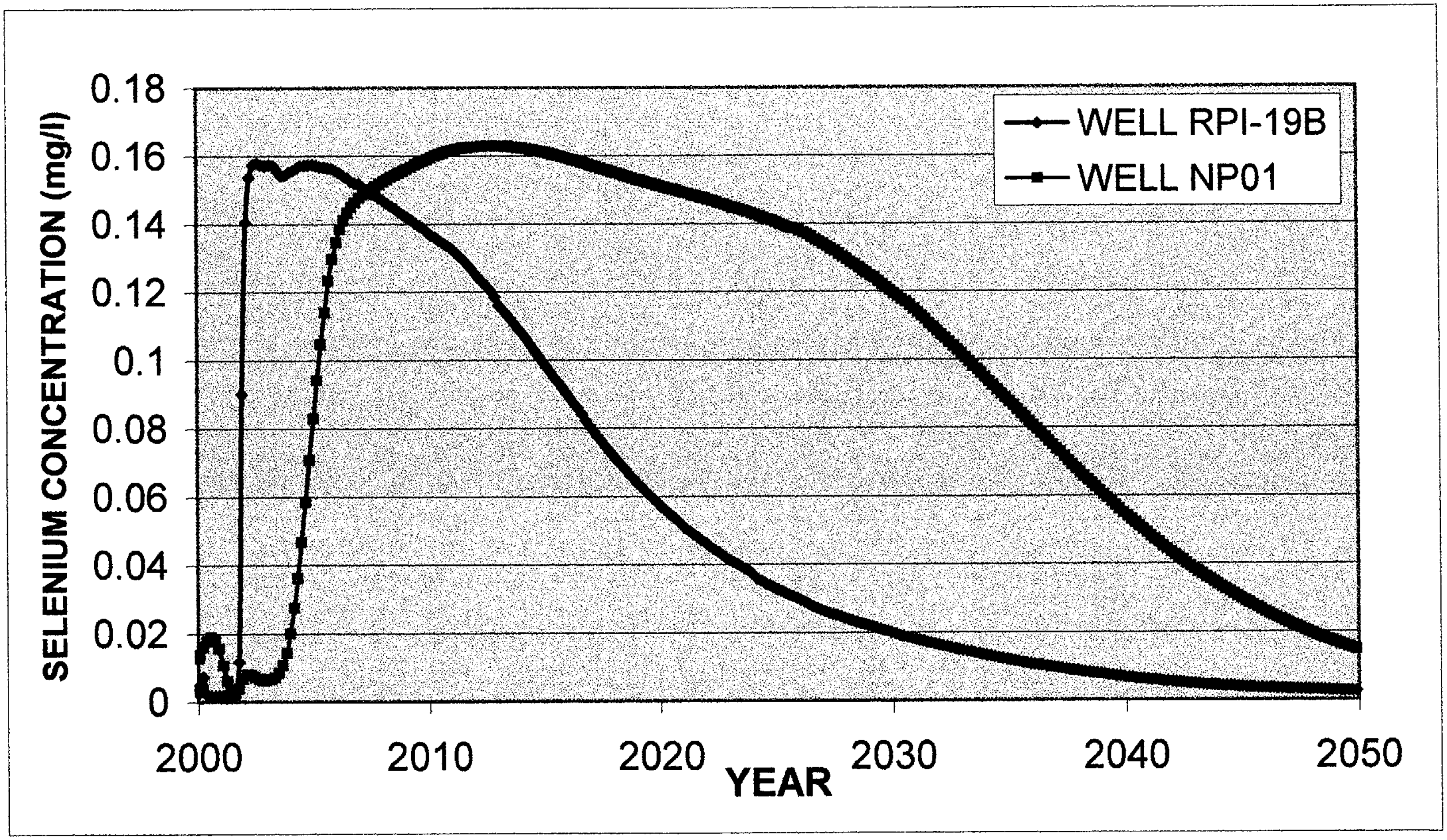

FIGURE 2.2-3. PREDICTED SELENIUM CONCENTRATIONS AT THE POC WELLS

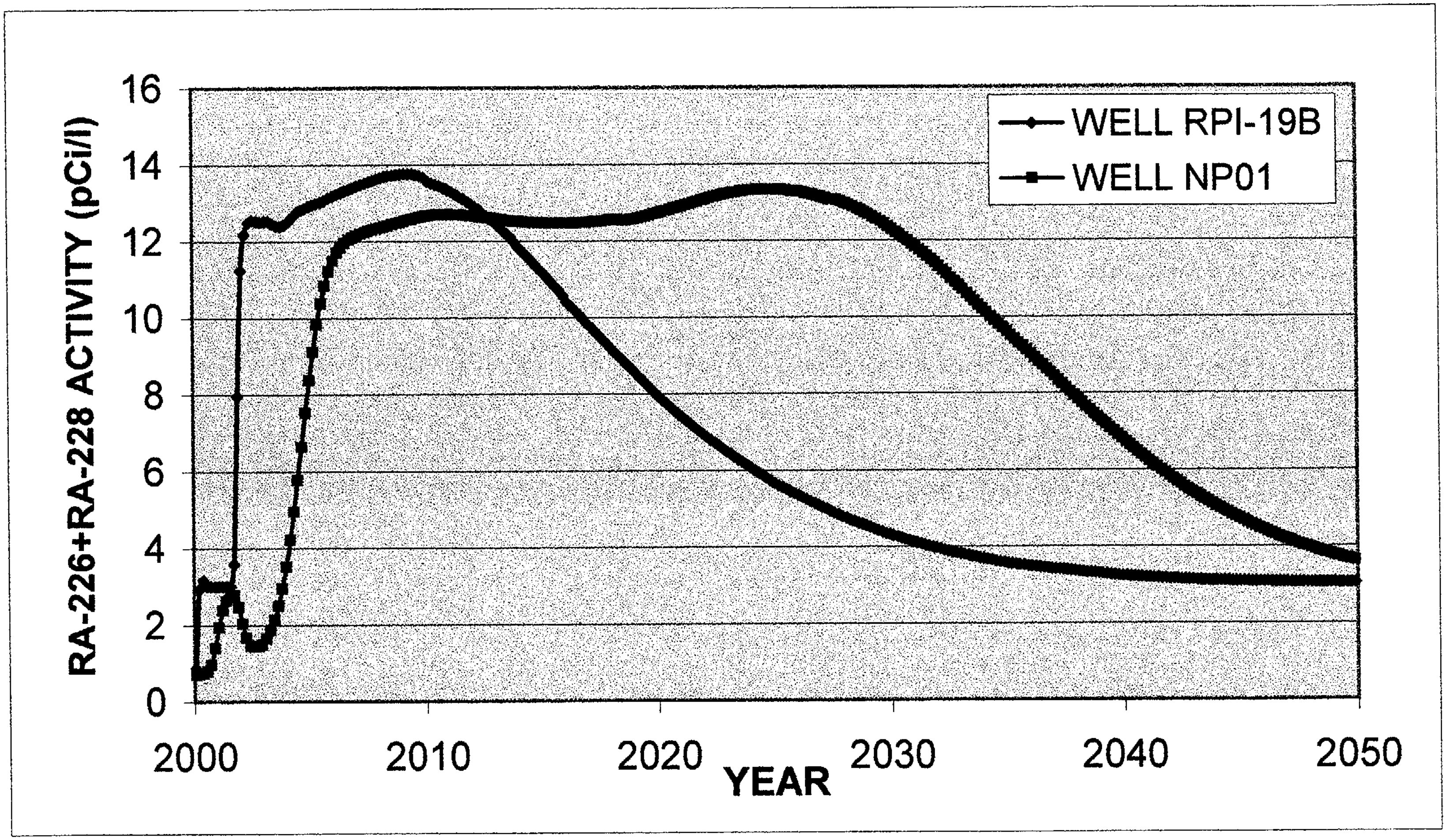

FIGURE 2.2-4. PREDICTED RA-226+RA-228 ACTIVITY AT THE POC WELLS

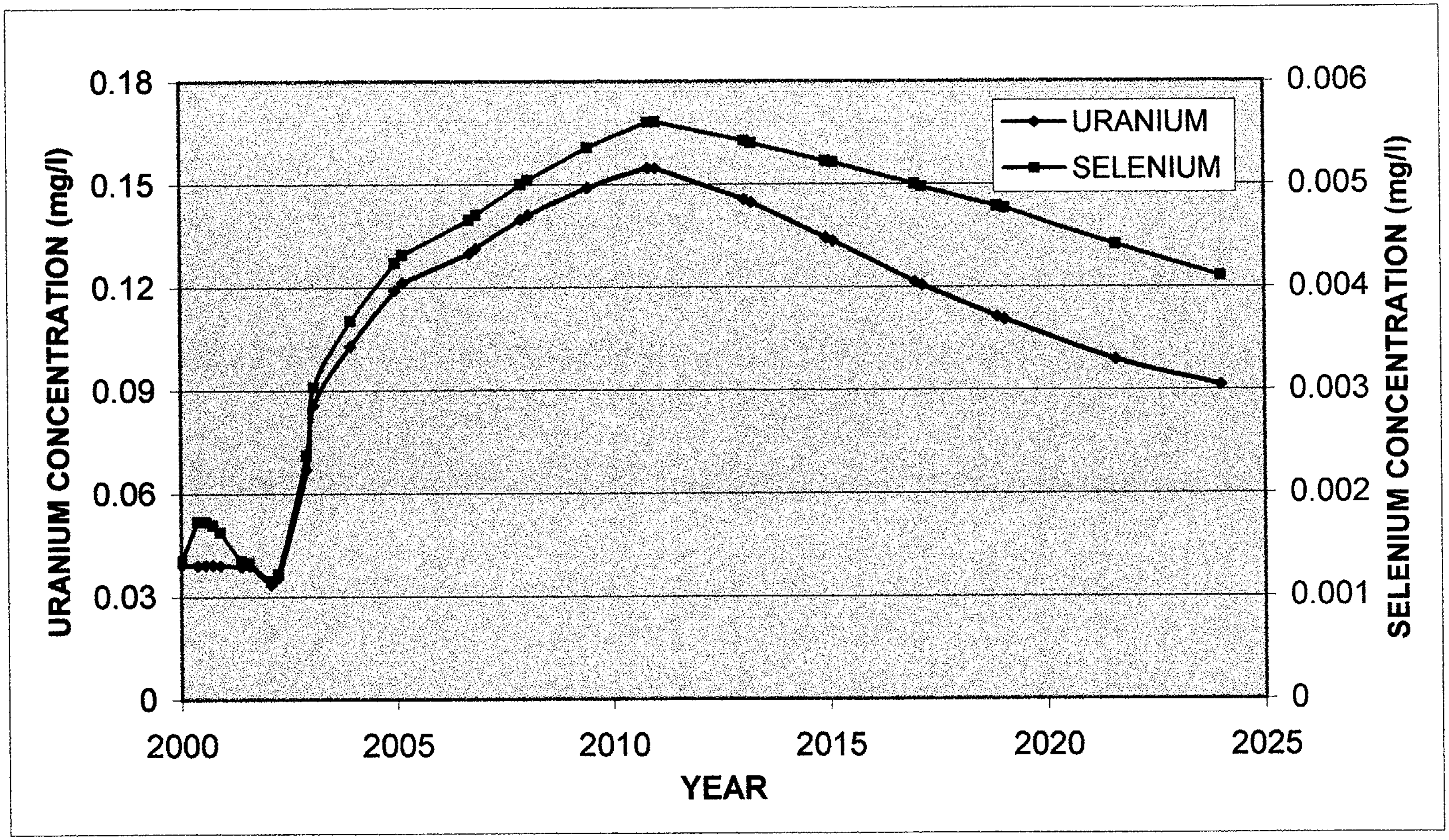

FIGURE 2.2-5. PREDICTED MAXIMUM URANIUM AND SELENIUM CONCENTRATIONS AT THE POE

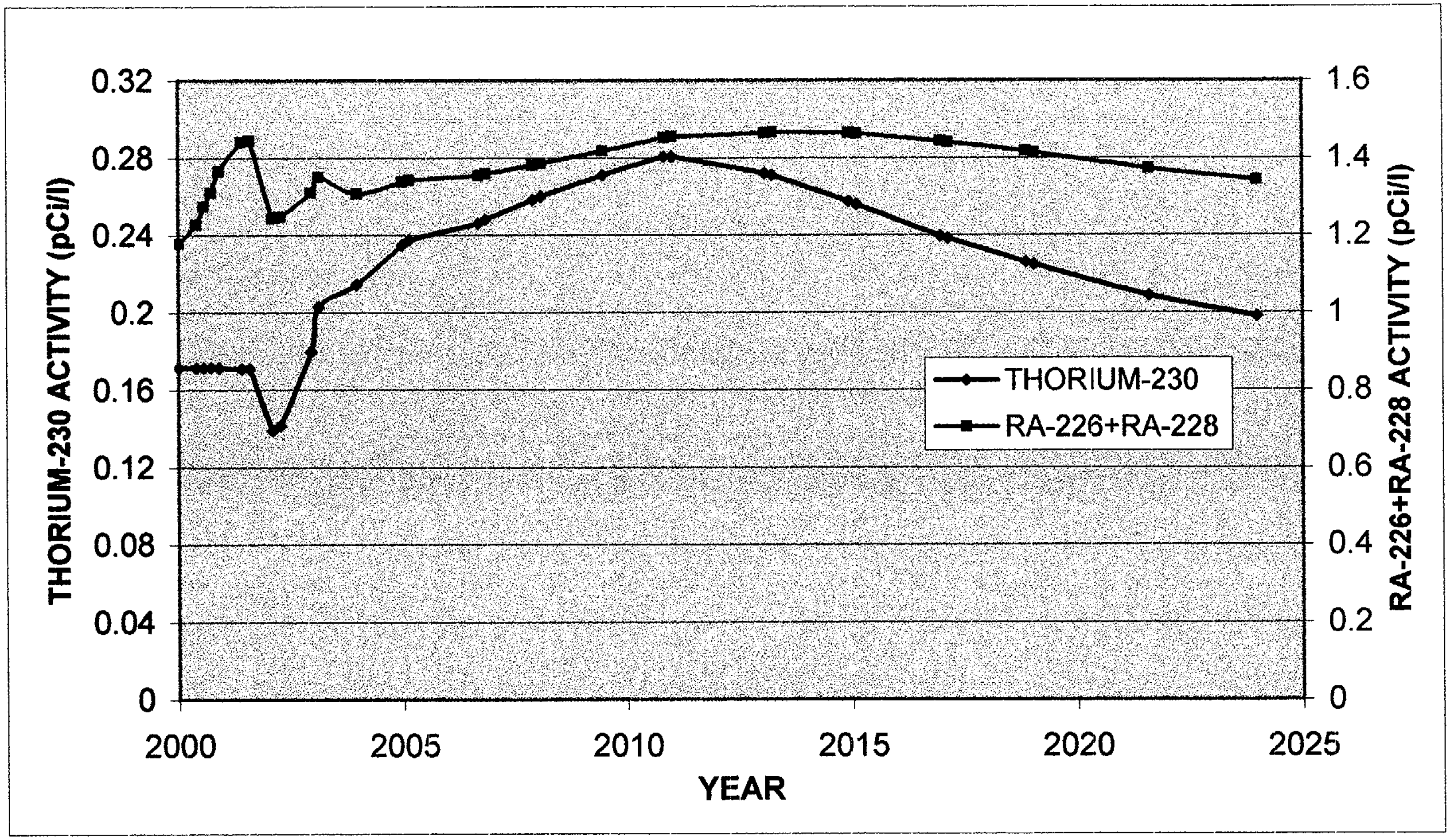

FIGURE 2.2-6. PREDICTED MAXIMUM THORIUM-230 AND RA-226+RA-228 ACTIVITY AT THE POE

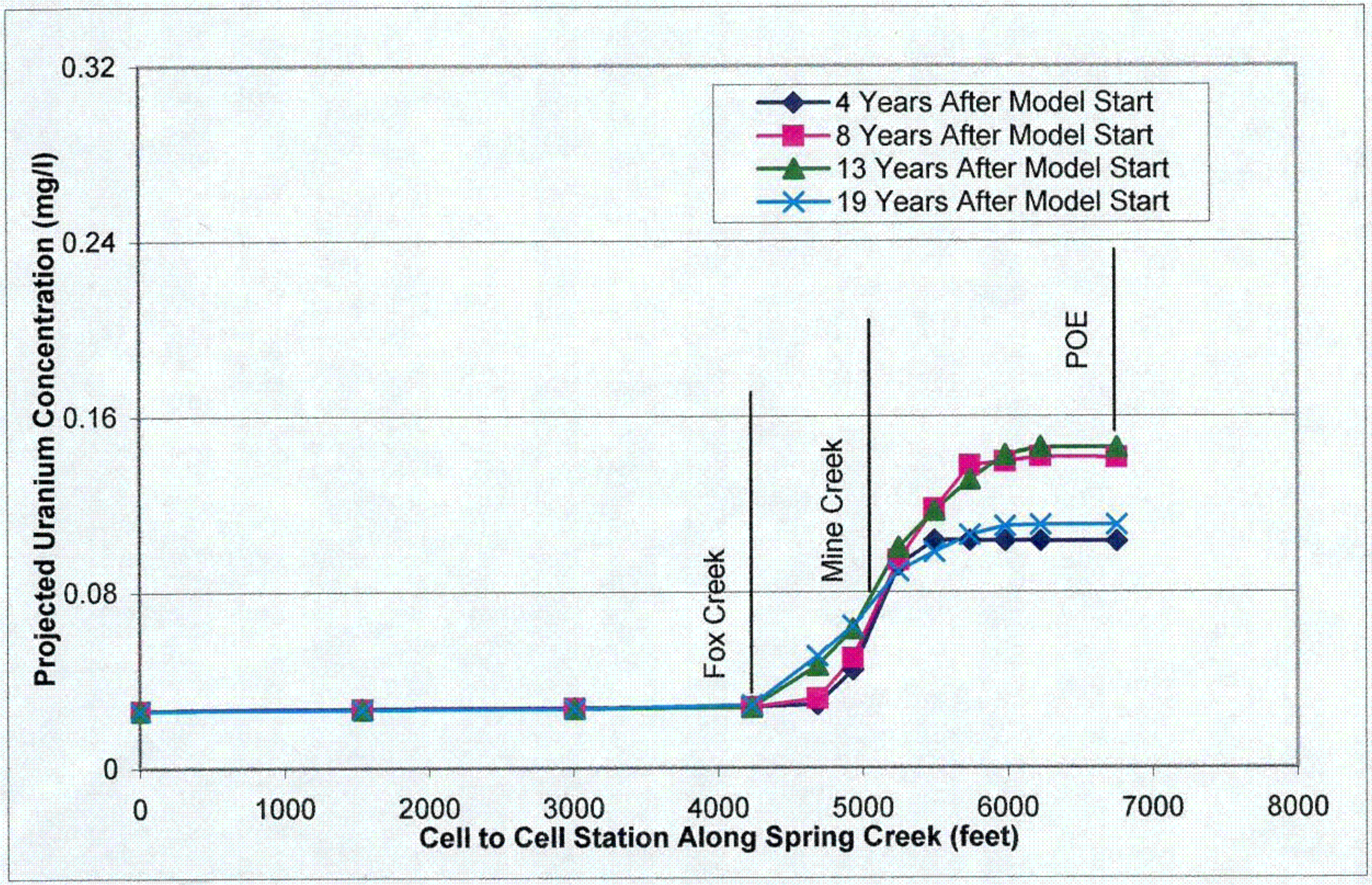

Figure 2.2-7. Projected Maximum Uranium Concentration Along Spring Creek

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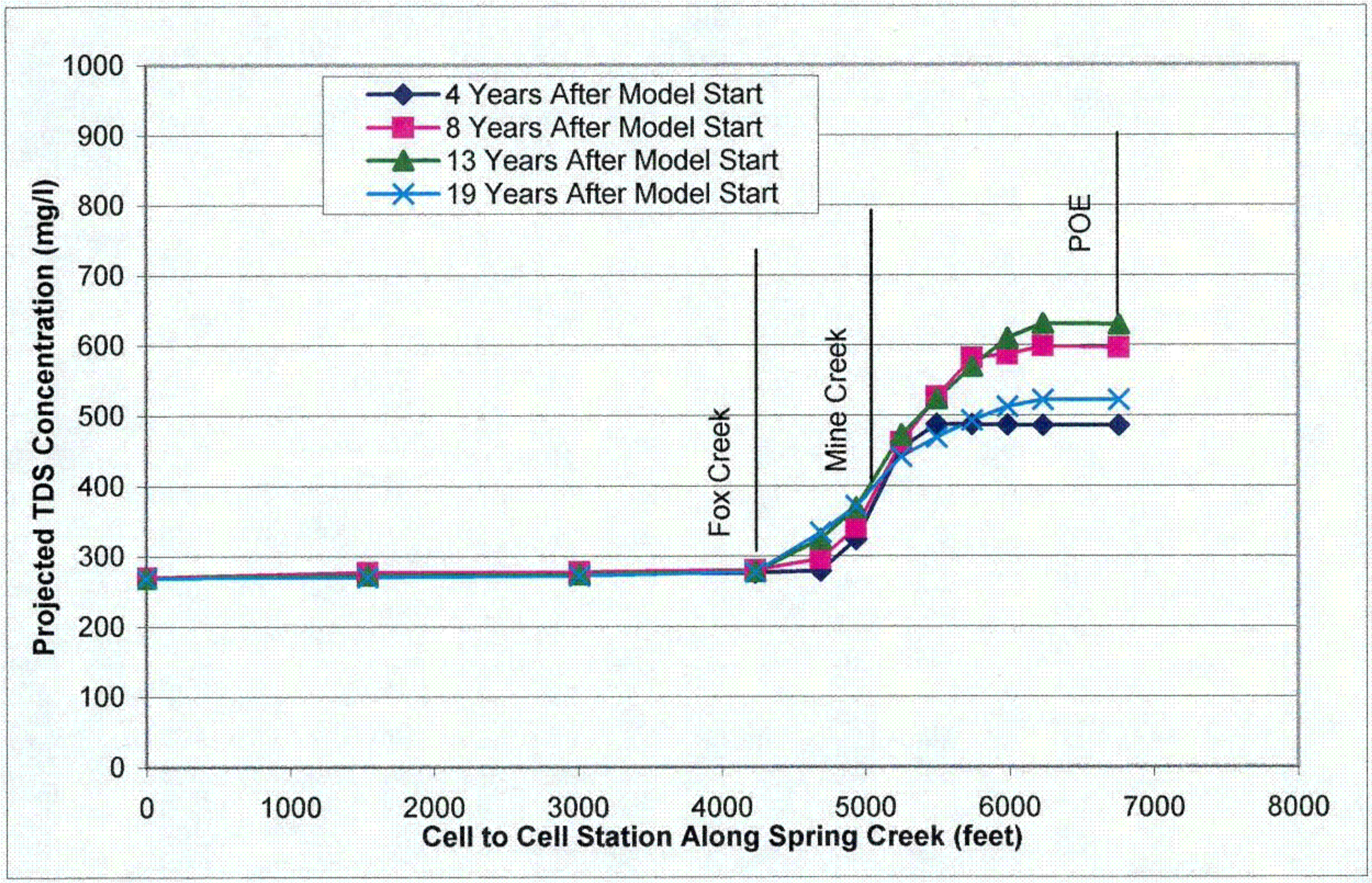

Figure 2.2-8. Projected Maximum TDS Concentration Along Spring Creek

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2.3 EXPOSURE ASSESSMENT

Exposure assessments (and risk characterization) for uranium, selenium, thorium-230, and Ra-226 + Ra-228 demonstrate that impacts on human health and the environment are acceptable at the projected POE concentrations in ground water and surface water. These conclusions are based on the results of a detailed exposure pathway analysis, exposure estimations, toxicity evaluations, and projections of the risk of adverse impacts on human health and the environment. The details of the assessments are presented in Appendices A, B, and C.

Two potential exposure scenarios were evaluated. The Spring Creek scenario considered a rancher living downstream of the site along Spring Creek. The potential for anything other than occasional human consumption of the surface water in the Spring Creek scenario is highly unlikely. The risk of bacterial contamination in surface water is simply too great to utilize the water without treatment. The potential for construction of a surface water treatment facility drawing from the reach of Spring Creek between the mine and the confluence with Little Medicine Bow River is so remote that it can be disregarded. Hence, the potential means of human exposure are indirect or are limited to very infrequent direct consumption of the water. The most direct of the plausible exposure pathways is extraction from a alluvial well directly adjacent to the Spring Creek channel. However, a well close enough to draw surface water from Spring Creek would be subject to the same treatment concerns as water drawn directly from the Creek, and is not expected to have an adequate yield for domestic supply. The well would also be extremely vulnerable to flooding. A rancher drilling a well would therefore drill into a nearby deeper aquifer with an adequate supply of better quality water. It was assumed that human drinking water would come from this well. Water for land irrigation and livestock watering would come from the river. The rancher would raise beef, dairy cattle, and poultry where the feed was obtained from the irrigated land. An irrigated home garden was assumed to produce 25 percent of the family's vegetables. All meat, poultry, and eggs consumed by the family are assumed to come from the ranch.

The Little Medicine Bow River scenario assumed that a rancher and family lived along the river just below the confluence of Spring Creek. Since the alluvial aquifer is more productive in this area, it was assumed that all drinking water was taken from an alluvial well and that the constituent concentrations were identical to that in the river. The other exposure assumptions were identical to those in the Spring Creek scenario.

2.3.1 EXPOSURE PATHWAYS

The analyses presented in Appendix A show that pathways other than ingestion are not significant when considering the human health assessment. Since Spring Creek intercepts all of the Surficial water that flows from the site within the site boundary, the Spring Creek scenario represents the closest possible POE to the site. The Little Medicine Bow River scenario represents the second closest user of water originating from the site. Exposure estimates were made for each important pathway for both scenarios, as presented in Appendix A.

2.3.1.1 GROUND-WATER USES

The future use of ground water within the current restricted area will be prevented when ownership of the site is transferred to the U. S. Government. Since the impacted ground water is intercepted by Spring Creek within this area, the nearest POE is the water in Spring Creek at the site boundary.

2.3.1.2 SURFACE-WATER USES

Spring Creek discharges to Little Medicine Bow River and eventually to the North Platte drainage. At present, there is no usage of the surface water upstream of the confluence with Little Medicine Bow River other than consumption by livestock and wildlife. The confluence with Little Medicine Bow River is less than two miles downstream from the closest POE location. At this point, the flow in the system increases several fold.

2.3.2 HUMAN HEALTH RISKS

Ingestion accounts for the largest contribution to the potential for an adverse health effect. The potential chemical toxicity risks from exposure, both directly and indirectly, to uranium and selenium at the projected POE values have been characterized. The radiation dose and accompanying fatal cancer risk has been assessed for uranium, Ra-226+Ra-228, and Th-230. In addition, an assessment of the risk from total dissolved solids and the major ions, sulfate and chloride, has been made. Estimates of human exposure are described in detail in Appendix A for both scenarios. Appendix A shows that the Little Medicine Bow River scenario is the most limiting since the direct ingestion of the water is included in this scenario. Human health hazards and assessments, based on the proposed POE concentrations in the Little Medicine Bow River, are described in detail in Appendix B.

The traditional approach of the EPA derives acceptable drinking water limits by very conservative methods and the use of reference oral doses (RfD_o) that can be applied anywhere in the United States. RfD_o's are a function of uncertainty factors and toxicity values for which no toxic effects have been observed (NOAEL), or the lowest dose at which toxic effects have been observed (LOAEL) in humans or laboratory animals. The EPA's objective is to develop drinking water quality criteria that will protect the entire U.S. population. Therefore, it must be more protective and conservative than the objective of an Alternate Concentration Limit. One significant difference between the two approaches is the weight of consideration given by the Nuclear Regulatory Commission to the probability, in this case, that the ground water will ever be used as a potable water source in the future. Currently, the ground water at the boundary of the site (simulated POE for the Spring Creek scenario) is not being used for drinking water, and it is unlikely that it will ever be. Consequently, the criteria for predicting the risk of toxic effects occurring at the proposed POE values are not the same. Concentrations of the constituents may be higher than those listed by the EPA, or other agencies, as long as the risks of adverse impacts on human health and the environment are shown to be acceptable.

2.3.2.1 URANIUM

Excessive exposure to uranium for the Little Medicine Bow scenario was linked to two possible end-points: chronic kidney disease due to chemical toxicity and cancer due to radioactivity. This risk assessment addressed the toxicology and the probable risks of adverse health effects for both end-points assuming the use of water containing the time-weighted-average uranium concentration mg/l. An estimated daily intake value was developed from a uranium concentration of 0.02 mg/l in the uranium exposure assessment in Table A.4-9 in Appendix A.

The biokinetic model for estimating the kidney burden of uranium was validated by comparing the reported values, from studies of residents in New York City and Japan, with the predicted model value (Fisenne and Welford, 1987; Igarishi, 1985). The reported and predicted values compared favorably, thus validating the model.

The uranium burden in the kidneys was estimated for potential residents who use water with a uranium concentration of 0.02 mg/l. Kidney concentration values were calculated to be 0.005 μg U/g kidney. In this assessment, a threshold value for preventing the occurrence of irreparable kidney damage was assumed to be 0.1μg U/g kidney, based on available data. The assessment concludes that the intake of well water and food is not expected to result in uranium burdens in the kidney that are associated with kidney damage. This is expected since the uranium concentration is within the EPA Primary Drinking Water Standard value of 0.03 mg/l.

2.3.2.2 SELENIUM

Natural selenium is not classified as a human or an animal carcinogen by the EPA. On the contrary, epidemiological demographic studies in areas high in natural selenium suggest that cancer rates are lower when compared to control groups, suggesting that selenium can reduce cancer risk with no adverse side effects.

Chronic exposure to excessive levels of selenium may result in selenosis. Selenosis is manifested by thickened and brittle nails, nail loss, hair loss, garlic breath, mottled teeth, skin lesions, and central nervous system disorders. While excessive selenium is normally excreted, excretion is a function of the liver and respiratory systems. People with weakened functions of these organs may be vulnerable to selenosis.

The EPA has recommended a chronic oral reference dose (RfD) for selenium of 0.005 mg/kg-day. The predicted intake of selenium in drinking water and food for the Little Medicine Bow River scenario is 3.8E-05 mg/kg-day, or less than one percent of the RfD value. Thus, the expected daily intake of selenium poses no additional risk when compared to the RfD.

2.3.2.3 RADIONUCLIDES

The potential risk of fatal cancer from ingestion of uranium, Ra-226+U-228, and Th-230 while living at the site for 30 years was estimated using the exposure pathways described in Section 2.3.1 and risk factors from the EPA. Details are provided in Appendix B. The conservative calculation resulted in a lifetime risk of 3.9E-6. This value is below the cancer risk criteria of the NRC of 1.0E-04 (NRC, 1996) and the EPA at 3.0E-04 (FR(57), 1992).

The potential annual radiation dose from ingestion of uranium in ground water was estimated using dose factors from the NRC. Details are provided in Appendix B. The calculations show that the total effective dose equivalent is 0.76 mrem/y. This is less than the NRC dose criterion of 100 mrem/y to members of the public from licensed nuclear facilities (FR(56) p.2335, 1991).

2.3.2.4 TOTAL DISSOLVED SOLIDS, SULFATE, AND CHLORIDE

Major constituents (major ions) to be considered at the Shirley Basin site in addition to those for which the NRC has established site standards include sulfate, chloride, and total dissolved solids (TDS). Addressing these constituents is required by 10CFR Part 40, Appendix A, Criterion 13. Nitrate was not included because concentrations in both the tailings and Surficial aquifer are low.

Most of the major ions do not have oral reference doses and may not have adequate data available to establish RfDs. Concentration limits may be based on other parameters such as odor or taste.

The total dissolved solids (TDS) for the Shirley Basin site are made up primarily of sulfate and chloride. The EPA secondary drinking water standard for TDS is 500 mg/l, based on taste and a possible relation between hardness and cardiovascular disease. The State of Wyoming domestic groundwater standards also limit TDS to 500 mg/l. The World Health Organization recommends a TDS level for drinking water of less than 1,000 mg/l. The maximum TDS concentration in Spring Creek has been projected at 649 mg/l with a time-weighted average (TWA) concentration of 384 mg/l. In the Little Medicine Bow River, the TWA concentration has been projected to be 173 mg/l at the confluence with Spring Creek. These TWA levels in Spring Creek and the Little Medicine Bow River are well within the limits for drinking water sources. It is therefore likely that little human health risk exists from using water under the proposed scenarios.

Sulfate ions contain sulfur, which is essential for normal body function. Water containing 500 mg/l tastes bitter, between 600-1,000 mg/l may produce a mild laxative effect, and greater than 1,000 mg/l may be cathartic (Heath, 1982). The human body appears to reduce the absorption of sulfate under high doses and eliminates excess sulfate, thus not accumulating sulfate. The EPA Primary Drinking Water Standard and the Wyoming Domestic Groundwater Standard for sulfate is 250 mg/l. The maximum predicted concentration near the tailing site at the POE is 183 mg/l. The predicted TWA concentrations for the Spring Creek and Little Medicine Bow River waters, under the respective exposure scenarios, are 73 and 16 mg/l. The Spring Creek scenario does not use this water for human drinking water. Since the quality of water complies with the drinking water standard, no measurable health impacts are anticipated from sulfate in water.

Chloride is the major anion in extra cellular fluid. The origin of chloride in the body is from the hydrochloric acid excreted by the stomach. Chloride helps maintain acid-base balance and is involved in the exchange of oxygen and carbon dioxide from hemoglobin. The EPA secondary drinking water standard for chloride is 250 mg/l based on taste and corrosion of pipes. The Wyoming Domestic Groundwater standard is also 250 mg/l. Wyoming surface water standard (aquatic life) for chronic exposure and the National Recommended Water Quality Criteria are 230 mg/l. Wyoming ground-water standards for agriculture limit the chloride concentration to 100 mg/l. The maximum concentration in Spring Creek is projected to be 118 mg/l at the POE with a TWA concentration of 39 mg/l. The TWA concentration in Little Medicine Bow River immediately below the confluence with Spring Creek is projected to be only 9.8 mg/l. Comparing these concentrations to the standards, there should not be toxic health effects from the presence of chloride in the water.

2.3.2.5 UNCERTAINTY

The numerous sources of uncertainty in this risk assessment have been discussed in each section of the analysis. In most cases, conservative assumptions have been made to increase the exposure estimate. The most conservative assumption is that a hypothetical resident(s) would consume water from an alluvial aquifer affected by the river quality. Beside the fact that deeper wells would be expected to produce a higher volume of water, the risk from natural bacterial contamination of the surface waters may be far greater than the chemical or radiotoxicity effects from constituents from the site. Table 2.3-1 lists some of the sources of uncertainty and associated consequences in predicting risk estimates for this human health assessment.

TABLE 2.3-1. UNCERTAINTIES IN HAZARDS ANALYSES.	
PROBABLE DIRECTION OF ERROR	**SOURCE OF UNCERTAINTY**
Underestimation of risk	Lack of measured concentration data for chemicals in environmental media
Overestimation of risk	POE concentrations are the maximum value that should occur at any of the POE locations. Average 30 year concentrations at all POE locations will be significantly less than the POE concentrations.
	Use of conservative parameters in the ion migration simulations
	Use of conservative parameters regarding Home-grown food
	Assume limited constituent losses in soil over time due to weathering or biodegradation
	Conservative assumptions for human and exposure animal parameter values
	Lack of adequate toxicity data relevant to exposure to these chemicals by ingesting drinking water
	Application of conservative uncertainty factors that may not represent the current knowledge base
Unknown direction	Variations in analytical measurements
	Uncertainties in hydrological modeling
	Toxicological interactions between chemical constituents or between the constituents and other biochemicals in the body
	Use of site reference doses RfD_o for uranium, Selenium, Ra-226+Ra-228 and Th-230
	Use of generic agricultural biotransfer factors

2.3.3 ENVIRONMENTAL HAZARDS

An analysis of the environmental impacts associated with constituents in Spring Creek water at the maximum concentrations (POE concentrations) was made. The details are presented in Appendix C. The concentration of all constituents, with the exception of uranium, are projected to be below or only slightly above government drinking water, surface water, or other applicable standards. A screening of the constituents was done to identify constituents of concern by comparing the POE concentration to known standards. This screening process eliminated all but uranium and the radioactive constituents as constituents of concern.

The toxic effects of uranium at POE concentrations in Spring Creek were assessed for non-human biota, including cattle and fish and other smaller aquatic and terrestrial species. It was concluded that the levels should not have any impact on terrestrial or aquatic species. There was only one study that indicated that specific aquatic invertebrates may be affected by uranium at concentrations below the POE concentrations and even at near background levels. Application of this work to Spring Creek is questionable since the studies were done in soft water rather than harder water where effects are only observed at much higher concentrations. Since a variety of invertebrate communities have been observed in rivers in the U. S. that have much higher uranium concentrations, it is improbable that an impact on one or more communities would seriously affect fish or other biota in the stream.

An analysis of the radiation dose to terrestrial plants and animals from the buildup of radionuclides in the soil from irrigation indicated that the total dose was below the proposed Canadian estimated no effect level (CAN, 2000) and only slightly higher (factor of four) than a dose threshold for any effects for all terrestrial species (NCRP, 1991; UNSCEAR, 1996). The radiation dose to aquatic species from intake of radionuclides from the water and the dose from direct radiation was calculated. The total dose was less than the dose considered protective of all populations of aquatic species (NCRP, 1991; UNSCEAR, 1996).

In summary, the constituents at POE concentrations in Spring Creek should not result in measurable impacts to aquatic or terrestrial life. The uncertainty of this assessment is, however, much higher than in a human health assessment since fewer impact studies have been conducted and the diversity of the aquatic and terrestrial species is very large.

3.0 CORRECTIVE ACTION ASSESSMENT

This section presents the results of the Corrective Action Program (CAP). Major topics to this subsection are the corrective actions relative to the tailings and the Surficial aquifer. The planned future corrective actions conclude the discussions in this subsection.

The feasibility of alternative corrective actions is presented as a second subsection. The final three subsections are the corrective action cost, corrective action benefits and ALARA conditions.

3.1 RESULTS OF CORRECTIVE ACTION PROGRAM

The corrective action program (CAP) for PMC's Shirley Basin site has included three basic components to restore ground-water quality. The first component was a series of Surficial aquifer collection wells that were pumped beginning in 1984. Additional wells were installed in 1986, and the second component of the CAP, a fresh-water recharge system was installed in 1986. Subsequent additions to the CAP have included additional recharge lines, improved fresh-water distribution systems and a series of fresh-water injection wells to construct a hydraulic barrier. The third component of the CAP has been the tailings dewatering program, which was begun in 1993 and has been expanded.

The purpose of the combination of Surficial collection and fresh-water injection/recharge is to create a hydraulic depression surrounded by a hydraulic ridge to effect a "sweeping" of the area between collection and recharge. The combination of both techniques allows the establishment of gradient reversal, which both contains seepage plumes and allows restoration of areas upgradient and downgradient of the hydraulic ridge or mound.

Originally, the collection water from the Surficial aquifer was recycled through the milling process. When milling ended in 1992, the collection water was returned to tailings for evaporation. In 1997, PMC began discharge of a portion of the Surficial collection water to the Area 2/8 pit after treatment. All remaining collection water is evaporated in the tailings area through a series of shallow ponds and spray enhanced evaporation systems. The results of the corrective action program are discussed below.

3.1.1 TAILINGS

Collection rates from the tailings wells currently average approximately 130 gpm. The gradual reduction in surface water volume in the tailings ponds has allowed progressive coverage of Tailings Pond #5 and the majority of Tailings Pond #4 with interim cover. Unfortunately, the Shirley Basin has experienced a relatively wet precipitation cycle since 1992, which has hampered efforts to dispose of water through evaporation.

A total of 65 tailings wells are in place on the tailings, with 52 of the wells constructed as potential pumping or extraction wells. The first tailings well was drilled and began pumping in 1993. Additional tailings wells have been added in more than four drilling programs. The operation of the tailings wells has been difficult with severe precipitation and corrosion problems. The high TDS and low pH of the tailings water makes constant maintenance of the dewatering system necessary. Frequent well development and rehabilitation is necessary to maintain well yields. Unfortunately, lower yielding wells in less permeable tailings require similar or greater maintenance efforts and expense when compared to better yielding wells. This leads to constantly escalating cost per unit volume of water extracted.

The remaining volume of water contained within the tailings is estimated at 137 Mgal at the end of 1999. This does not include tailings solution stored in No. 4 pond or a series of shallow evaporation ponds. The surface tailings water is being disposed of with evaporation systems, and construction of a clay-lined pond is planned to contain the remaining water. Also under consideration is a reverse osmosis (R.O.) system to create a good quality water stream that can be discharged to the mine. Infiltration of precipitation or runoff and leakage from evaporation ponds on the tailings surface has resulted in a large rate of recharge to the tailings in the past. This has effectively offset a substantial portion of the tailings dewatering extraction volume. However, replacement of leaky evaporation ponds with clay-lined ponds, and diversion or capture of runoff from surrounding areas has reduced the recharge to the tailings.

3.1.2 SURFICIAL AQUIFER

Fresh water injection has been used at this site to build a hydraulic mound to reverse the gradient back to collection wells to remove the contaminated water. Collection started in 1984 and has continued to the present with staged addition of collection wells. A total of 22 fresh-water injection wells were added on the crest of the No. 5 dam to create a hydraulic barrier to seepage in the Surficial aquifer. An additional recharge line was added in 1995.

3.1.2.1 COLLECTION AND INJECTION

Figure 1.2-3 presents the location of the injection and collection systems. Improvement in water quality resulting from operation of these systems is presented in the following sections. Pumping from five collection wells (5A1, P3, P4, P6, and P7), began in November of 1984 (see Figure 1.2-3 for location of wells). The initial monitoring program indicated that containment of seepage, or gradient reversal, was successful only in the permeable portions of the Surficial aquifer. It was determined that a water recharge system in conjunction with more pumping wells would be needed to insure continuous gradient reversal in the Mine Creek seepage areas of the Surficial aquifer. Consequently, a fresh water recharge system was constructed during the summer of 1986, and three more collection wells were added to the pumpback system.

Pumping from the three new wells, P1, P8A, and P9, began on October 6, 1986. Further monitoring, during late 1986 through August 7, 1987, indicated the need for two more pumping wells and better distribution of water in the North recharge line. Consequently, collection wells P10 and P11 and a permanent re-distribution water line from WW23 were added. Pumping of collection wells P1 and P7 was discontinued on August 9, 1990 because of low yields.

A series of injection, collection, and monitor wells were added to the ground-water restoration system in 1994. Twelve Surficial injection wells were installed on the interior of the northern edge of the No. 5 tailings dam (see Figure 1.2-3) with operation beginning on 5/2/94. The wells were placed 100 to 200 feet apart to produce a ground-water "ridge" as a barrier to seepage. The initial injection rate was approximately 25 gpm, but has declined to approximately 9 gpm with development of a ground-water mound. The source of the injection water is well WW20. With the exception of brief periods of down time for maintenance of individual wells, the system has operated continuously. Additional Surficial collection wells are distributed throughout the tailings area. Five additional Surficial monitoring wells were also installed on the northeast side of the No. 5 Tailings Dam to analyze the effectiveness of the injection/collection system. In 1995, additional collection and injection wells were installed. Collection wells P12 through P21 were installed and pumping with a common suction line began in 1996. The pumping system was later converted to individual pumps. Injection wells TWI-12 through TWI-20 and TWI-22 extended the injection system along the No. 5 Dam to the south.

3.1.2.2 SURFICIAL WATER-QUALITY RESTORATION

With respect to the ACL constituents, uranium and thorium-230, the water-quality restoration in the seepage plume area has been very successful. In areas where data for uranium, thorium-230, selenium and Ra-226 + Ra-228 are sparse or less frequent, chloride concentration has been used as an indicator of the success of restoration programs. Figure 1.3-6 presents measured uranium concentrations in the Surficial aquifer. The uranium concentration contours clearly indicate that the area of significantly elevated concentrations has been drawn to the immediate vicinity of the collection wells. In contrast, uranium concentrations for well RPI-20A at the confluence of Mine Creek and Spring Creek were as high as 3.5 mg/l in the mid 1980's but now are at 0.1 mg/l or less. In the south plume area, the uranium concentration in well RPI-21B has declined from a high of 3.14 mg/l to less than 0.2 mg/l. In the north plume area, the chloride concentration in well MC-8 has declined from a high of 750 mg/l to less than 50 mg/l in recent years. There is no uranium concentration data available for this well prior to 1989, so the nature of the restoration with respect to uranium can only be inferred from restoration of other constituent concentrations. The restoration of uranium concentration does lag restoration of chloride concentration due to retarding processes, and this is evident from slightly elevated uranium concentrations at many wells distributed throughout the Mine Creek area. However, for all practical purposes, the ground-water quality in the seepage plume area has been restored back to the immediate vicinity of the collection system.

As mentioned earlier, thorium-230 activities in the seepage plume area are more erratic than uranium concentrations, and this makes evaluation of the success of restoration efforts far less certain. Using well RPI-20A as the primary indicator well, there were six occurrences of thorium-230 activity in excess of the site standard of 0.3 pCi/l prior to 1990. Since 1990, there has been only one detection of thorium-230 in samples from this well, and that particular detection was highly questionable. This indicates that restoration with respect to thorium-230 activity has been successful.

Ra-226 + Ra-228 and selenium, like thorium-230, do not exhibit distinctive contaminant plumes. Rather, these constituents are found at levels of concern in very local areas or in an occasional and seemingly anomalous sample. As such, there was no original plume to demonstrate restoration. In reviewing plots in Appendix D of Hydro-Engineering L.L.C. (2000), it could be argued that exceedence of the site standard for Ra-226 + Ra-228 was more frequent prior to 1996, and in that respect there has been some restoration with respect to this constituent. However, the very limited mobility of Ra-266 + Ra-228 and selenium in the Surficial aquifer has been the primary factor in preventing the migration of these constituents.

Directly beneath the tailings and in close proximity to the collection system, the ongoing seepage from tailings is maintaining uranium and thorium-230 levels. There has been an improvement trend over the last 3 to 4 years in collection wells P-3, P-6, P-8A and 5A-1, and this is attributed to retrieval of the seepage front east of these wells. However, unless the tailings are completely dewatered and seepage ceases, restoration of the Surficial aquifer water beneath the tailings and in the capture area (near the collection wells), will never be complete. Both selenium and Ra-226 + Ra-228 have very limited mobility and have not migrated into the Surficial aquifer below the tailings in sufficient quantities to be of the same concern as uranium and thorium- 230. Since it is impossible to completely dewater the tailings, the restoration of the Surficial aquifer water quality beneath the tailings is not feasible.

3.1.3 PLANNED CORRECTIVE ACTION

The planned corrective action has been broken into subsections of collection and injection, and tailings dewatering.

3.1.3.1 COLLECTION AND INJECTION

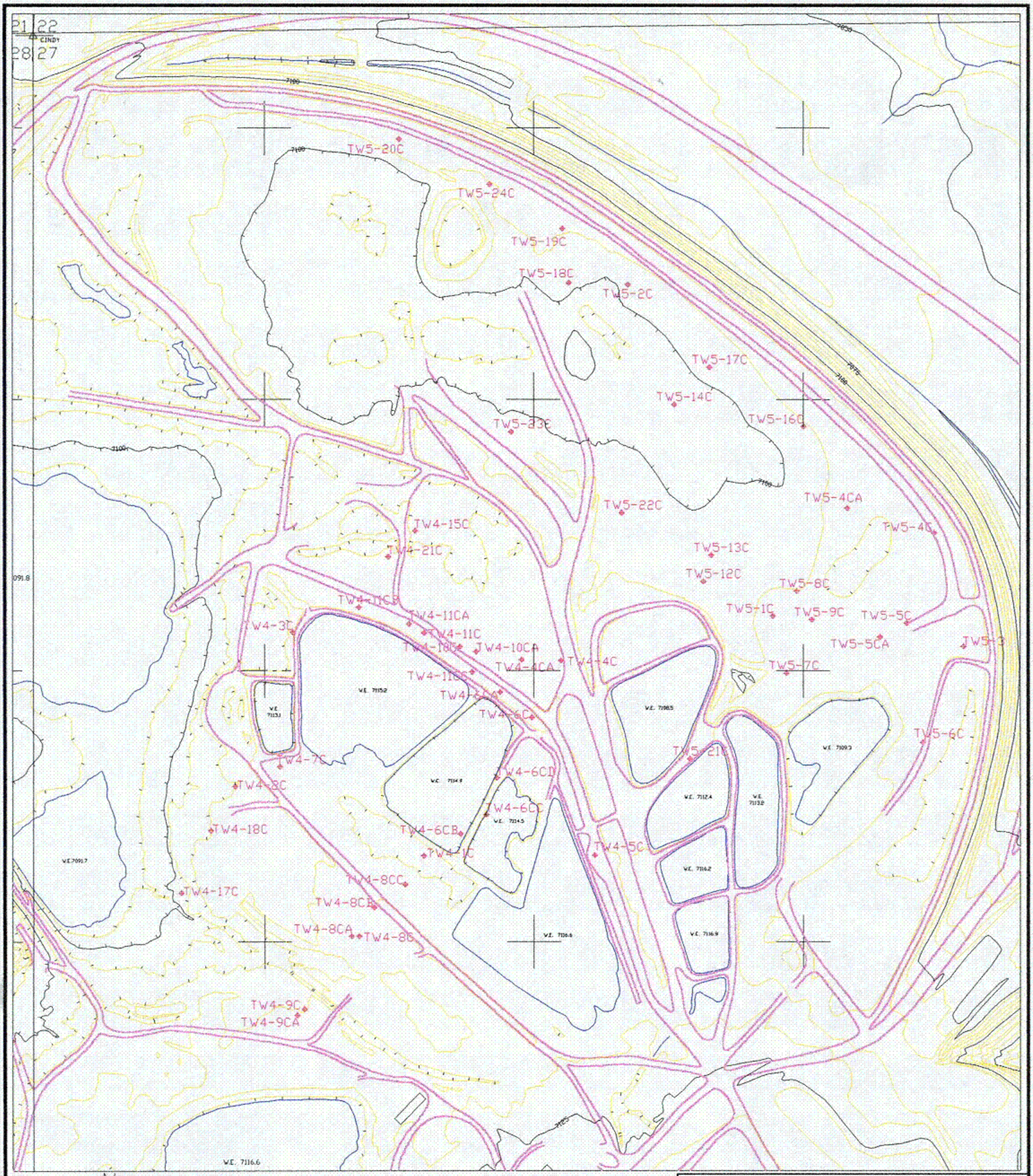
The existing collection and injection system will continue operation until mid 2001. This includes Surficial collection wells throughout the tailings and Mine Creek areas, recharge lines in the Mine Creek area, and the fresh-water injection wells on crest of the No. 5 dam. The only potential change in the current system is the conversion of selected wells near the toe of the No. 5 dam from collection wells to injection wells. This change is under consideration because water quality in these wells is improving, and the conversion could produce additional restoration benefits in the immediate collection area.

3.1.3.2 TAILINGS DEWATERING

The present tailings dewatering program will be continued until mid 2001. There is an expected decline in well yields, and projections of extraction rates were adjusted accordingly. The well yields were also adjusted to reflect a net extraction rate rather than the actual projected well yield. This adjusts for ongoing infiltration that will continue until the infiltration barrier is place. Once the infiltration barrier is in place, the infiltration rates will be dramatically reduced. The continuation of the dewatering is projected to extract approximately 39 Mgal of water from the tailings, leaving an estimated 98 Mgal in the tailings.

3.1.3.3 INFILTRATION BARRIER

The schedule for the construction of the radon/infiltration barrier is dependent on several factors, and is not yet finalized. Extension of the interim cover as the surface water is eliminated will reduce infiltration, but the final clay cover with grading to eliminate ponding will reduce infiltration to a fraction of current rates.



LEGEND:
◆ TAILINGS WELL LOCATION

PATHFINDER
PATHFINDER MINES CORPORATION
SHIRLEY BASIN, WYOMING
T28N, R78W

FIGURE 3.1-1. TAILINGS DEWATERING WELLS

DRAWN BY: TGM	DATE: 8-2001	SCALE: 1"=500'
FIG31_1.DWG	HYDRO-ENGINEERING L.L.C.	

C10

3.2 FEASIBILITY OF ALTERNATE CORRECTIVE ACTIONS

The three alternative corrective action programs presented herein (Sections 3.2.1, 3.2.2 and 3.2.3) were developed to allow comparison of the planned corrective action plan with a variety of alternatives for purposes of demonstrating that the planned action meets ALARA conditions. The alternatives that utilize a time frame for corrective action are assumed to start in January of 2000. The planned corrective action includes continued operation of both the dewatering and collection/injection systems for 18 months. The first two alternatives are changes in the duration of continued operation of the current corrective action program. The third alternative is a barrier to serve as a seepage containment system. A variation of the planned corrective action truncated the injection system operation and a portion of the Surficial collection system at 12 months as a test of sensitivity to the injection system operation. This variation of the corrective action has been rendered moot by this revision of the ACL application.

3.2.1 CESSATION OF COLLECTION/INJECTION AND DEWATERING

The first alternative correction program consists of cessation of collection/injection system and dewatering efforts immediately. This is potentially the least costly option because operational and maintenance costs are eliminated, and there are no direct capital costs except common decommissioning costs.

3.2.2 EXTENDED COLLECTION/INJECTION AND DEWATERING

This alternative is based on an extended dewatering program with additional operational time for the collection/injection system. The tailings dewatering would be extended for 3½ years to a total of 5 years (dewatering until late 2004), giving a total of 75 Mgal removed from the tailings. The net annual extraction rate is decreased with subsequent years to reflect the anticipated decline in well yields. Operation of the injection wells is discontinued after 18 months (mid 2001), and operation of the Surficial collection wells and recharge lines is discontinued after 3½ years (mid 2003). The primary effect of the extended operation is the reduction of the seepage rate and the reduction in the duration of the measurable seepage impacts at the POE.

3.2.3 SLURRY TRENCH

A slurry trench in the more permeable area of the Surficial aquifer could potentially reduce the seepage impacts. The installation of a slurry trench to a depth ranging from 35 feet to approximately 70 feet along the toe of the No. 5 dam would reduce the seepage to the Mine Creek area (see Figure 3.2-1). Unfortunately, the use of this type of ground-water flow barrier will eventually divert the flow over or around the barrier or require perpetual collection efforts. There will be ongoing recharge to the Surficial aquifer upgradient of the barrier, and eventually the ground-water will discharge through an alternate pathway. Because of the large elevation difference between the recharge areas and the land surface in the Mine Creek area, it is plausible that the ground water will discharge to the surface just upgradient of the barrier. It is also plausible that the ground water will be diverted to the north or south of the barrier as the head in the Surficial aquifer increases.

The installation of a slurry trench across the more permeable portion of the Surficial aquifer would require a barrier length of approximately 2000 feet, but this wall would be circumvented relatively rapidly. In order to extend the duration of containment by the wall, a wall length of nearly one mile would be required with additional fill to bring the surface elevation in the Mine Creek area up to approximately 7060 feet above MSL. A typical depth in this area would be 45 feet, and a typical trench width would be 3-4 feet. The incremental benefit of extending the trench length is small. The estimated cost of the slurry trench installation is $4,400,000 with the cost of a berm to raise the land surface in the Mine Creek area estimated at $300,000. The slurry trench cost was developed using scaling from a similar but larger proposed slurry wall containment system at another site.

The installation of a physical barrier to seepage is considered an undesirable approach to mitigation of seepage effects because the cost is very large, and eventually the seepage problem will reoccur. The nature and location of the eventual seepage is difficult to predict, and this uncertainty makes this option very undesirable.

3.3 CORRECTIVE ACTION COSTS

This section summarizes the capital and yearly operational and maintenance (O & M) costs of both the planned corrective action plan (Section 3.1), as well as the alternative corrective action plans discussed above. Capital and yearly O & M costs are presented in 1999 dollars. Because the maintenance requirements for the tailings dewatering system are substantially greater than those for the Surficial injection/collection system, the projected O & M costs are extended for the duration of the dewatering effort. There will be some reduction in component O & M costs as the injection, recharge and Surficial aquifer collection systems are shut off, but these are some of the least demanding components of the overall corrective action systems, and the reduction is likely to be offset by increasing O & M costs of the tailings dewatering system. These costs are presented in Table 3.3-1. Costs common to all alternatives are not included in the table. Common costs include decommissioning of the dewatering, injection, collection and recharge systems; construction of the infiltration/radon barrier; and disposal of the existing surface water. There are also some intangible costs associated with some options that are difficult to quantify. The most prominent of these is delays in completion of the reclamation due to continued operation of dewatering systems or the lagging of consolidation with less aggressive tailings dewatering.

The exclusion of common costs provides a fairer comparison of the merits of various options, but also gives a distorted picture of the effort expended in restoration of the Surficial aquifer. This is particularly true in the case where restoration systems and dewatering systems are in place and the large capital expenditures have already been made. The cost of the decommissioning of these systems will only be a small fraction of the original installation cost, and there is virtually no salvage value in system components. The cost of disposal of the surface water is not included in the comparison because the planned clay-lined pond will be required to dispose of existing surface water in a timely manner. However, these disposal systems do provide substantial benefit to the corrective action program and the cost of these systems is assignable to demonstration of ALARA conditions.

The cost of continued operation of the dewatering system and the collection/injection system is estimated at $400,000 per year. This includes labor, equipment replacement, and energy costs.

TABLE 3.3-1. CORRECTIVE ACTION COST SUMMARY.

PROGRAM	TOTAL OPERATIONAL AND MAINTENANCE COST (Thousands)	CAPITAL COST (Thousands)
PLANNED CORRECTIVE ACTION		
Tailings Dewatering & Surficial Restoration for 18 months	600	----
ALTERNATIVE CORRECTIVE ACTIONS		
Cessation of Dewatering And Surficial Restoration	----	----
Extended Dewatering And Surficial Restoration	2000	300*
Slurry Trench	----	4700

* Estimated cost of well replacement or rehabilitation.

3.4 CORRECTIVE ACTION BENEFITS

The primary benefit of the proposed corrective action plan is to remove a substantial part of the remaining water in the tailings in a time frame that will not appreciably delay reclamation of the tailings. A secondary benefit of the proposed corrective action plan is the continued containment of the seepage while the seepage rate from the tailings is declining with the ongoing dewatering. When the operation of the dewatering and collection/injection system is discontinued after 18 months (mid 2001), the seepage rate from the tailings will have declined significantly due to reduced head and a shrinking footprint of the saturated tailings. The removal of 39 Mgal of the remaining tailings water over 18 months takes advantage of the period when the extraction is most efficient. The decommissioning of the dewatering and collection/injection systems after 18 months allows reclamation construction to proceed. The cessation of dewatering discharge to the clay-lined pond will allow final disposal of the remaining surface water. A variation of the proposed corrective action plan terminates injection well operation, recharge line operation, and collection at the toe of the No. 5 dam at the end of year 2000. Although this variation is now moot, the predicted maximum uranium concentration at the POE was increased less than 0.01 mg/l over the proposed CAP. This is well within the expected modeling resolution and is not considered a measurable change in the simulation results. The change in POE thorium-230 activity with this variation is within rounding error. Hence, cessation of the operation of these portions of the system at the end of year 2000 is functionally equivalent to continuation through mid-2001.

The proposed corrective action plan reduces the maximum concentrations of uranium and thorium-230 to the proposed POE values in Spring Creek. Based on the modeling projections, the maximum concentration or activity of uranium and thorium-230 will occur at the POE approximately 9 years after the cessation of dewatering. The peak concentration or activity of other constituents occurs in roughly the same time period. The delay is due to the fact that the Surficial water quality in the Mine Creek area has been restored, and the seepage front will have to reach Spring Creek. There is a strong likelihood that the peak concentration will be delayed and slightly reduced due to retarding processes in the Surficial aquifer. The peak concentrations may also be reduced due to increased base flow in Spring Creek.

There is a distinct advantage to placing the radon barrier as soon as practicable as the construction of the radon/infiltration barrier will dramatically reduce the rate of infiltration into the tailings. The rate of infiltration will likely be reduced to a fraction of a gpm with the installation of the clay cap. The surface drainage system is designed to eliminate permanent ponding over the tailings.

The proposed corrective action is not the least cost option available, but does provide some benefit over the least cost option of cessation of collection/injection and dewatering. The benefit is some reduction in the predicted maximum POE concentrations.

3.4.1 COMPARISON WITH ALTERNATE CORRECTIVE ACTIONS

The least cost option of immediate cessation of collection/injection and dewatering programs has the significant benefit of eliminating discharge of the tailings water to the evaporation/disposal system. There are potential savings in the size of the planned clay-lined evaporation pond with this option. A second benefit of this option is that it provides immediate access for preliminary reclamation construction. However, the disadvantage of this option is that the predicted maximum concentrations at the POE will increase by a measurable amount (increase of 0.07 mg/l). The health and safety implications of this minor increase are trivial.

A water-flow modeling scenario was developed for the option where dewatering and collection/injection programs were terminated at the end of 1999. This left approximately 137 Mgal of water in the tailings and the initial predicted seepage rate is much higher than the proposed corrective action plan with 18 months of dewatering. The larger seepage rate combines with un-impacted ground-water seepage and base flow in Spring Creek to yield a composite water quality. Therefore, a simplistic approach comparing the critical fractions of the total flow represented by seepage from tailings and resident ground water should provide an approximate ratio of the POE concentrations for this option compared to the proposed corrective action plan. Recharge to the Surficial aquifer by precipitation was assumed to be at background concentration and uranium concentration was used as the indicator parameter for comparison. Because this approach does not consider initial concentrations and transport processes, it is functional only for a rough comparison between various dewatering scenarios. This ratio of percentage seepage and percentage ground-water recharge for this option versus the proposed corrective action option is 1.50. This gives roughly a 50% increase in predicted concentration at the POE. The incremental benefit of 18 months of continued remediation system operation is a measurable reduction in POC concentrations, and ultimately, a measurable reduction in POE concentrations of up to 50%. The variation of the planned corrective action with cessation of all recharge/injection system operations and Surficial collection in the Mine Creek area at the end of year 2000 is functionally equivalent to the planned corrective action which extends the operation of these systems to mid 2001. Hence, this ratio is applicable to both the planned corrective action and the variation of the planned corrective action.

The second alternate corrective action plan extends the operation of the dewatering program to 5 years and also extends the operation of the collection/injection systems. The primary benefit of this option is the further reduction of the remaining volume of water in the tailings, and consequently, the maximum seepage rate from tailings. The primary disadvantage to this alternative is the cost of operating the system. A significant, but difficult to quantify disadvantage of this option is the interference with reclamation construction by the tailings dewatering program. It may be possible to work around an active dewatering system, but both the construction activities and dewatering efforts will be compromised. The continued discharge from the dewatering system will also extend the operation of the clay-lined evaporation pond, further delaying complete site closure.

Using the same composite ratio method described above with the extended operation plan versus the proposed corrective action plan gives a ratio of 0.54. This will provide a measurable decrease in uranium concentration at the POE. An additional model run extending the dewatering to 12 years gave a ratio of 0.46. The diminishing incremental benefit with additional dewatering reflects the anticipated declining efficiency of dewatering in successive years.

The previously mentioned ratios are referenced to the uranium concentration for the proposed corrective action plan and provide a means of making a rough cost/benefit comparison between the three modeled scenarios. Using the cost estimates in Table 3.3-1, the improvement from a ratio of 1.5 to 1.0 between scenario #1 and scenario #2 is $600,000. The additional cost of improving the ratio from 1.0 to 0.54 between scenario #2 and scenario #3 is estimated at $1,700,000 ($2,300,000 - $600,000). This indicates the cost per increment of benefit roughly triples when the operation of dewatering and Surficial recharge/collection systems is extended beyond the planned 18 month period. In addition to the cost of continued system operation, extension beyond this period will interfere with reclamation construction.

The third alternate corrective action plan proposes use of a slurry wall to cut off seepage in the Mine Creek area. The viability of this option is questionable because it would divert ground-water flow around or over the barrier, or require pumping for decades. The assumption in analyzing this option was that no maintenance or pumping would be required after installation. The benefit of this option is that it would delay and spread the seepage impacts over a much longer time period. In the absence of a pumping and disposal system, the spreading of the seepage impacts over a longer time period will reduce peak concentrations. The seepage impacts will eventually reach Spring Creek, but the transport time would likely be increased by a factor of two or more. This could conceivably reduce the maximum POE concentrations by 30% to 50%. However, the uncertainties associated with this option make it undesirable, particularly in consideration of the significant costs associated with slurry wall construction.

3.5 AS LOW AS REASONABLY ACHIEVABLE DEMONSTRATION

Pathfinder Mines Corporation has operated a corrective action program over the last 16 years that has resulted in successful restoration of the Surficial aquifer water quality in the seepage plume area near Mine Creek. The corrective action plan has undergone substantial modification to enhance performance and has been expanded to include hydraulic barriers to seepage and collection directly beneath the tailings. Tailings dewatering was initiated at the earliest possible opportunity and has been progressively expanded to remain aggressive in the extraction effort. An enhanced evaporation system consisting of spray systems and shallow evaporation ponds has been operated for more than nine years to dispose of tailings solution. Coverage of accessible areas of exposed tailings has reduced the recharge to the tailings in spite of a period of above average precipitation.

The present corrective action program consists of containment measures and extraction and disposal of the seepage source. The containment measures are represented by the Surficial collection/injection systems. The water quality in the historic seepage plumes in the Mine Creek area has been almost completely restored back to the collection wells near the toe of the No. 5 dam. There is modest progress in restoration of the area between the recharge lines and the collection wells, but the remaining "band" of seepage-impacted area east of the collection wells has become very narrow. Because of the radial inflow pattern to collection wells, there is a practical limit to how closely a downgradient seepage front can be "drawn" back to the well. The existing collection system at the toe of the No. 5 dam has nearly reached this limit along most of the system. As such, the present Mine Creek area collection/injection system is functioning primarily as a seepage containment system. The small area immediately around the collection wells is the only remaining portion of the seepage plume area where appreciable water quality restoration can occur. However, unless the entire seepage source could be eliminated, complete restoration of the immediate collection area is not possible without a radical change in the system configuration. Thus, there is very little additional benefit in restoration to be gained by continuing the collection/injection system operation beyond the cessation of tailings dewatering. This meets the ALARA condition for aquifer restoration.

Surficial collection wells operating within the tailings area are intercepting a portion of the seepage-impacted water moving in the Surficial aquifer. In combination with the fresh-water injection wells on the crest of the No. 5 dam, there is a functional system that is providing some restorative effect in the Surficial aquifer beneath the tailings. However, the distributed nature of the ongoing seepage prevents a complete restoration of the Surficial aquifer water quality as occurred in the Mine Creek area. As the tailings dewatering progresses and the head in the tailings declines, the excess fresh-water injection could eventually result in a local reversal of flow from the Surficial aquifer to the tailings. This is undesirable because it adds water to the tailings and slows dewatering progress. Preliminary MODFLOW model runs indicate that this reversal of the seepage direction may occur when operation of the injection wells is continued beyond two years. The use of the hydraulic barrier to contain seepage has been effective and there is some additional benefit that will occur with continued operation over the next 18 months. However, the ALARA condition with respect to Surficial aquifer restoration beneath the tailings is achieved when the fresh-water injection is continued in conjunction with tailings dewatering for a one to two year period. Continuation of the fresh-water injection beyond this period will maintain the hydraulic barrier, but will likely be detrimental to the dewatering progress.

The Surficial collection within the tailings area has served to intercept seepage impacted water before it migrates outside of the tailings area. It is supplemental to the tailings dewatering effort and will be discontinued after 18 months when the dewatering program ends. This is an ALARA condition because Surficial collection rates from the wells are modest at best, and once the dewatering program ends, collection from seepage impacted Surficial wells essentially becomes a very inefficient dewatering program.

The tailings dewatering effort has been ongoing since 1993, with several drilling programs to expand the dewatering system. As the water level in the tailings drops, well yields decline and precipitation problems and maintenance costs increase. The water levels in more permeable areas of the tailings have dropped and well yields from the strongest wells have declined dramatically. An aggressive well development and maintenance program has been successful in maintaining total dewatering yield. However, as more permeable portions of the tailings are dewatered, the practical dewatering rate is expected to decline to approach a long-term drainage rate from the low permeability slimes. The yield from slime wells is very poor (typically a fraction of a gpm), and the practice of inducing drainage from slimes by pumping on the periphery of slime areas has been an effective dewatering technique.

The modeling of extended dewatering included an aggressive (and possibly optimistic), estimate of dewatering rates over a 5 year period. The projected net tailings dewatering rate at the end of the 5 year period was 13 gpm. It is difficult to predict what the dewatering rate will be several years in the future, but there is little question that the practicably achievable rate will decrease. With the drawdown in more permeable tailings, the prospect for well replacement to bolster yield also diminishes dramatically. At an assumed yield of 0.3 gpm per slime well, it would take 43 slime wells to replace the projected yield of 13 gpm.

In addition to the probable limits on dewatering rates, the cost per unit volume of water extracted increases dramatically with time. For the projected extraction of 39 Mgal over 18 months at a cost of $600,000, the cost per 1000 gallons extracted is $15.38. With an extension of the dewatering to 5 years, an estimated additional 36 Mgal will be removed at an additional cost of $1,400,000. This gives a cost of $47.22 per 1000 gallons extracted with an assumed cost of $300,000 for pumping well replacement and well rehabilitation. These costs represent only projected extraction costs and do not include disposal costs for the water or the less tangible but highly significant costs of construction delays with the extension of tailings dewatering.

The ultimate potential benefit of extending the dewatering and collection/injection system operation is a projected reduction in the maximum POE uranium concentration from 0.15 mg/l to 0.086 mg/l. Both values exceed the current site standard of 0.07 mg/l and are based on the simple ratio approach described previously. Because of the comparatively higher background values with respect to the seepage activities for thorium-230, the improvement in POE activity for thorium-230 with extended dewatering is smaller. In fact, the potential improvement in thorium-230 activity at the POE with additional remedial activity likely falls within analytic resolution. Therefore, the comparison for ALARA conditions will be based on uranium concentrations.

The implication to human health and safety of the reduction in uranium concentration with extension of the dewatering program is minimal. The maximum POE concentrations are based on the assumption of usage of water during late season base flow during a relatively dry weather cycle above the confluence of Spring Creek with Little Medicine Bow River. Even with a very conservative analysis of the human or animal exposure to the increased uranium concentration, the analyses presented in Appendices A, B, and C indicate that there will no measurable effects on public health or safety under the alternative. Thus, the proposed corrective action plan with respect to tailings dewatering meets ALARA conditions.

4.0 PROPOSED ALTERNATE CONCENTRATION LIMITS

4.1 PROPOSED ALTERNATE CONCENTRATION LIMITS

The following alternate concentration limits are proposed for the point of compliance wells.

TABLE 4.1-1. PROPOSED ALTERNATE CONCENTRATION LIMITS.

CONSTITUENT	ALARA POC* WELLS	
	RPI -19B	NP01
Uranium	4.45	4.40
Thorium-230	5.76	5.53
Selenium	0.158	0.163
Ra-226 + Ra228	13.76	12.7

NOTE: Uranium and selenium concentrations are in mg/l
Thorium-230 and Ra226+Ra228 activity is in pCi/l

These alternate concentration limits have been developed by simulating the migration of these constituents from tailings to the Surficial aquifer and then to Spring Creek. The Spring Creek POE concentrations are developed by combining the ground-water discharge to Spring Creek with the base flow in the creek. The resulting POE concentrations have been shown to provide adequate health protection for the public.

4.2 PROPOSED IMPLEMENTATION MEASURES

The alternate concentrations will be met by completing the corrective action plan for the ground-water systems at the Shirley Basin site, which includes the continuation of Surficial collection/injection system operation and aggressive tailings dewatering until at least mid-2001. Surficial collection/injection programs will continue to contain seepage and will restore water quality in the immediate area of the Mine Creek collection wells. The Surficial collection/injection within the tailings area will provide some additional restoration of water quality in this area. The tailings dewatering will reduce the quantity of water remaining in the tailings, and consequently, the long-term seepage rate to the Surficial aquifer. The construction of the radon/infiltration barrier and surface drainage system after termination of dewatering efforts will reduce recharge to the tailings.

4.2.1 COMPLIANCE MONITORING

The monitoring program will consist of a quarterly monitoring program for one year after the CAP is discontinued. The first sampling will occur within two months of cessation of the CAP operation. Samples will be taken from the two POC wells (NP01 and RPI-19B) and wells MC-8, RPI-20A and RPI-8A to span the area of measurable seepage impacts along Spring Creek. Samples will also be taken from the POE location, Spring Creek upstream of the culvert and Spring Creek just downstream of the Mine Creek confluence (current SW-2 site). The samples will be analyzed for uranium, selenium, TDS, chloride and sulfate concentrations, and thorium-230 and radium-226 + radium-288 activities. Following the four quarterly samples, a semi-annual monitoring program of the POC wells and the designated POE will continue through 2005. Samples from these POC wells will be analyzed for the constituents listed above.

The final step in the implementation of the ACL process will be turning over the site to the DOE. A three-sample average will be used to evaluate the concentration/activity of the ACL constituents. This average for the monitoring data will be analyzed to show that the alternate concentration at each well has not been exceeded at the points of compliance. This analysis will be submitted prior to the transfer of the property to the DOE.

5.0 MAJOR CONSTITUENT ASSESSESSMENT

Major constituents of chloride and sulfate are present in the tailings and in the seepage at concentrations of concern. In addition to the two major ions, the TDS concentration in tailings and attendant seepage is a concern.

5.1 MAJOR CONSTITUENT TRANSPORT

Transport of chloride, TDS and sulfate was modeled to assess the impacts of tailings seepage on the POE. The migration of these relatively conservative constituents has been used as an indicator of seepage impacts and the success of restoration. As with the hazardous constituents, the transport modeling of these constituents included input from the tailings to the Surficial aquifer in the Mine Creek area. Matrices of existing concentrations were established for the Surficial aquifer for TDS and chloride. Sulfate concentration and migration closely parallels TDS, and a scaling approach based on the TDS transport modeling was used to predict long-term sulfate transport. The dispersivity used in the model was 10 feet, with a ratio of 0.2 for transverse/longitudinal dispersivity. Retardation was not used (distribution coefficient = 0) in the transport simulation of the conservative ions chloride and sulfate. Transport of the major constituents was only simulated for Scenario #2 (CAP to mid-2001).

5.1.1 CHLORIDE

Figure 5.1-1 presents the predicted chloride concentrations for POC wells NP01 and RPI-19B. The predicted peak chloride concentration at the Spring Creek POE is 118 mg/l (see Figure 5.1-2). The maximum predicted concentration at the POE is significantly below the state livestock standard of 2000 mg/l and is also well below the current drinking water standard. Table 5.1-1 presents predicted POC and POE concentrations.

5.1.2 TDS

Figure 5.1-3 presents the predicted TDS concentrations for POC wells NP01 and RPI-19B. The predicted peak TDS concentration at the Spring Creek POE is 649 mg/l (see

Figure 5.1-4). The maximum predicted concentration at the POE is significantly below the state livestock standard of 5000 mg/l.

5.1.3 SULFATE

Sulfate transport was not simulated directly, but because it is a major component of the TDS, a scaling of TDS allows a reasonable approximation of anticipated sulfate concentration at the POE. The predicted peak sulfate concentration at the Spring Creek POE is 183 mg/l. The scaling approach assumed 40% of the TDS concentration in the seepage impacted ground water was made up of sulfate (derived by comparison of sulfate and TDS concentrations in seepage impacted wells). The same compositing technique was then used to calculate the POE concentration.

TABLE 5.1-1. MAJOR CONSTITUENT POC CONCENTRATIONS

CONSTITUENT	POC* WELLS		
	RPI-19B	NP01	POE
Chloride	3712	3275	118
TDS	12641	11529	649
Sulfate			183

NOTE: Concentrations are in mg/l

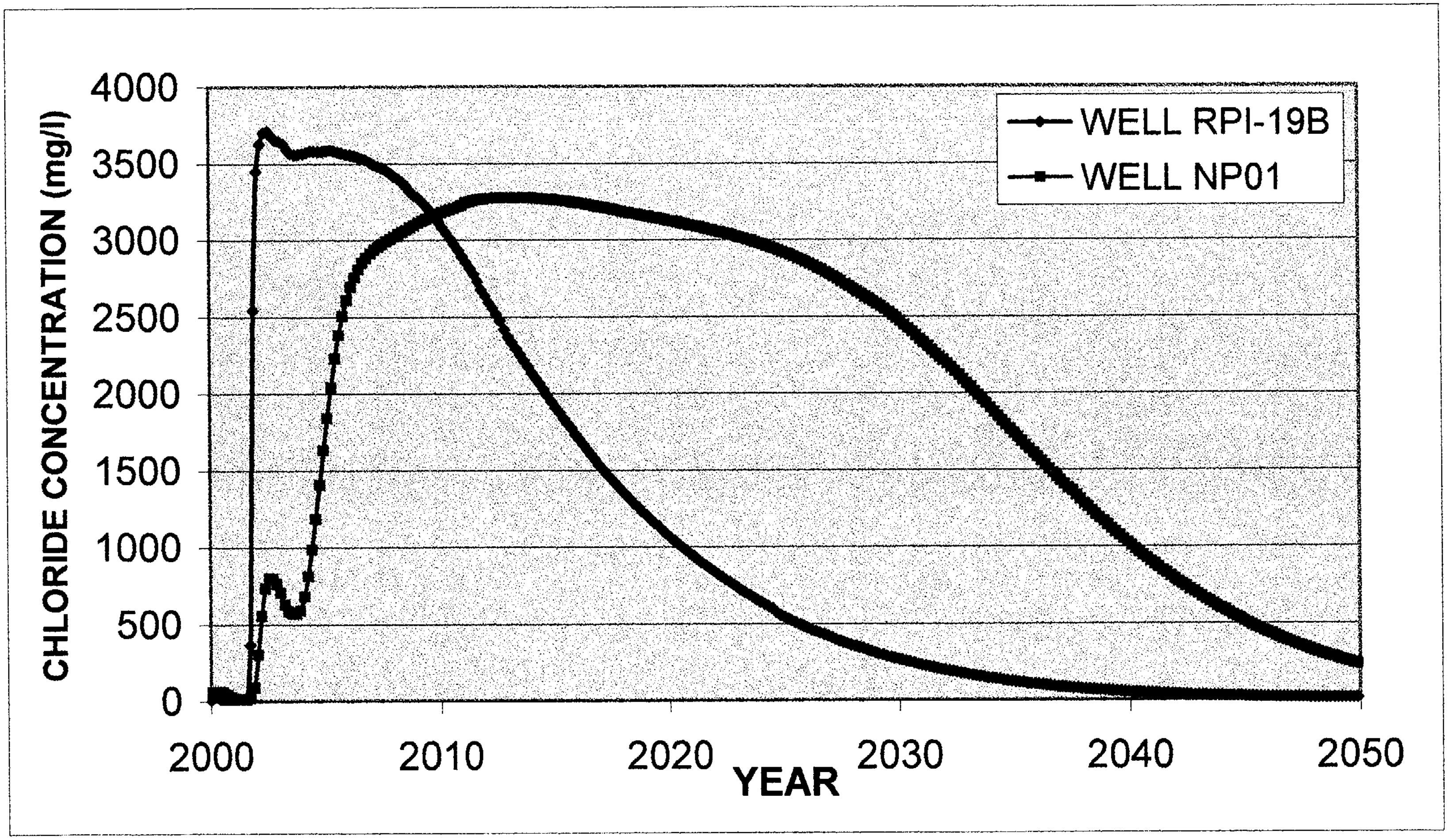


FIGURE 5.1-1. PREDICTED CHLORIDE CONCENTRATIONS AT THE POC WELLS

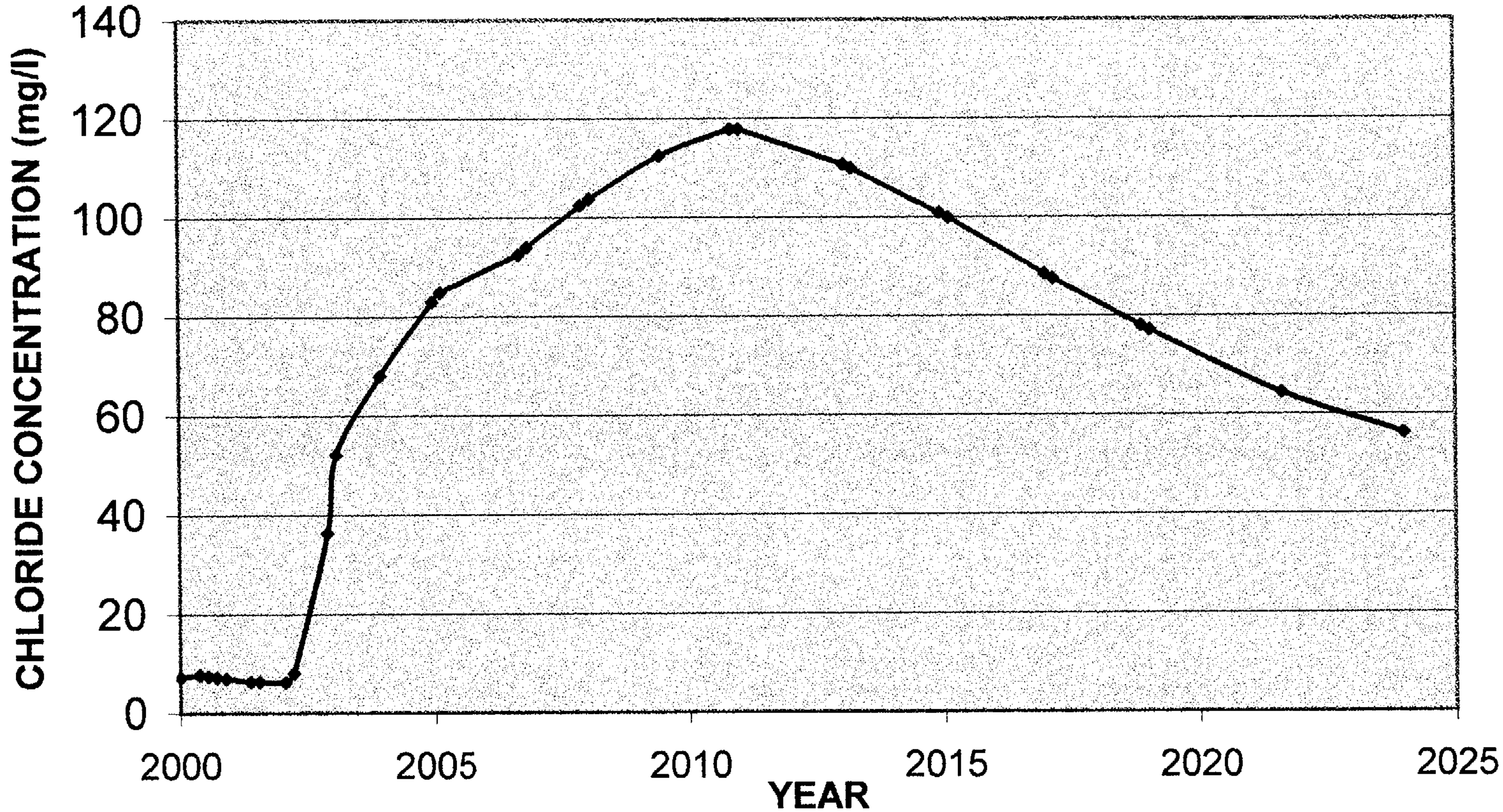


FIGURE 5.1-2. PREDICTED MAXIMUM CHLORIDE CONCENTRATIONS AT THE POE

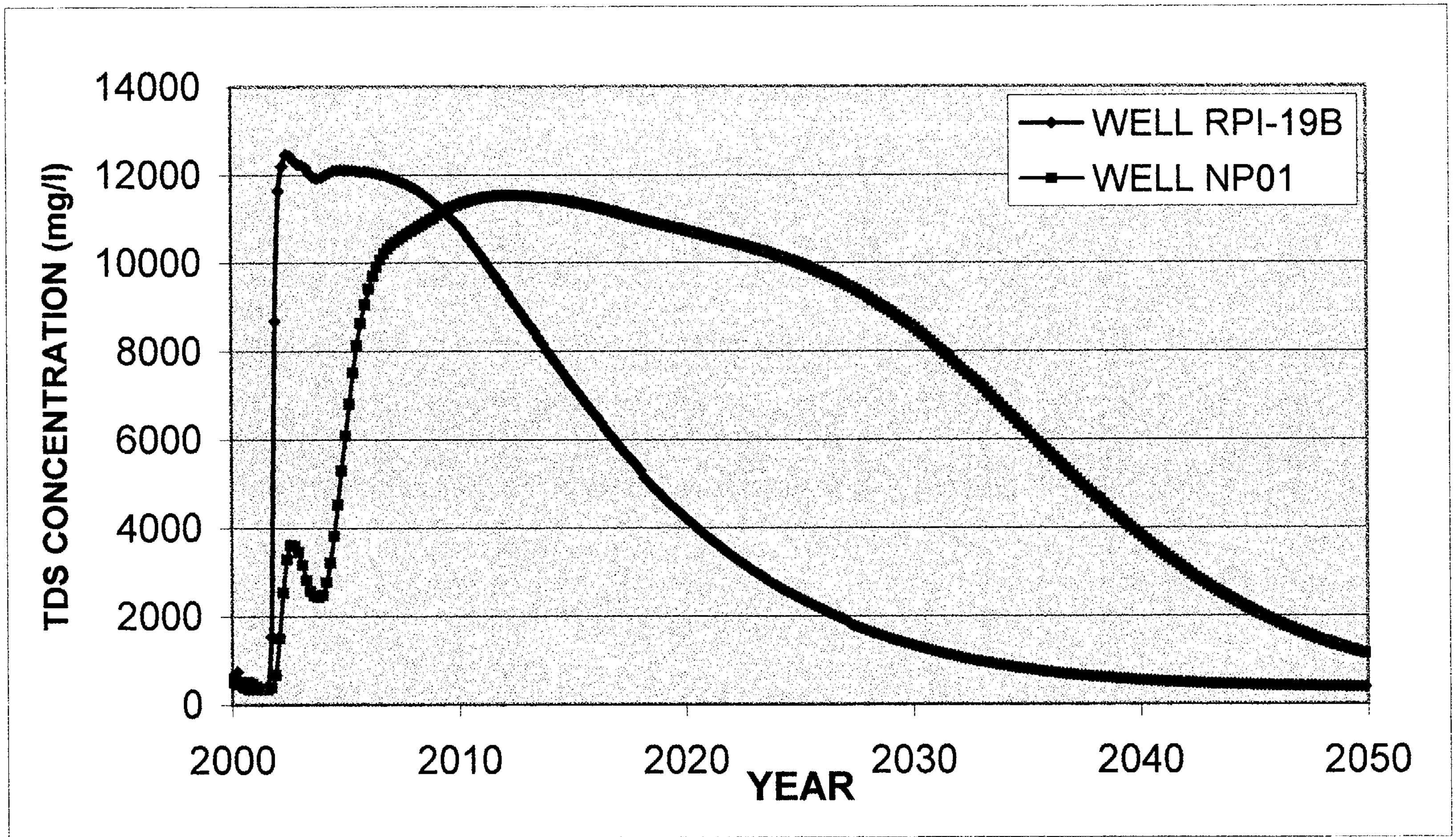


FIGURE 5.1-3. PREDICTED TDS CONCENTRATIONS AT THE POC WELLS

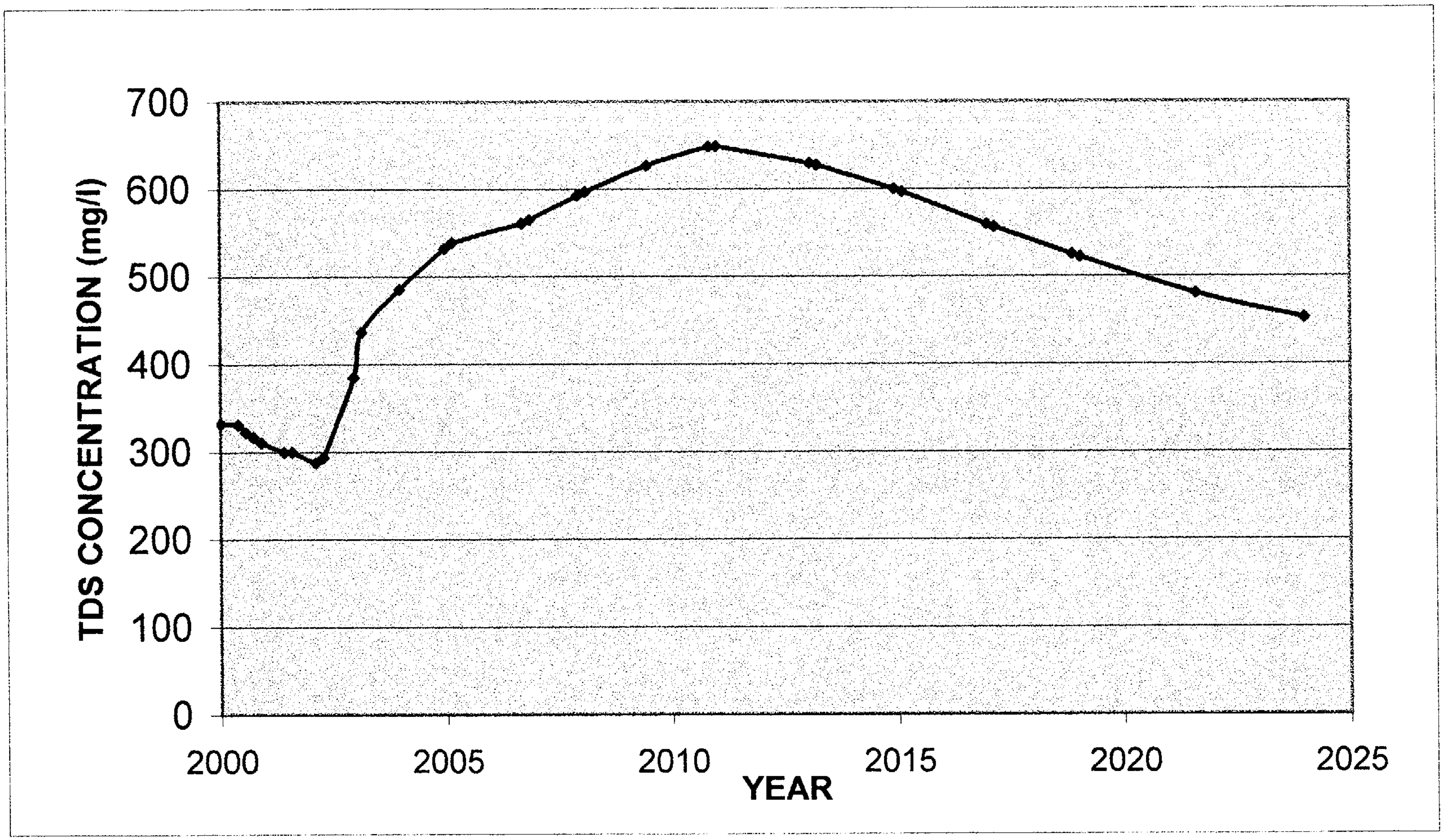


FIGURE 5.1-4. PREDICTED MAXIMUM TDS CONCENTRATIONS AT THE POE

5.2 OTHER CONSTITUENTS RISK

A risk assessment for chloride, sulfate, and TDS is presented for the Surficial aquifer. The likely use of the water in Spring Creek is livestock and wildlife watering. The State livestock use standards for chloride, sulfate, and TDS are 2000, 3000, and 5000 mg/l, respectively. The critical point of potential use of this surface water is at the POE in Spring Creek. The human health hazards are discussed in Appendix B and the environmental hazards are discussed in Appendix C.

5.2.1 CHLORIDE

Predicted chloride concentrations at the POE are well below the livestock use standard of 2000 mg/l. The maximum chloride concentration predicted at the POE is 118 mg/l. A concentration of less than one tenth of the use standard shows that additional risk analysis for this parameter is not warranted.

5.2.2 TDS

The maximum predicted TDS concentration at the POE is 649 mg/l. With a concentration at much less than the use standard, additional risk analysis for this constituent is not warranted.

5.2.3 SULFATE

Predicted sulfate concentrations at the POE are less than one-tenth of the livestock use standard of 3000 mg/l at 183 mg/l. With a concentration at much less than the use standard, additional risk analysis for this constituent is not warranted.