RISK ASSESSMENT FOR THE WATER RECLAMATION FACILITY EXPANSION SITE HENDERSON, NEVADA

Prepared for

City of Henderson, Nevada

For Submission to:

Nevada Division of Environmental Protection

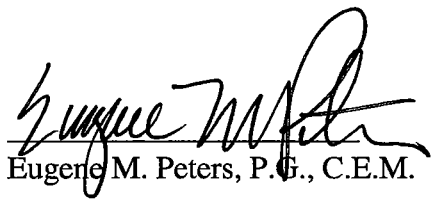
Prepared by

ENVIRON International Corporation

October 15, 2003

CERTIFICATION

I hereby certify that I am responsible for the services described in this document and for the preparation of this document. The services described in this document have been provided in a manner consistent with the current standards of the profession and, to the best of my knowledge, comply with all applicable federal, state, and local statutes, regulations, and ordinances.



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EXECUTIVE SUMMARY

ENVIRON International Corporation (ENVIRON) was retained by the City of Henderson, Nevada to conduct a site characterization and risk assessment of a currently undeveloped parcel of land adjacent to the City's water reclamation facility (WRF). The current WRF is approaching its capacity and the City intends to expand the operation onto the adjacent parcel. The approximately 100-acre parcel, which is situated east of the current WRF, was used historically for the disposal of wastewater from the BMI Industrial Complex, located one to two miles southwest of the WRF.

Previous soil sampling on the 100-acre parcel (also referred to as the "site" in this report) has indicated the presence of several chemicals, including metals, perchlorate, and certain pesticides, some of which have been detected at concentrations above or approaching U.S. Environmental Protection Agency (USEPA) Region 9 preliminary remediation goals (PRGs). This risk assessment is being conducted to support a determination by the Nevada Division of Environmental Protection (NDEP) that the project can be constructed and operated without posing unacceptable risks to human health. Additional issues that do not have a direct effect on construction and operation of the WRF expansion (e.g., regional ground water quality and leaching from site soils) are being deferred to a later date. Specifically, according to correspondence from NDEP to Basic Environmental Company (BEC), dated May 2, 2003, NDEP is contemplating the following:

- An evaluation of regional hydrogeologic conditions, including stratigraphic conditions within the aquifers, lateral and vertical extent of ground water contamination, and the potential for migration of contaminants to Las Vegas Wash.

- An analysis to evaluate the potential for chemicals in soil to leach to ground water and the effects of leaching chemicals on ground water quality, including possible effects from the use of the emergency storage basin at the WRF expansion site.

- An assessment of potential adverse effects to downgradient receptors (e.g., ecological populations, recreational users of Las Vegas Wash, and possible consumers of ground water) associated with exposure to contaminants in ground water.

- A review of remedial alternatives to mitigate risks.

BEC responded that it was in the process of preparing a Groundwater Characterization Work Plan to address issues relating to these items. BEC noted that the other issues would be addressed after completion of the characterization.

A comprehensive site characterization program was conducted by ENVIRON in May 2001 to provide data for the risk assessment. This report summarizes the site characterization program conducted by ENVIRON, the analytical results of the program, the analysis of the collected environmental data, and the assessment of estimated risks based on the data.

A. Site Overview

The site characterization and risk assessment focus on the proposed WRF expansion site located northeast of the core facilities of the BMI Industrial Complex, in Clark County, Nevada, approximately 13 miles southeast of the City of Las Vegas (Figures 1 and 2 in the report). Wastewater was transported from the BMI Industrial Complex to the site via ditches (referred to as the Alpha and Beta ditches) that discharged to a series of discrete pond cells, which are defined by earthen berms, generally along the north, east, and west sides of each cell (Figure 3 in the report). The Alpha Ditch traverses the southern portion of the site, and the Beta Ditch runs along the eastern boundary of the site. The area surrounding the site is currently sparsely developed, with a mixture of commercial, industrial, and residential land use. A residential development (Tuscany Hills) has been proposed for a portion of undeveloped land approximately one mile east of the site. Approximately one-half mile north of the site is Las Vegas Wash, a natural waterway that eventually discharges to Lake Mead.

B. Site Characterization Overview

As discussed in the *Site Characterization and Risk Assessment Work Plan* for the site (ENVIRON 2001), the sampling that had been conducted prior to the date of the work plan was not sufficient to conduct a comprehensive risk assessment due to gaps in the available data. Thus, a comprehensive site characterization was conducted by ENVIRON in May 2001. The purpose of the site characterization program was to collect and analyze samples of environmental media, including surface soil (0 to 1 foot below grade), subsurface soil (>1 foot below grade), and ground water, primarily to provide data for the risk assessment but also to revise the conceptual site model (CSM), as necessary.

For the purposes of the risk assessment, the site was divided into two exposure areas based on anticipated future land use: 1) the northern exposure area and 2) the southern exposure area. Samples of surface and subsurface soils, as well as shallow ground water, were collected from each of these two exposure areas, as described below.

- Soil Sampling (Northern Exposure Area) – The soil sampling conducted by ENVIRON in the northern exposure area included the collection of individual soil samples from each of seven former pond areas in the northern exposure area, and the collection of soil samples from five locations outside the pond areas (two samples from the Beta Ditch; two samples

from the area east of the Beta Ditch; and one sample from the proposed "A" Street alignment). At each location, samples were collected from the 0-to-1 foot and the 4-to-5 foot depth intervals. These sample depths were selected to represent the approximate depth of grading to be conducted in the northern exposure area as part of the WRF expansion process. After grading, it is expected that the top 5 feet of soil will be mixed; thus, an individual in the northern exposure area during or after construction could be exposed to soils within this entire range of soil depths. Additionally, samples were collected from the interval immediately above the water table at four locations.

- Soil Sampling (Southern Exposure Area) – The soil sampling in the southern exposure area included the collection of discrete soil samples within each of the ten former ponds, and from four locations outside the ponds (one sample from the Beta Ditch; two samples from the Alpha Ditch; and one sample from the "A" Street alignment). Soil samples, except those to be analyzed for volatile organic compounds (VOCs), were collected at approximately the 0-to-1 foot and 10-to-12 foot soil intervals, as well as the interval immediately above the water table. These depths were selected because some construction activities may require excavation to the water table. Samples for VOC analysis were collected from the 0-to-1 foot soil interval, the soil interval immediately above the water table, and at an intermediate depth that is coincident with the highest level recorded in the field with a PID. At locations where no PID detections were observed, the intermediate-depth VOC sample was collected from the 10-to-12 foot soil interval.

- Ground Water Sampling – ENVIRON collected ground water samples from six pre-existing ground water monitoring wells, including two wells in the southern exposure area, two wells in the northern exposure area, and two wells 350 feet to 500 feet north of the site boundary.

The soil and ground water samples collected at the site were shipped to Severn Trent Laboratories, Inc. (STL) of Earth City, Missouri, which analyzed the samples for VOCs, SVOCs, pesticides, metals, perchlorate, radionuclides, dioxins/furans, polychlorinated biphenyl compounds, and asbestos, using standard USEPA methods. The suite of analyses for each soil and ground water sample is summarized in Table 1 of the report.

ENVIRON conducted a background soil sampling program in April 2002, after the site characterization work at the WRF expansion site had been completed. The sampling and analysis plan for this investigation was modified in response to comments from the NDEP and approved in March 2002. Samples of soil were collected from eight locations selected to represent conditions that might be expected at the WRF expansion site in the absence of waste disposal activities or

migration from the BMI industrial complex. Soil samples were collected at two depth intervals at each background sampling location. The surface sample at each location was collected from the 0-1 foot depth interval; the depth intervals for the deeper samples ranged from 2.5-3 feet to 3.5-4 feet. All of the background soil samples were analyzed for metals, radionuclides, perchlorate, and dioxins/furans. The surface samples were also analyzed for organochlorine and organophosphorus pesticides.

In September 2002, NDEP requested additional asbestos analysis of soil samples from the WRF expansion site. The supplemental asbestos analysis was conducted using a refined analytical technique proposed by Berman and Crump (1999). ENVIRON collected additional soil samples in October 2002 under a plan approved by Dr. Wayne Berman, who had been retained by the NDEP as a consultant. One sample of surface soil (0-3 inches) was collected at each of the locations that were sampled during the site characterization work in May 2001. These samples were sieved and sent to EMS Laboratories in Pasadena, California for compositing and analysis by the elutriator method developed by Dr. Berman and his colleagues.

The analytical data received from STL was compiled into a data base that includes the results from the seven ground water samples (including one field duplicate) and 74 soil samples (which includes 4 field duplicates) for more than 200 chemical constituents. Most of the chemicals analyzed for were not detected in any of the samples, as indicated in Table ES-1. A summary of descriptive statistics for the data base of detected chemicals is provided in Chapter II in the text and in Appendix D. A similar summary for the soils data collected at the background locations is provided in Chapter II and Appendix E.

ENVIRON conducted a data usability analysis and a data adequacy analysis (Appendices F and G, respectively). The data usability analysis indicates that the site characterization data collected by ENVIRON in May 2001 are usable for the purposes of the risk assessment. The data adequacy analysis leads to the conclusion that the data set is sufficient to support a decision to allow construction of the WRF expansion project. This evaluation is based on assumed values of the cumulative risk action levels, and tolerable probabilities of decision errors have not been specified. The final determination of these factors is a risk management decision that will be made by the appropriate regulatory agencies. The action levels assumed in this report include 1×10^{-6} for cumulative chemical cancer risks; a hazard index of one for cumulative chemical non-cancer risks; and 3×10^{-4} for cumulative radionuclide cancer risks. These levels were selected because they are consistent with USEPA recommendations.

The data adequacy analysis in Appendix G indicates that the probability that the risk associated with any chemical in soil exceeds the assumed action levels is small (about 5 percent). Because the exceedence probabilities are based on RME exposure patterns, the decision error probabilities are considerably lower. The worst-case (5 percent) probability relates to arsenic (which is present primarily as a result of background conditions) and to an assumed carcinogenic

risk action level of 1 x 10^{-6} (which is the lower end of the range of acceptable risk established in the National Contingency Plan). For this reason, ENVIRON believes that the soils data set is adequate for each of the 14 chemicals that contribute significantly to the cumulative risks.

TABLE ES-1
Overview of Site Characterization Results
WRF Expansion Site

Chemical Class	Ground Water		Soil	
	Number of Chemicals Detected	Number of Chemicals Not Detected	Number of Chemicals Detected	Number of Chemicals Not Detected
Volatile organic compounds	5	31	7	29
Semi-volatile organic compounds	1	63	3	61
Pesticides*	2	45	14	34
Metals	21	3	23	1
Other inorganics (perchlorate, cyanide)	2	0	1	1
Radionuclides**	9	10	18	0
Dioxins/furans	0	17	17	0
Polychlorinated biphenyl compounds	0	7	0	7
Asbestos	Not analyzed		1***	0

Note:
* - Tetrachlorovinphos was analyzed for in soil but not in ground water.
** - Total does not include the decay products of the detected radionuclides. In addition, Cesium 137 was analyzed for in ground water but not in soil.
*** - Asbestos was not detected during the May 2001 site characterization program, using PLM; however, it was detected during a supplemental sampling program in October 2002, using the elutriator method.

C. Chemical Risk Assessment Overview

1. Approach

In order to focus the risk assessment on those substances that are expected to pose the greatest concern, a subset of all the chemicals for which analyses were performed, referred to as Chemicals of Potential Concern (COPCs), was identified for quantitative evaluation in the risk assessment. Individual sets of COPCs were developed for soil and ground water at the site. For soil, all detected chemicals were treated as COPCs with the following exceptions. ENVIRON conducted an additional review of the analytical results for the seven VOCs and three SVOCs detected at the site by applying criteria recommended by USEPA in *Risk Assessment Guidance for* Superfund (USEPA 1989) (e.g., frequency of detection, toxicity, presence in background). As a result of applying this approach, the

VOCs and SVOCs were eliminated from further quantitative evaluation in the risk assessment. In addition, lead was eliminated as a COPC based on a comparison of the maximum detected concentration with the Region 9 PRG for lead in industrial soil, as proposed in the work plan (ENVIRON 2001). After the elimination of VOCs, SVOCs, and lead, the remaining chemical COPCs that are evaluated quantitatively in the risk assessment include the 22 metals, 17 dioxin/furan congeners, 14 pesticides, and perchlorate, as identified in Table 12 of the text.

In selecting COPCs for ground water, results from one of the six wells were not included because it appears that this well is not downgradient of the WRF expansion site. In the other five wells, a total of 28 non-radionuclide chemicals were detected, including 5 VOCs, 21 metals, and 2 inorganic compounds. All of the chemicals detected in the five ground water wells on or downgradient of the site are evaluated quantitatively in the risk assessment. These chemicals are summarized in Table 14 of the text.

The exposure assessment component of the risk assessment involves the estimation of the magnitude of exposure (i.e., dose) for individuals who may come into contact with site contaminants. The exposure assessment process comprises several steps, which include 1) identifying the potentially exposed populations and exposure pathways; 2) estimating concentrations of chemicals in media to which individuals may be exposed; and 3) estimating the dose of chemicals from each medium to exposed individuals. Although the details of these steps are not provided in this executive summary, each of these steps was conducted in the risk assessment for the exposure scenarios identified in Table ES-2.

The potential for both carcinogenic and noncarcinogenic health effects is evaluated in the risk assessment. To evaluate toxicity of the COPCs, USEPA toxicity values from the Integrated Risk Information System (IRIS), the *Health Effects Assessment Summary Tables* (USEPA 1997b), and provisional toxicity values in EPA's National Center for Environmental Assessment (NCEA) were used.

2. Results

For each of the exposure scenarios identified in Table ES-2, excess lifetime cancer risks and the potential for adverse noncancer health effects (i.e., HI values) were estimated for the chemical COPCs, as summarized in Table ES-3. A discussion of the quantitative results for each of the scenarios is provided below.

TABLE ES-2
Summary of Populations and Pathways Evaluated in the Risk Assessment of the Proposed WRF Expansion Site

Population	Exposure Area	Exposure Pathways					
		Soil			Ground Water		
		Ingestion	Dermal	Inhalation of Dust	Incidental Ingestion	Dermal	Inhalation of Vapors
During WRF Construction							
WRF Construction Worker	South	X	X	X	X[3]	X[3]	X
Off-site Resident	Off-site	Incomplete	Incomplete	X	Incomplete	Incomplete	X[1]
Off-site Worker	Off-site	Incomplete	Incomplete	X	Incomplete	Incomplete	X[1]
Future Use – After WRF Construction							
Trespasser	North	X	X	X[4]	Incomplete	Incomplete	X[1]
Indoor Worker	South	Not significant[2]	Not significant[2]	Not significant[2]	Incomplete	Incomplete	X[1]
Indoor Worker	North	Not significant[2]	Not significant[2]	Not significant[2]	Incomplete	Incomplete	X[1]
Maintenance Worker	North	X	X	X[4]	X	X	X[1]
Maintenance Worker	South	X	X	X[4]	X	X	X[1]
Off-site Resident	Off-site	Incomplete	Incomplete	X[4]	Incomplete	Incomplete	X[1]
Off-site Worker	Off-site	Incomplete	Incomplete	X[4]	Incomplete	Incomplete	X[1]
Default Construction Worker	North	X	X	X[4]	X[3]	X[3]	X[1]

Notes:
X – Exposure by this pathway is evaluated for the indicated population. "Incomplete" indicates that the specified receptor population will not be exposed to the specified medium by this pathway.
1 – Although this pathway is believed to be incomplete or insignificant, potential exposures are evaluated in this assessment, given that ground water could be a continuing source of emissions in the future.
2 – Although assumed to be on-site, indoor workers are expected to spend most or all of the time indoors.
3 – Dewatering is being required (in the construction specifications) for the WRF expansion project in the southern exposure area. In the future, if the northern portion of the site were developed, it would likely be used for surface uses (e.g., parking lot, warehouse); however, if excavation were required, dewatering would be conducted. For the purposes of the risk assessment, exposure to ground water by a WRF construction worker in the southern exposure area and a future default construction worker in the northern exposure area is evaluated assuming an individual who maintains the dewatering pipeline periodically contacts ground water.
4 - Exposure to airborne dust is estimated assuming that the northern area of the site is not developed immediately and that it represents a source of dust emissions for all scenarios, with one exception. For the maintenance worker in the northern exposure area, it is assumed that the northern area is eventually developed but a portion (50%) remains undeveloped/unvegetated. ENVIRON recognizes that these are somewhat conflicting assumptions, but they are applied in this risk assessment to evaluate the scenarios conservatively.

TABLE ES-3
Summary of Estimated Chemical Cancer Risks and Noncancer Hazard Index Values

Time Frame	Exposure Scenario	Estimated Cancer Risk	Estimated Hazard Index	Target-organ-specific HI Values[1]
During WRF Construction	WRF Construction Worker (Southern Exposure Area)	1×10^{-6}	3.8	Thyroid (GW) – 1.8[2] Thyroid (soil) – 0.26 CNS – 0.96 Nasal – 0.45 Respiratory – 0.16 GI Tract – 0.062 Reproductive – 0.054 Skin – 0.034 Other – <0.02
	Off-site Resident	8×10^{-8}	0.3	NA
	Off-site Worker	5×10^{-8}	0.2	NA
Future (Post WRF Construction)	Maintenance Worker (Northern Exposure Area)	1×10^{-6}	0.5	NA
	Maintenance Worker (Southern Exposure Area)	2×10^{-6}	0.4	NA
	Trespassing Child (Northern Exposure Area)	5×10^{-7}	0.3	NA
	Indoor Worker (Northern Exposure Area)	8×10^{-7}	0.3	NA
	Indoor Worker (Southern Exposure Area)	6×10^{-7}	0.2	NA
	Off-site Resident	6×10^{-7}	0.2	NA
	Off-site Worker	3×10^{-7}	0.1	NA
	Default Construction Worker (Northern Exposure Area)	3×10^{-7}	5.7	Thyroid (GW) – 3.5[3] Thyroid (soil) – 0.54 CNS – 0.65 Nasal – 0.58 Respiratory – 0.20 GI Tract – 0.08 Reproductive – 0.04 Skin – 0.04 Other - <0.1

Notes:
NA – Not applicable
1 - Target-organ specific HI values were not calculated for scenarios with an HI value less than 1.0.
2 - Most (1.8) of the HI value associated with the thyroid is due to exposure to perchlorate in ground water, which can be eliminated through the use of PPE during dewatering pipeline maintenance activities.
3 – Most (3.5) of the HI value associated with the thyroid is due to exposure to perchlorate in ground water, which can be eliminated through the use of PPE during dewatering pipeline maintenance activities.

Exposure Scenarios During Construction of the WRF

WRF Construction Workers – A worker involved with various aspects of the WRF expansion could be exposed to chemicals in soil and ground water through incidental ingestion of and dermal contact with soil, and inhalation of dust and vapors (from ground water). In addition, direct contact (incidental ingestion and dermal contact) with ground water could occur during maintenance of the dewatering system. Exposure to ground water will not occur, however, by most construction workers at the WRF expansion site. The total estimated cancer risk and HI value for all exposure pathways combined (including exposure to ground water) are 1×10^{-6} and 3.8, respectively. The estimated HI value exceeds USEPA's target HI value of 1.0. Perchlorate in ground water contributes 1.8 of the total HI value of 3.8. Although this assessment is based on a series of highly conservative assumptions and adverse noncancer health effects are not expected, use of personal protective equipment (PPE) for any individual who may have long-term contact with ground water[1] is recommended. For most WRF construction workers, exposure to ground water will not occur. The estimated cancer risk and noncancer HI value for WRF construction workers not involved in dewatering pipeline maintenance are 9.5×10^{-7} and 2.0, respectively. Consistent with USEPA guidance, a target organ analysis was performed. The following target-organ-specific HI values were estimated: 0.96 for the central nervous system, 0.45 for nasal effects, 0.26 for the thyroid (perchlorate in soil/air), 1.8 for the thyroid (perchlorate in ground water), 0.16 for respiratory effects, 0.062 for the GI tract, 0.054 for reproductive effects, 0.034 for the skin, and <0.02 for all other effects combined, as indicated in Table ES-3. Based on the results of the target organ analysis, the thyroid HI for ground water exposure is the only HI exceeding 1. As noted above, exposure to ground water by a construction worker can be controlled through use of appropriate PPE.

Off-site Residents and Off-site Workers – The estimated risks for these populations are based on exposure to chemicals in airborne dust emitted during construction activities and vapors emitted from ground water. The total estimated cancer risk and HI value for an off-site resident are 8×10^{-8} and 0.3, respectively. For the off-site workers, the estimated cancer risk and HI value are 5×10^{-8} and 0.2, respectively. Thus, the estimated cancer risks and noncancer HI values are below the risk threshold identified by USEPA.

The cancer risks and noncancer HI values for these off-site populations are based on highly conservative estimates of dust and vapor transport from the site. For residents, it is assumed that an individual is exposed continuously (24 hours/day, 350 days/year for 30 years) at the

[1] The WRF construction worker scenario assumes weekly exposure to ground water during dewatering pipeline maintenance for a period of 1.5 years.

property boundary. Off-site workers are assumed to be exposed 8 hours/day, 250 days/year, for 25 years at the property boundary. Actual risks to off-site populations will be significantly below the risks estimated in this assessment.

Future Exposure Scenarios (After WRF Construction)

Maintenance Workers – Two separate maintenance worker scenarios were evaluated in the risk assessment, one assuming exposure in the southern portion of the site and a second based on exposure in the northern portion of the site (if development of this area were to occur in the future). The estimated cancer risks for the two scenarios are almost equivalent. The estimated cancer risk to a maintenance worker in the northern exposure area is 1×10^{-6}, and in the southern exposure area, the estimated cancer risk to a maintenance worker is 2×10^{-6}. For chemicals with noncarcinogenic effects, HI values of 0.4 and 0.5 were estimated for a maintenance worker in the southern and northern exposure areas, respectively.

These estimates of risk are believed to be conservative because they do not take into consideration the contribution of background soil concentrations, nor the presence of paving, buildings, and landscaping that would tend to limit exposure to soil. In addition, the estimated cancer risks and HI values assume some limited exposure to ground water during routine maintenance activities. If no exposure to ground water occurs, estimated risks would be lower.

Trespassing Child – It was assumed that a trespassing child in the northern exposure area could be exposed to soil through incidental ingestion, dermal contact, and inhalation of wind-blown dust. The total estimated cancer risk and HI value for a child trespasser are 5×10^{-7} and 0.3, respectively. Both of these estimates are significantly below USEPA risk thresholds for carcinogenic and noncarcinogenic chemicals.

Indoor Workers – The indoor worker scenario assumes that volatile chemicals in ground water migrate upward through the soil column and infiltrate an overlying building. There is very little evidence that such migration of vapors is actually occurring; however, cancer risks and noncancer HI values were estimated in case vapor migration were to occur in the future. The total estimated cancer risk and HI value associated with exposure to VOC vapors emitted from ground water by an indoor worker in the southern part of the site are 6×10^{-7} and 0.2, respectively. Although not currently planned, if development were to occur in the northern portion of the site, the estimated cancer risk and HI value for an indoor worker in this part of the site is 8×10^{-7} and 0.3, respectively. The model used to estimate concentration of chemicals

in indoor air is a screening-level model. Given that the estimated cancer risks and noncancer HI values are below USEPA risk thresholds, application of a more refined model is not necessary.

Off-site Residents and Off-site Workers –The total estimated cancer risk and HI value for a future off-site resident after construction of the WRF expansion has been completed are 6×10^{-7} and 0.2, respectively. For future off-site workers after completion of the WRF, the estimated cancer risk and HI value are 3×10^{-7} and 0.1, respectively. Thus, the estimated cancer risks and noncancer HI values are below risk thresholds identified by USEPA. As noted above, the cancer risks and noncancer HI values for these off-site populations are based on highly conservative estimates of dust and vapor transport from the site. Actual risks to off-site populations will be significantly below the risks estimated in this assessment.

Default Construction Worker - If the City were to develop the northern portion of the site in the future, a construction worker associated with these activities could be exposed to chemicals in soil, ground water, and air. The estimated cancer risk and noncancer HI value for this population are 3×10^{-7} and 5.7, respectively, assuming the same exposure pathways as applied for the WRF construction worker in the southern exposure area. This is a highly conservative exposure scenario, because it assumes the same level of construction activity in the northern portion of the site as is planned for the WRF expansion. The City has indicated that development of the northern portion of the site, if any, would likely be limited to surface uses (e.g., warehouse, parking, equipment storage). In addition, this exposure scenario assumes that direct contact (incidental ingestion and dermal contact) with ground water will occur for an individual involved in maintenance of the dewatering system associated with the construction activities. As noted above, this type of exposure will not occur to most construction workers.

Perchlorate in ground water contributes 3.5 of the total HI value of 5.7. Thus, for future long-term construction workers in the northern exposure area who come into contact with ground water routinely, use of PPE is recommended. For most workers, however, exposure to ground water will not occur. The estimated cancer risk and noncancer HI value for future default construction workers in the northern exposure area not involved in dewatering pipeline maintenance are 3×10^{-7} and 2.2, respectively. Consistent with USEPA guidance, a target organ analysis of the chemicals with the greatest contribution to the total HI value (discussed in Section C.2.b of Chapter VII) was conducted. The target organ analysis indicates that the noncancer target organ HI values do not exceed the USEPA target level of 1.0, other than the thyroid HI value for ground water, as indicated in Table ES-3. As noted above, exposure to ground water by a construction worker can be controlled through use of appropriate PPE.

D. Radiological Risk Assessment

For the purposes of this assessment, ENVIRON applied the radiological risk assessment methodology recommended by USEPA in RAGS, Chapter 10 (USEPA 1989) and the *Soil Screening Guidance for Radionuclides: User's Guide* (USEPA 2000b). These guidance documents recommend that estimates of cancer risk associated with radionuclides be developed and reported separately from cancer risks associated with chemical exposure. The radionuclide COPCs evaluated quantitatively in the risk assessment are listed in Table 35 of the text and the exposure scenarios evaluated for the radionuclide COPCs are summarized in Table ES-4.

A summary of the estimated cancer risks for the identified populations due to exposure to radionuclides associated with the WRF expansion site is provided below and in Table ES-5. The highest cancer risks were estimated for the maintenance worker scenario in both the northern and southern exposure areas of the site. The estimated lifetime cancer risk for these populations is approximately 9×10^{-5}, which is below the USEPA risk threshold for exposure to radionuclides. Estimated cancer risks associated with the other scenarios are lower. The total cancer risks to the WRF and future default construction workers are estimated as 5×10^{-5} and 2×10^{-5}, respectively. Estimated cancer risks for the trespasser are approximately 1×10^{-5}, and the risks to the off-site populations (residents and worker, before and after construction) are very low (3×10^{-9} and lower). In all cases, the primary contributing pathway to total cancer risk is external exposure. Based on these results, it does not appear that the presence of radionuclides at the site poses a significant concern.

E. Asbestos Risk Assessment

The asbestos-related risks are assessed using a method described by Berman and Crump (1999). The data required by this method were generated by analyzing soil samples using the methods described by Berman and Kolk (2000). All of the asbestos-related risk estimates for exposure scenarios during the WRF construction period are below 10^{-5}, as indicated in Table ES-6. During WRF construction, the maximum risk estimate is for the WRF construction worker; the upper bound risk estimate for this scenario is about 1×10^{-6}. This potential asbestos risk is due primarily to exposure to chrysotile asbestos in soils in the southern exposure area.

With one exception, the asbestos-related risk estimates for the post-WRF construction scenarios are less than 10^{-6} (i.e., below the lower end of the range of cancer risks that are considered acceptable under the National Contingency Plan). The exception is for the default construction worker scenario in the northern exposure area, which is hypothetical; at present, the City of Henderson has no plans for development of the northern exposure area. The upper bound risk estimate for this scenario is about 5×10^{-6}. Almost 100 percent of the potential asbestos-related

TABLE ES-4
Summary of Populations and Pathways Evaluated in the Radionuclide Risk Assessment of the Proposed WRF Expansion Site

Population	Exposure Area	Exposure Pathways			
		Soil			Ground Water
		Ingestion	External Exposure	Inhalation of Dust	Incidental Ingestion
During WRF Construction					
WRF Construction Worker	South	X	X	X	X[2]
Off-site Resident	Off-site	Incomplete	Incomplete	X	Incomplete
Off-site Worker	Off-site	Incomplete	Incomplete	X	Incomplete
Future Use – After WRF Construction					
Trespasser	North	X	X	X[3]	Incomplete
Indoor Worker	South	Not significant[1]	X	Not significant[1]	Incomplete
Indoor Worker	North	Not significant[1]	X	Not significant[1]	Incomplete
Maintenance Worker	North	X	X	X[3]	X
Maintenance Worker	South	X	X	X[3]	X
Off-site Resident	Off-site	Incomplete	Incomplete	X[3]	Incomplete
Off-site Worker	Off-site	Incomplete	Incomplete	X[3]	Incomplete
Default Construction Worker	North	X	X	X[3]	X[2]

Notes:
X – Exposure by this pathway is evaluated for the indicated population. "Incomplete" indicates that the specified receptor population will not be exposed to the specified medium by this pathway.
1 – Although assumed to be on-site, indoor workers are expected to spend most or all of the time indoors.
2 – Dewatering is being required (in the construction specifications) for the WRF expansion project in the southern exposure area. The northern portion of the site, if developed, would likely be used for surface uses (e.g., parking lot, warehouse); however, if excavation were required, dewatering would be conducted there as well. For the purposes of the risk assessment, exposure to ground water by a WRF construction worker in southern exposure area and a future default construction worker in the northern exposure area are evaluated, assuming an individual who maintains the dewatering pipeline periodically contacts ground water.
3 - Exposure to airborne dust is estimated assuming that the northern area of the site is not developed immediately and that it represents a source of dust emissions for all scenarios, with one exception. For the maintenance worker in the northern exposure area, it is assumed that the northern area is eventually developed but a portion (50%) remains undeveloped/unvegetated. ENVIRON recognizes that these are somewhat conflicting assumptions, but they are applied in this risk assessment to evaluate the scenarios conservatively.

TABLE ES-5 Summary of Estimated Cancer Risks for Radionuclides		
Time Frame	**Exposure Scenario**	**Estimated Cancer Risk**
During WRF Construction	WRF Construction Worker (Southern Exposure Area)	5×10^{-5}
	Off-site Resident	2×10^{-9}
	Off-site Worker	3×10^{-9}
Future (Post WRF Construction)	Maintenance Worker (Northern Exposure Area)	9×10^{-5}
	Maintenance Worker (Southern Exposure Area)	9×10^{-5}
	Trespassing Child (Northern Exposure Area)	1×10^{-5}
	Indoor Worker (Northern Exposure Area)	8×10^{-5}
	Indoor Worker (Southern Exposure Area)	8×10^{-5}
	Off-site Resident	1×10^{-9}
	Off-site Worker	2×10^{-9}
	Default Construction Worker (Northern Exposure Area)	2×10^{-5}

TABLE ES-6
Summary of Estimated Cancer Risks for Asbestos

Time Frame	Exposure Scenario	Estimated Upper-bound Cancer Risk	Estimated Average Cancer Risk
During WRF Construction	WRF Construction Worker (Southern Exposure Area)	1×10^{-6}	3×10^{-7}
	Off-site Resident	7×10^{-8}	3×10^{-8}
	Off-site Worker	2×10^{-8}	7×10^{-9}
Future (Post WRF Construction)	Maintenance Worker (Northern Exposure Area)	3×10^{-8}	2×10^{-8}
	Maintenance Worker (Southern Exposure Area)	5×10^{-8}	2×10^{-8}
	Trespassing Child (Northern Exposure Area)	2×10^{-9}	7×10^{-10}
	Off-site Resident	3×10^{-7}	1×10^{-7}
	Off-site Worker	5×10^{-8}	2×10^{-8}
	Default Construction Worker (Northern Exposure Area)	5×10^{-6}	2×10^{-6}

Average cancer risk estimates are based on measurements (numbers of structures/gram of dust) reported by the laboratory. Upper-bound cancer risks are based on upper bounds derived from the laboratory measurements, as explained in section IX.B.2 of this report.

risk for the northern exposure area soils is associated with amphibole asbestos. As noted in the discussion of uncertainties, the laboratory report indicates that the only amphibole fibers observed during the elutriator analysis were tremolite cleavage fragments. These nonasbestiform amphibole materials are not addressed by U. S. health regulations because there is insufficient evidence that they produce adverse health effects of the same type and severity produced by chronic exposure to asbestos. Risk estimates based on the presence of nonasbestiform tremolite cleavage fragments may be significantly higher than the actual asbestos risks at the WRF site. On the other hand, the toxicological properties of cleavage fragments that qualify as protocol structures for the risk assessment method described by Berman and Crump (1999) on the basis of their geometry may not differ significantly from those of asbestiform structures of the same size and mineralogy (Berman, personal communication). The actual asbestos-related risk for the default NEA construction worker scenario may be considerably lower than the 10^{-6} threshold.

F. Conclusions

A statistical comparison of background and site characterization sampling results suggests that both exposure areas have elevated concentrations (relative to background) of several chemicals, including dioxins, perchlorate, twelve metals, and two radionuclides (uranium 238 and uranium 234, which is a decay product of uranium 238). The northern exposure area also appears to be elevated for aluminum, chromium, and uranium 235; the southern exposure area also appears to be elevated for lead, mercury, bismuth 214, lead 214, and thorium 230. These results are based on interpretation of 78 statistical hypothesis tests at a five percent level of significance, so some false rejections of the null hypothesis are likely. While individual tests are not necessarily conclusive, the pattern and number of elevated levels indicate that soils in both exposure areas have been affected by wastes associated with the BMI industrial complex.

The highest estimated chemical cancer risk for any of the exposure scenarios evaluated in this risk assessment is 2×10^{-6}, which was estimated for the maintenance worker in the southern exposure area. The cancer risk to the maintenance worker in the northern exposure area and the WRF construction worker in the southern exposure area is 1×10^{-6}. The estimated risks for all other exposure scenarios are below 1×10^{-6}. These estimates of risk are based on highly conservative assumptions; thus, there is no significant concern associated with potential carcinogenic effects from exposure to chemicals at the WRF expansion site.

The target organ HI value exceeded 1.0 for two exposure scenarios, both of which assume long-term exposure to ground water (i.e., WRF construction worker in the southern exposure area and the future default construction worker in the northern exposure area, with dewatering pipeline maintenance). If exposure to ground water is eliminated through the use of PPE, or if ground water exposure does not occur, as is expected for most construction workers, the target organ HI values are less than 1.0. Thus, with the exception of long-term, repeated exposure to ground water,

exposure to noncarcinogenic chemicals at the WRF expansion site does not pose a significant concern.

The estimated cancer risks associated with exposure to radionuclides in soil and ground water at the WRF expansion site are well below the USEPA acceptable radionuclide cancer risk level of 3×10^{-4}. Furthermore, the estimated risks appear to be almost entirely associated with background. The primary contributor to total radionuclide cancer risks (Potassium 40) is not present above background levels, based on a statistical comparison of activities in site soils to background levels. Thus, there is no concern associated with the presence of radionuclides in soil and ground water at the site.

The asbestos risk estimates during WRF construction derived from the supplemental asbestos investigation are well below the 10^{-5} risk level identified as acceptable by the NDEP in a letter to ENVIRON dated October 18, 2002. This is also true for the total carcinogenic risk estimates during construction obtained by adding the worst-case upper bound asbestos risk estimates to the cumulative cancer risk estimates developed for exposure to other chemicals. The only total carcinogenic risk estimates that exceed the 10^{-6} risk level (i.e., the action level assumed in preparing this report) are for construction and maintenance workers at the WRF expansion site. The highest of the total risk estimates is 5×10^{-6} for the default NEA construction worker scenario, which is hypothetical; at present, the City of Henderson has no plans for development of the northern exposure area. Exposure to asbestos accounts for more than 90 percent of this total carcinogenic risk estimate. Because the asbestos risk estimates are based on upper-bound concentrations derived from observations of nonasbestiform tremolite cleavage fragments, they may be significantly higher than the actual asbestos risks at the WRF site. On the other hand, the toxicological properties of cleavage fragments that qualify as protocol structures for the risk assessment method described by Berman and Crump (1999) on the basis of their geometry may not differ significantly from those of asbestiform structures of the same size and mineralogy (Berman, personal communication). The actual asbestos-related and total carcinogenic risks for the default NEA construction worker scenario may be considerably less than 10^{-6}.

The risk estimates presented in this report were derived using reasonable maximum exposure (RME) assumptions. With the exception of the HI values for the SEA and NEA construction workers (which can be mitigated by the use of appropriate PPE) and total cancer risk levels (chemicals and asbestos combined) for future maintenance workers at the SEA and future default construction workers in the NEA, the reasonable worst-case risk estimates are below the assumed action levels. In this sense, this risk assessment supports a decision to allow construction of the WRF expansion to proceed. Such a decision would be erroneous if the actual risks exceed the assumed action levels. This could occur if the average concentrations of the chemicals of concern at the site are significantly higher than indicated by the available data. The adequacy of the data set to support a no-action decision is determined by reference to the likelihood that the

actual concentrations exceed the concentrations that correspond to the assumed action levels. The analysis presented in this report indicates that this likelihood may be as high as five percent for arsenic in surface soils in the southern exposure area, but that this arsenic may be present primarily (perhaps entirely at some locations) as a result of background conditions. In light of the many other conservative elements of the risk assessment process, the likelihood that the actual risk associated with site-specific conditions exceeds the assumed action levels is far less than five percent.

I. INTRODUCTION

The City of Henderson, Nevada is planning an expansion of its water reclamation facility (WRF) onto a parcel of land adjacent to the current WRF. This approximately 100-acre parcel (also referred to as the "site" in this report), which is currently undeveloped, was used historically for the disposal of wastewater from the BMI Industrial Complex, located one to two miles southwest of the site. Previous soil sampling at the site has indicated the presence of several chemicals, including metals, perchlorate, and certain pesticides, some of which have been detected at concentrations above or approaching USEPA Region 9 preliminary remediation goals (PRGs). As a result, the City has retained ENVIRON International Corporation (ENVIRON) to conduct a human health risk assessment of potential exposures at the proposed WRF expansion site. This risk assessment has been conducted in accordance with ENVIRON's *Site Characterization and Risk Assessment Work Plan* (ENVIRON 2001) for the site, conditionally approved by the Nevada Division of Environmental Protection (NDEP) on August 20, 2001. The sampling that had been conducted prior to the work plan was not sufficient to conduct a baseline risk assessment. Thus, a comprehensive site characterization program was conducted by ENVIRON in May 2001 to provide data for the risk assessment.

The purpose of this risk assessment is to estimate potential health risks to current and future users of the site and populations in the vicinity of the property. Risk estimates are compared with levels considered acceptable by NDEP and the U.S. Environmental Protection Agency (USEPA). This risk assessment is being conducted to support a determination by the Nevada Division of Environmental Protection (NDEP) that the project can be constructed and operated without posing unacceptable risks to human health. Additional issues that do not have a direct effect on construction and operation of the WRF expansion (e.g., regional ground water quality and leaching from site soils) are being deferred to a later date, as discussed below. If the results of the risk assessment indicate that additional actions at the site are required (e.g., remediation), a supplemental work plan will be prepared for such actions.

Of particular importance for the WRF site will be the development of appropriate soil criteria for the protection of underlying ground water ("leaching criteria"). Specific leaching criteria for the WRF site can be developed once a regional strategy for the regulation and management of ground water is established by NDEP. For the purposes of this report, ENVIRON conducted a preliminary screening analysis to determine if any of the constituents detected at the site could represent a potential threat to underlying ground water, and to determine what impact, if any, the presence of such constituents could have on the construction and operation of the WRF expansion. Specifically, the following analysis was conducted:

- ENVIRON compared the maximum concentration of each contaminant detected in site soils, with the published USEPA Soil Screening Level (SSL) using a Dilution Attenuation Factor (DAF) of one. Based on the results of this analysis, several site contaminants were determined to have the potential to leach to underlying ground water.

- ENVIRON examined the spatial distribution of these constituents to determine if any primary sources of ground water contamination (i.e., "hot spots") existed on the site. Based on the results of this analysis, ENVIRON concluded that these constituents generally are present site-wide in vadose zone soils and no obvious hot spots exist.

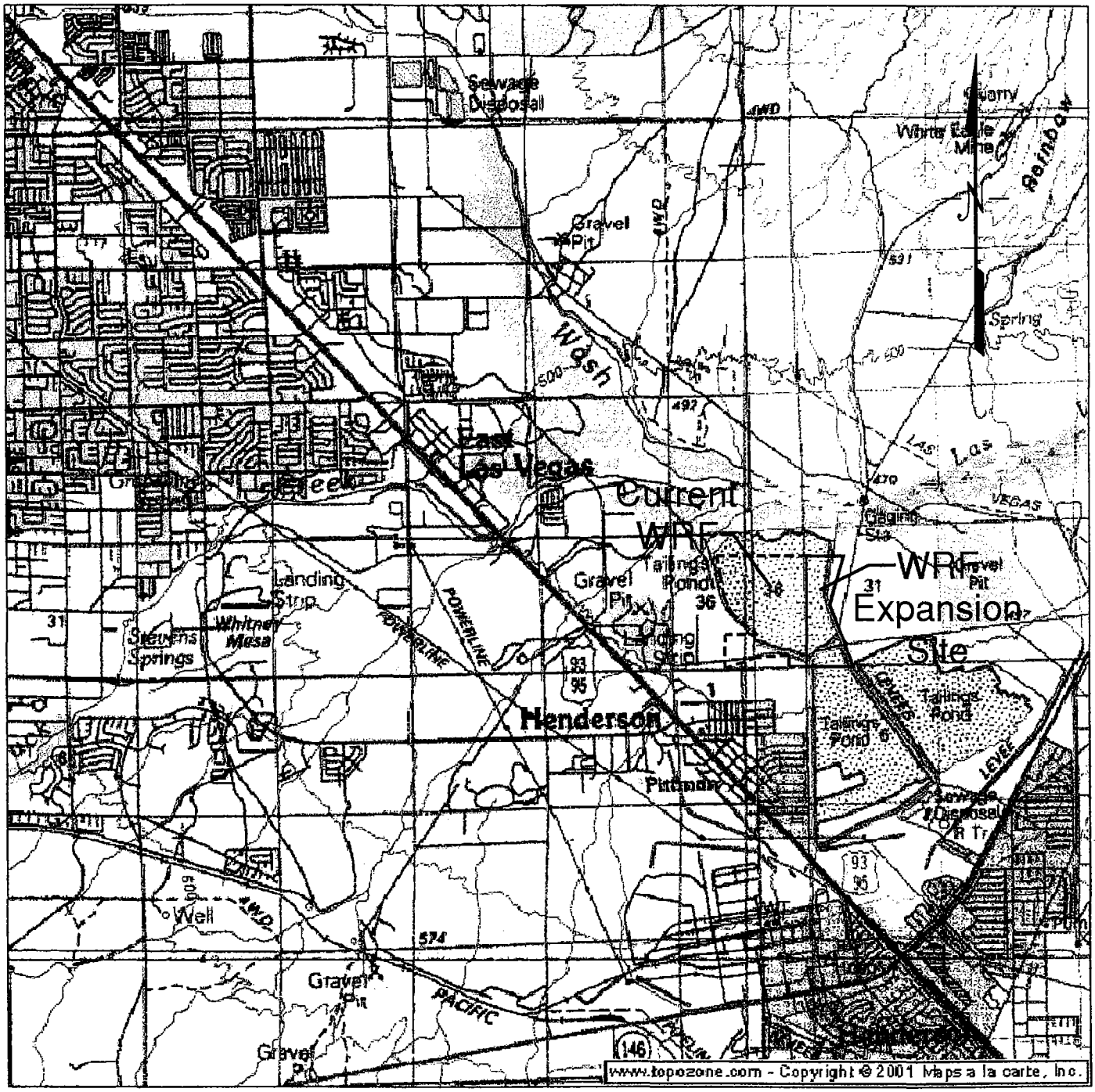
ENVIRON's analysis indicates that a more thorough evaluation of the potential for site constituents to leach to underlying ground water will be required. As discussed with NDEP, ENVIRON intends to conduct the further evaluation of leaching separately from the current risk assessment. However, the diffuse spatial distribution of the constituents identified in our screening analysis indicates that excavation will not be a practical future remedial alternative for site soils. Therefore, the future presence on-site of the WRF will not impact the selection and implementation of future remedial action (if required) for site soils.

A. Site Description

This risk assessment focuses on an approximately 100-acre property located northeast of the core facilities of the BMI Industrial Complex, in Clark County, Nevada, approximately 13 miles southeast of the City of Las Vegas (Figures 1 and 2). The site lies within an area of the BMI Industrial Complex known as the BMI "Common Areas" (so called because their use was common to several operating companies within the Complex). A detailed discussion of the physical character, design, and operational history of these features is provided in the *Phase I Environmental Conditions Assessment for the Basic Management, Inc. Industrial Complex – Clark County, Nevada* (Geraghty & Miller April 1993).

The site is primarily located in part of the BMI Common Areas known as the Lower Ponds. Historically, the Lower Ponds received industrial wastewater, storm water, and cooling water that was transmitted from the BMI Complex via a series of earthen channels (the Alpha and Beta Ditches and the Northwestern and Western Ditches).

Discrete pond cells were present within the site and were defined by berms, generally along the north, east, and west sides of each cell (Figure 3), consistent with the northward-descending topography of the area. Reportedly, the berms were four-to-six feet tall during the period of operations. The pond cells are identified on Figure 3 by three-character alphanumeric values, with the first letter representing the location of the pond as either in the Upper (U) or Lower (L) ponds, the second letter identifying the row (starting with "A" in the south and



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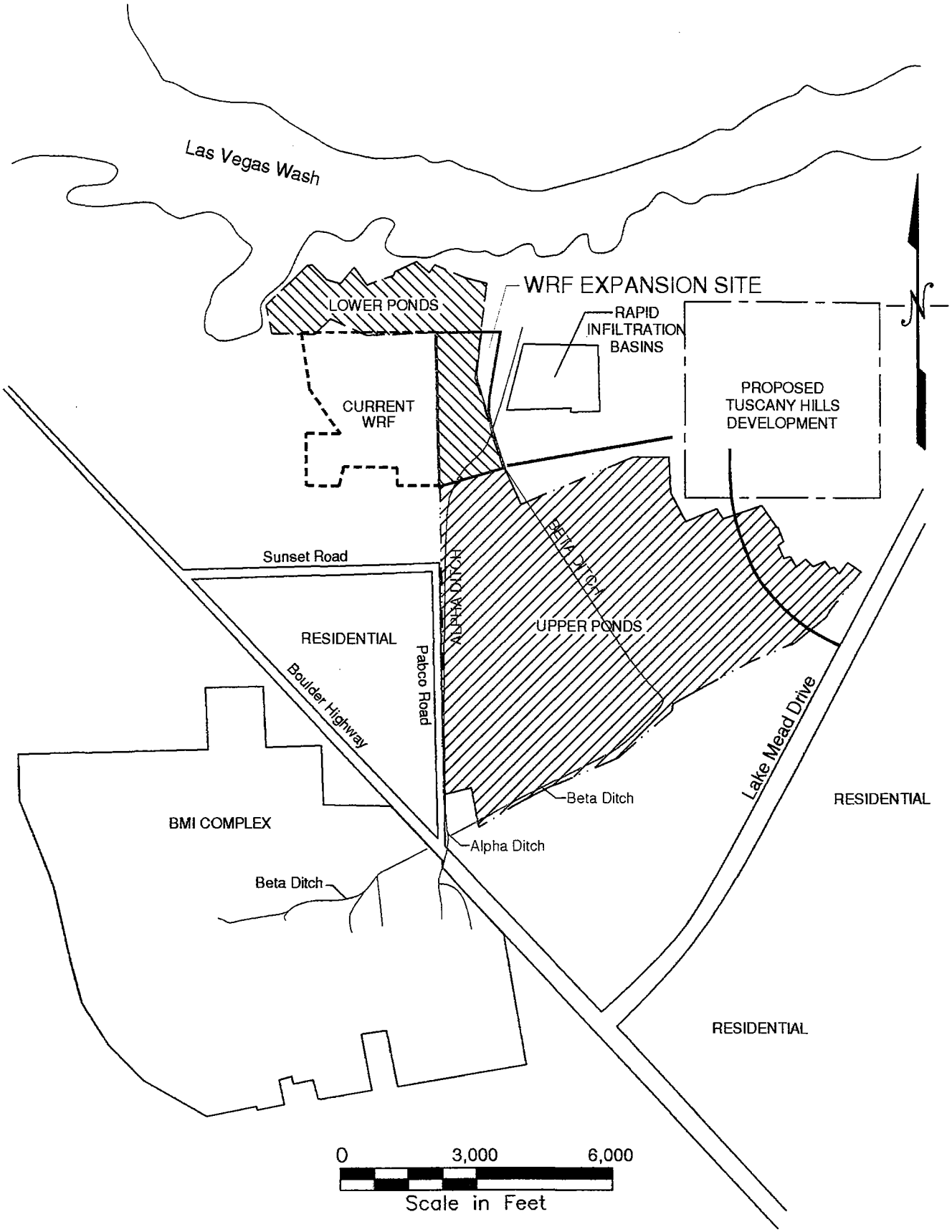
NOTE: Not to Scale
SOURCE: WWW.TOPOZONE.COM; MAPS A LA CARTE, INC.

ENVIRON

SITE LOCATION MAP
PROPOSED WRF EXPANSION PROPERTY
HENDERSON, NEVADA

Figure
1



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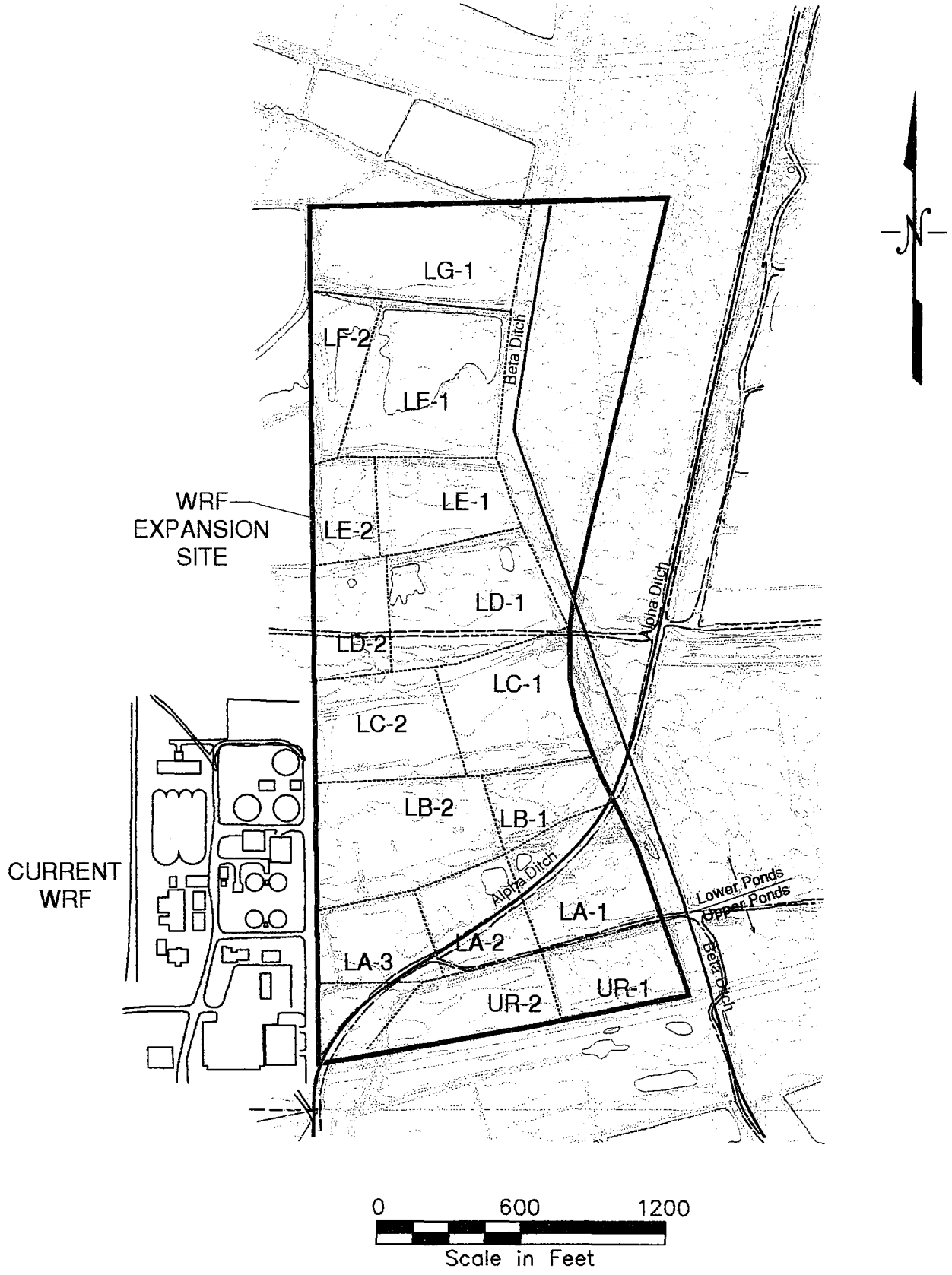
ENVIRON

REGIONAL WRF EXPANSION SITE LOCATION
HENDERSON, NEVADA

Figure
2



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ENVIRON

FORMER POND AND DITCH LOCATIONS
PROPOSED WRF EXPANSION PROPERTY

Figure
3

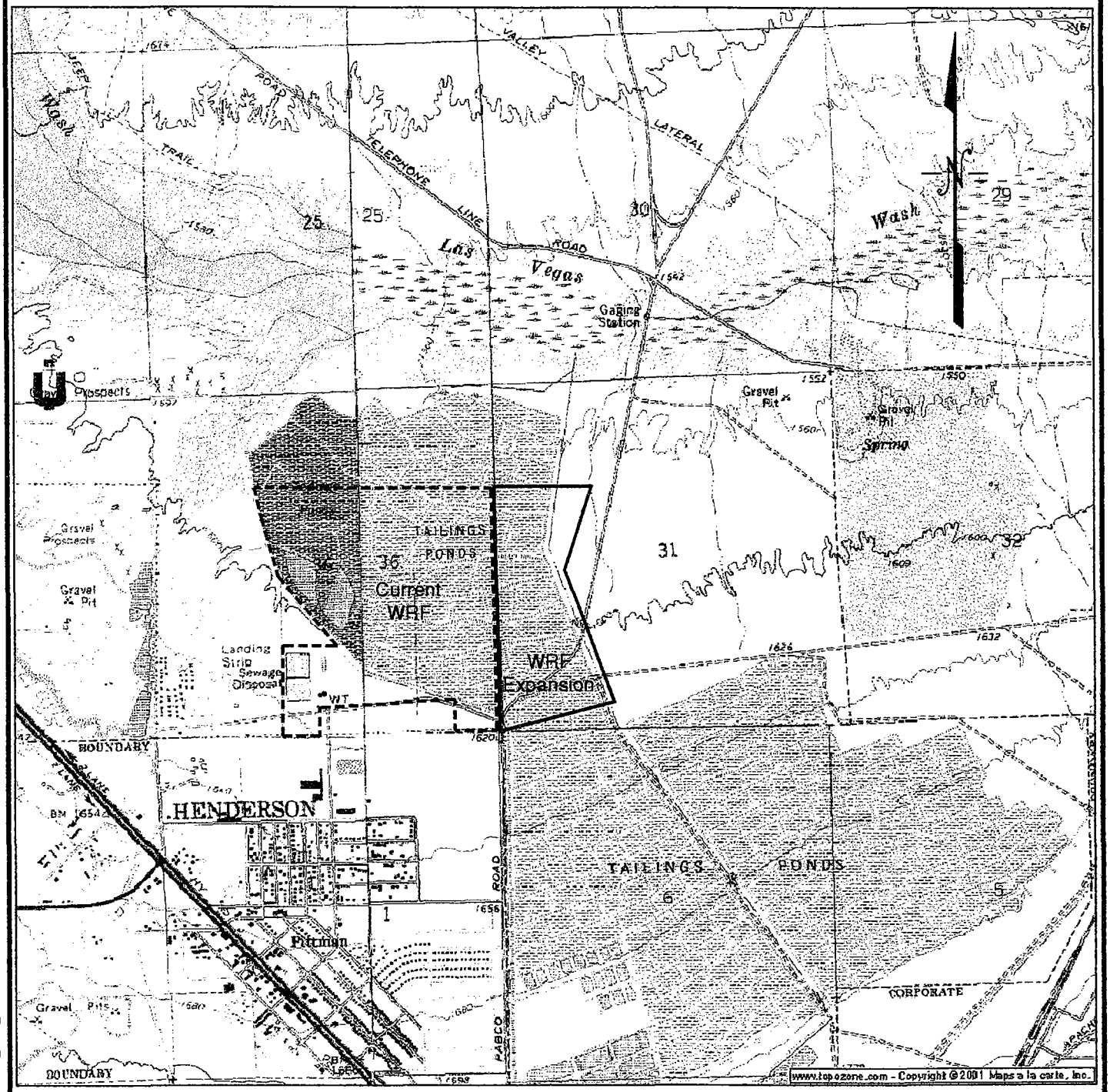
increasing in a northerly direction), and the third value representing the pond number within the row (starting with 1 and increasing in a westerly direction). Portions of the Alpha Ditch traverse the southern portion of the site. The Beta Ditch, which is located adjacent to the eastern boundary of the site, has been filled in limited areas to allow roadway access to the site.

The area surrounding the site is currently sparsely developed, with a mixture of commercial, industrial, and residential land use. As shown on Figure 2, the area west of the site is the location of the City's current WRF facilities. To the southwest of the site is a commercial/industrial area along Sunset Road, to the south of which lies a residential community located within the triangular area formed by Sunset Road, Pabco Road, and Boulder Highway. The BMI Complex lies further to the south, across Boulder Highway. The area south of the site is currently undeveloped, but was used historically as wastewater disposal ponds for the BMI Complex. This area of ponds is commonly referred to as the Upper Ponds. The area east of the site is undeveloped and, with the exception of the City's rapid infiltration basins, has never been developed or used for any known waste disposal. This undeveloped land continues for two to three miles to the east until Lake Mead Drive, along which are located numerous commercial establishments. A residential development (Tuscany Hills) has been proposed for a portion of this undeveloped land approximately one mile east of the site. North of the site, the Lower Ponds continue for a little more than a quarter mile, beyond which is undeveloped land and eventually Las Vegas Wash (approximately one-half mile north of the site), a natural waterway that eventually discharges to Lake Mead.

B. Site Geology and Hydrogeology

The Las Vegas Valley occupies a topographic and structural basin that lies within the Basin and Range physiographic province. The valley is wide and flat, and slopes to the southeast from an elevation of approximately 2,000 feet above mean sea level at Las Vegas to approximately 1,200 feet at Lake Mead. The topographic gradient at the site gradually slopes to the north. A portion of the USGS topographic map of the site is provided in Figure 4.

The area consists of unconsolidated Quaternary alluvial fan deposits, which are underlain by the Tertiary Muddy Creek Formation. Younger Quaternary alluvial deposits rest unconformably on the Muddy Creek Formation. During the site investigations, the shallow alluvial deposits were observed to consist generally of light tan to light brown fine-grained silty sand and gravel. Sand and gravel content generally increased with depth at the site, and occasional lenses of well-sorted medium-grained sand and gravel were observed. Moderately cemented caliche strata were observed within the Quaternary fill deposits at depths generally ranging from 6 to 12 feet below ground surface and thicknesses of less than one foot.



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ENVIRON	TOPOGRAPHIC MAP OF THE SITE AND SURROUNDING AREA	Figure 4

The Muddy Creek Formation is a valley-fill deposit and has a wide range of lithologies, including coarse-grained sands and gravels near the mountain fronts, and fine-grained silts and clays approaching Las Vegas Wash. In the site vicinity, the Muddy Creek Formation consists of a gray to greenish-gray moist plastic silty clay. The Muddy Creek Formation was encountered at depths ranging from 17 to 20 feet below ground surface in the southern part of the site but was not observed at similar depths at deep borings installed in the northern portion of the site.

Ground water in the area occurs mainly in the unconsolidated sediments of the valley fill. The uppermost water-bearing zone is associated with the surficial alluvium. The deposit represents the water table or near-surface aquifer in the valley. Based on soil boring installation and existing on-site ground water wells, the water table at the site was observed at depths ranging from approximately 17 feet in the northern part of the site to approximately 24 feet below ground surface in the southern portion of the site; although, in several borings located along the northern boundary of the site "wet" soil was observed at depths of between 5 and 8 feet below ground surface. In ground water monitoring wells located 350 feet to 500 feet north of the site, ground water has been observed at a depth of 6 to 7 feet below ground surface. Ground water flow across the site is generally from south to north toward Las Vegas Wash, a shallow, narrow stream that flows southeasterly across the valley and drains into Lake Mead. The water table aquifer ultimately discharges to Las Vegas Wash.

Based on recent work conducted by Kerr-McGee Chemical LLC and American Pacific Corporation (Kerr-McGee 2001), alluvial ground water flow in the vicinity of the site may be influenced by a system of paleochannels that trend generally southwest-northeast. The primary paleochannels identified during the Kerr-McGee investigation exist to the east and west of the site. Additional paleochannels may be present adjacent to or on the WRF site; however, current site characterization data are insufficient to identify and locate such features.

C. Summary of the Data Quality Objectives (DQO) Process

The analytical data used in this risk assessment were collected within a Data Quality Objectives (DQO) framework, in general accordance with USEPA guidance (USEPA 2000a). The DQOs process is a systematic planning process that is appropriate for use when environmental data will be used to select between two alternatives. As described by the USEPA guidance, the process is used to develop DQOs that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors. The application of the first five steps of the seven-step DQOs process was discussed briefly in the site characterization work plan (ENVIRON 2001).

The WRF expansion project has progressed through the planning and implementation phases and is now in the assessment phase. In order to expedite the site characterization effort, Steps 5, 6, and 7 of the DQOs process were not completed in the planning phase of this project.

In applying the DQOs process to a site risk assessment problem, action levels that set the boundaries between the alternative outcomes of the decision process are identified at Step 5. Step 6 of the process involves setting tolerable limits for decision errors, and Step 7 involves optimization of the sampling design. USEPA guidance for the DQOs process (USEPA 2000a) indicates that action levels and tolerable limits for decision errors should be selected by a planning team that includes regulators and stakeholders, as well as technical personnel.

Because Step 5 was not completed, the assessment described in this report is based on assumed action levels. The action levels assumed in this report include 1×10^{-6} for cumulative chemical cancer risks; a hazard index of one for cumulative chemical non-cancer risks; and 3×10^{-4} for cumulative radionuclide cancer risks. These levels were selected because they are consistent with USEPA recommendations in the National Contingency Plan (NCP) and other guidance documents (USEPA 1997c; USEPA 1991a,b). Additional discussion of target risk levels is provided in Sections A and B of Chapter VII for carcinogens and noncarcinogens, respectively, and in Section D of Chapter VIII for radionuclides. The adequacy of the data set is evaluated in the context of the probability of decision errors under these assumed action levels. This evaluation is explained in detail in Appendix G. The current status of the project with respect to the DQOs process is summarized in the following paragraphs.

Step 1 – State the Problem

Wastes have been released into the WRF expansion area, resulting in concern about potential risks to people who may be exposed to affected media. The problem is to determine whether these potential risks are inconsistent with the proposed development and future use of the property. The details of this problem are described in later sections of this report. Specifically, the ways in which receptors could be exposed to these media during and after the proposed site development are discussed in Section 4 of the conceptual site model presented in Chapter III of this report. Other activities to be performed in Step 1 include identifying the planning team members and determining the available resources (budget, personnel, and schedule). Because the project is now in the assessment phase, these activities are not addressed at this time.

Step 2 – Identify the Decision

The principal study question in this project is (in general terms) whether the risks associated with exposure to chemicals in the WRF area are low enough to allow construction of the WRF expansion (and subsequent operation of the WRF) to proceed as planned. If the investigation establishes that these risks are acceptable, the appropriate action is to proceed with construction as planned. If the risks are not acceptable, alternate actions that may be considered include:

- Further investigation,
- Implementation of appropriate measures (e.g., dust control, personal protective equipment) to protect the health and safety of potentially-exposed populations,
- Removal of some high-concentration materials from the WRF expansion site before or during construction, or
- Selection of another site for the WRF expansion.

The USEPA guidance indicates that a decision statement that links the principal study question to the possible actions should be developed at this step. In general terms, the decision statement that is appropriate to this problem is "Determine whether or not the risks associated with exposure to chemicals in the WRF area during and after the planned development require modifications to the development plan for the WRF expansion project." This general statement can be refined by linking the risks for each of the exposure scenarios to one or more alternative actions. For example, if the risks to construction workers are judged to be unacceptable, the appropriate alternative action may be to implement additional health and safety measures during construction. The alternative actions are only identified in a general way at this time. If the risk estimates provided in this report are judged to be unacceptable, specific alternative actions and decision statements will be developed through consultation with the stakeholders and decision-makers. A discussion of the risks, possible actions that may be required based on the results of the risk assessment, and the factors that affect risk management decisions for the site, is provided in Chapter X (Conclusions).

Step 3 – Identify the Inputs to the Decision

The primary inputs to the decision are (1) a characterization of the nature and extent of the impacted media at the WRF site, and (2) a description of the ways in which receptors could be exposed to these media during and after the proposed site development. The site characterization effort described in Chapter II was conducted to determine the nature and extent of chemical impacts in the WRF expansion area in sufficient detail to support the risk assessment. The media that are relevant to this risk assessment include soil, ground water, indoor air, and outdoor air. Exposure concentrations for each medium are developed from the site characterization data set by the methods described in Chapter V. As explained in Appendix G, the data set is judged to provide adequate support for this risk assessment, so additional input is not currently being sought. The ways in which receptors could be exposed to the impacted media are outlined in the conceptual site model in Chapter III and described in more detail in the

exposure assessment in Chapter V. Thus, the primary inputs to the decision process have been addressed. The basis for selecting the action levels that will be used in making the final decision has not been identified, so action levels have been assumed at Step 5 of the DQOs process.

Step 4 – Define the Boundaries of the Study

The primary goal of this step of the DQOs process is to identify and define the target population of potential sampling units that is being studied. This target population is composed of the environmental media within specified boundaries to which the receptors addressed in the risk assessment may be exposed. The media that are relevant to this risk assessment include soil, ground water, indoor air, and outdoor air. The lateral boundaries of the data set coincide with the boundaries of the WRF expansion site, which are shown in Figure 3. The depth zone of interest is from the surface to 30 feet below ground surface (bgs) in the southern exposure area and to 5 feet bgs in the northern exposure area. The risks associated with potential exposure to chemicals in the remaining portion of the vadose zone are not addressed in this risk assessment. Institutional controls will stipulate that the portions of the vadose zone that have not been included in the risk assessment will be evaluated if future exposure is anticipated. The time frame addressed in this project includes the construction period (which is expected to last about three years) and the post-construction period (i.e., the period in which the WRF is operational). The total target population for this project is the combination of the target populations for the individual exposure scenarios described in Chapter V. The scale of the decision is defined by the two exposure areas defined in the conceptual site model (Chapter III) because the risks for each area are evaluated separately.

Step 5 – Develop a Decision Rule

The DQO guidance (USEPA 2000a) suggests development of an "IF. . .THEN" statement as a decision rule. A complete decision rule for the WRF expansion project should include a statement of the alternative actions to be considered if the conditions in the IF statement are not achieved. This complete rule is analogous to an "IF. . .THEN. . .ELSE" statement. The general decision rule for this project may be stated as:

> "If the cumulative risk estimates for each of the potentially-exposed populations are deemed acceptable by the risk manager, then no further action will be required before proceeding with construction of the WRF expansion facility. If the risk estimates are not deemed acceptable, the alternative actions that may be required include further investigation, implementation of appropriate measures to protect

the health and safety of potentially-exposed populations, removal of some high-concentration materials, and selection of another site for the WRF expansion."

The risk estimates referred to in this general decision rule are conservative estimates of the cumulative chemical cancer risks, chemical non-cancer risks, and radionuclide cancer risks. The risk estimates are cumulative in that they are generated by summing over many chemicals and exposure pathways. These estimates are derived using procedures and parameter values that tend to overestimate the actual risks to human health. In addition, the risk estimates presented in this report have not been adjusted for background conditions; although the potential effects of considering the risks associated with background are discussed. The risk estimates are generated separately for each of two exposure areas using the higher of two upper-bound estimates of the mean concentration of each chemical. The risk associated with each chemical is estimated for a number of potential exposure pathways, and the cumulative risk to each potentially exposed population is calculated by summing the chemical-specific risk estimates. These cumulative risk estimates may be compared to action levels established for the corresponding types of cumulative risks.

The assessment described in this report is based on the following assumed action levels: 1×10^{-6} for cumulative chemical cancer risks; a hazard index of one for cumulative chemical non-cancer risks; and 3×10^{-4} for cumulative radionuclide cancer risks. The adequacy of the data set is evaluated under these assumed action levels in Appendix G. Other essential details of the decision rule (i.e., the potentially-exposed populations and the relevant exposure patterns) are described in Chapter V.

The general decision rule is written with action levels expressed in terms of risk, rather than in terms of concentration. This facilitates a decision based on cumulative risks, rather than on the concentrations of individual chemicals. In accordance with USEPA guidance for risk assessment (USEPA 1989), the appropriate population parameter for use in evaluating the risk associated with each chemical is the 95 percent upper confidence limit (UCL) of the mean concentration. The risks corresponding to the 95 percent UCLs for various chemicals are added to estimate the cumulative risks. One of the conservative elements of this risk assessment is that the 95 percent UCL for the mean concentration of each chemical in soil is selected as the higher of two estimates derived from different subsets of the larger data set.

The mean concentration within each exposure area is the relevant concentration for each chemical in this risk assessment. This is because the exposure patterns described in Chapter V will result in contact with soils throughout the exposure areas; there are no on-site residents or workers who will be exposed continually to soils at one specific

location. Another reason for focusing on the mean concentration is that the site will be re-graded at the beginning of the construction period, so the near-surface soils will be mixed and redistributed across the site. In Appendix G, the dose equations developed for the various exposure patterns are used to derive critical concentration levels for individual chemicals that correspond to the assumed cumulative action levels. The mean concentrations derived from the data set are then compared to these chemical-specific critical levels to evaluate the probability of decision errors.

Step 6 – Specify Tolerable Limits on Decision Errors

The DQO guidance (USEPA 2000a) indicates that the possibility of incorrect decisions must be recognized and considered in the planning process. Tolerable limits on the possible decision errors are to be specified by evaluating the consequences of incorrect decisions and identifying a "gray region" in which the consequences are minor. This step was not performed in the planning process, and the WRF expansion project is currently in the assessment phase. The data have been collected and analyzed. Therefore, rather than attempt to specify tolerable limits for the decision errors, ENVIRON has estimated the probabilities of these errors. These probabilities are presented and considered in Appendix G, where the adequacy of the data set is evaluated by comparing the mean concentrations to chemical-specific critical levels. Determining whether the probabilities of decision errors associated with the available data set are tolerable is a risk management decision to be made by the appropriate regulatory agencies.

Step 7 – Optimize the Design for Obtaining Data

This step is used in the planning process to develop a sampling design that is expected to provide data that are adequate to support the decision. Because the data have already been collected, this step will not be performed at this time. The adequacy of the data set is discussed in Appendix G. If the data are judged to be inadequate to support the decision process, this step will be considered in developing a plan for collection of additional data.

II. SITE CHARACTERIZATION

Previous sampling at the site has indicated the presence of several classes of chemicals, including metals, perchlorate, and certain pesticides, some of which have been detected at concentrations above or approaching USEPA Region 9 PRGs. As discussed in the *Site Characterization and Risk Assessment Work Plan* (ENVIRON 2001), the sampling that had been conducted at the site prior to the date of the work plan was not sufficient to conduct a comprehensive risk assessment due to gaps in the available data, including the lack of site-wide analytical data for certain chemicals and chemical classes, potential biases or differences between sampling events, and limited or no data from certain potential exposure locations (e.g., certain depth intervals and certain areas of the site). Given these data gaps, a comprehensive site characterization was conducted by ENVIRON in May 2001. The purpose of the site characterization program was to collect and analyze samples of environmental media, including surface soil (0 to 1 foot below grade), subsurface soil (more than 1 foot below grade), and ground water, primarily to provide data for the risk assessment but also to revise, as necessary, the conceptual site model (CSM) that was presented previously by ENVIRON (2001).

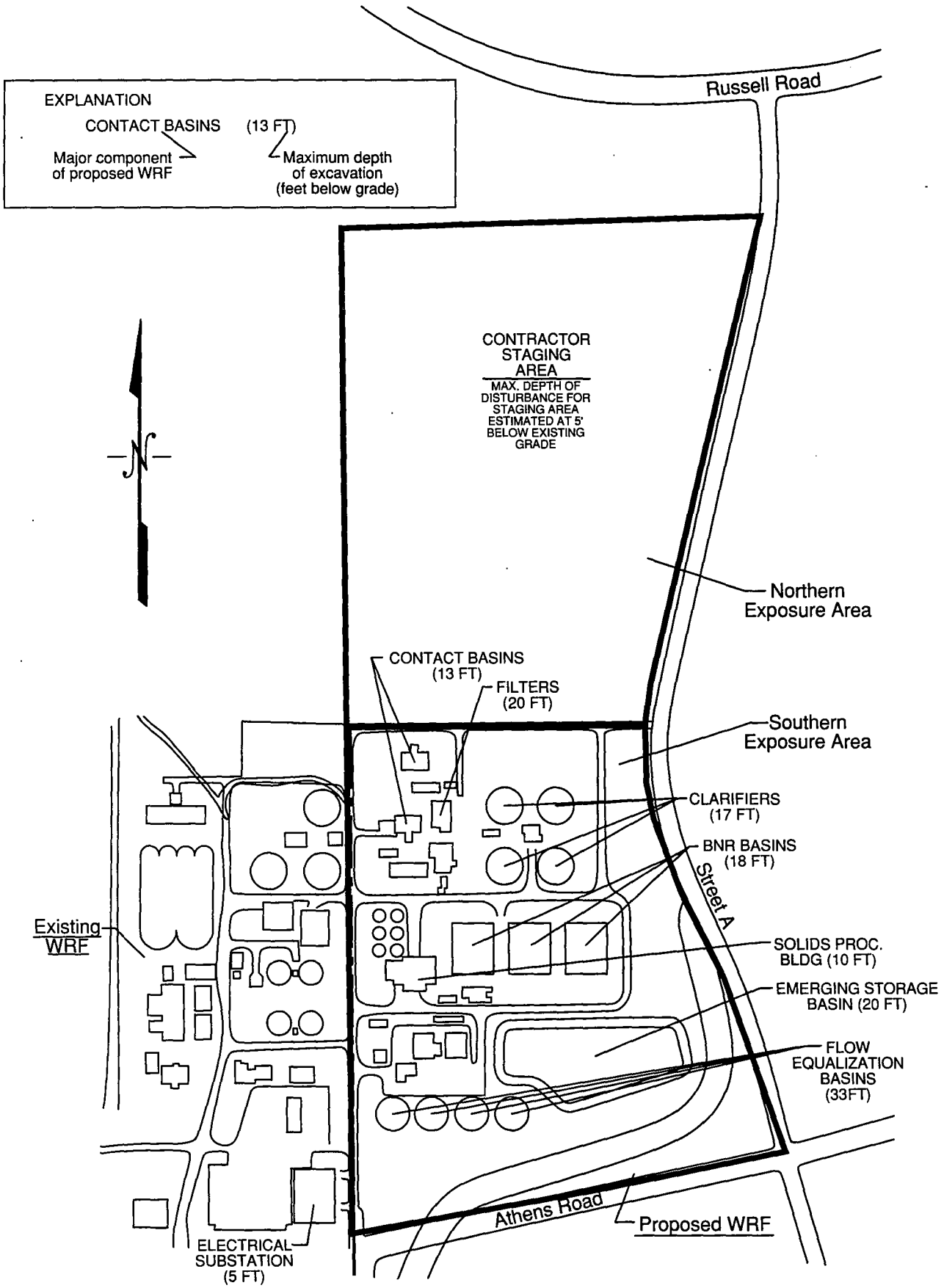
This chapter discusses the field sampling approach and laboratory analyses conducted, and summarizes the results of the laboratory analysis. In addition, a summary of the data usability analysis is provided. Sample collection, laboratory, and quality assurance/quality control (QA/QC) procedures employed during the site characterization program are summarized in Appendix A.

A. Field Sampling Approach

For the purposes of the risk assessment, the site was divided into two exposure areas based on future land use: 1) the northern exposure area and 2) the southern exposure area, as shown in Figure 5. Samples of surface and subsurface soils, as well as shallow ground water, were collected from each of these two exposure areas, as described below. Boring logs are provided in Appendix B. The basis for selecting the sampling locations and depth intervals is discussed in the site characterization work plan (ENVIRON 2001).

1. Soil Sampling (Northern Exposure Area)

The soil sampling conducted by ENVIRON in the northern exposure area during the May 2001 site characterization program is summarized below. The soil sampling locations are shown on Figure 6.



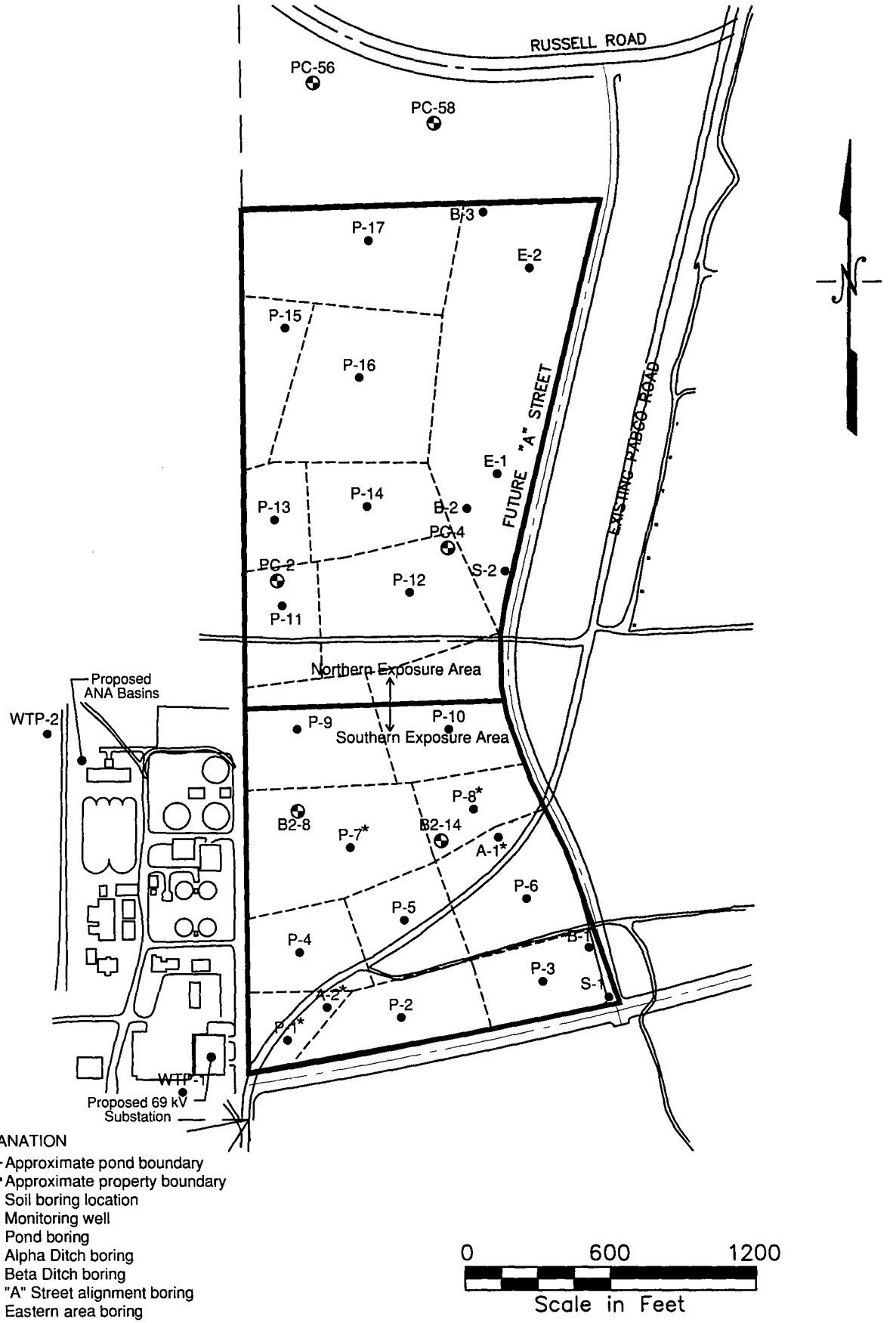
NOTE: Not to Scale

c:\acad\01-2131A\12131AB8.DWG

ENVIRON

PROPOSED WRF EXPANSION FOOTPRINT

Figure 5



ENVIRON

SOIL AND GROUND WATER SAMPLING LOCATIONS IN THE PROPOSED WRF EXPANSION PROPERTY

Figure 6

Former Ponds

Soil sampling within the seven former pond areas in the northern exposure area included the collection of discrete soil samples at locations P-11 through P-17 (Figure 6).

Each of the soil sampling locations was selected in the field to be representative of the area in which it was located. Pond samples were collected at the approximate geometric center of each pond cell, where possible. The field personnel found it difficult to identify the perimeter of some ponds and did not attempt to locate the geometric centers precisely. In certain ponds, the center of the pond was inaccessible due to the presence of dense vegetation (e.g., sample P-15).

Non-Pond Areas

Outside of the pond areas, soil sampling consisted of the following. The locations of the identified samples are indicated on Figure 6.

- Two samples from the Beta Ditch (samples B-2 and B-3)
- Two samples from the area east of the Beta Ditch (samples E-1 and E-2), and
- One sample from the proposed "A" Street alignment (sample S-2).

At each location in the northern exposure area, samples were collected from the 0-to-1 foot and 4-to-5 foot depth intervals. The only exception was at location S-2, which was sampled as though it were a southern exposure area location (i.e., samples were collected at depth intervals of 0-1 feet, 10-12 feet, and directly above the water table). This error resulted from difficulty in locating the boundary between the northern and southern exposure areas in the field, due in part to regrading associated with installation of a water line in this area. Additional soil samples were collected from the interval directly above the water table at five locations (P-11, P-12, P-17, S-2, and E-2). A field duplicate soil sample (DUP-2) was collected from the 0-to-1 foot depth horizon at location P-17 to provide an indication of the precision of field samples. All borings and soil cores were logged by an ENVIRON field geologist in accordance with ASTM Standard D-2488 (ASTM 1990).

2. Soil Sampling (Southern Exposure Area)

Soil sampling in the southern exposure area (see Figure 6) included the collection of discrete soil samples within each of the ten former ponds (samples P-1 through P-10). As in the northern exposure area, each soil sampling location was selected in the field to be representative of the area in which it was located. Where possible, soil sampling points were located near the approximate geometric center of each former pond. Outside the pond areas, soil samples were collected from the Beta Ditch (sample B-1), the Alpha Ditch (samples A-1 and A-2), which traverses the Southern Exposure Area along the southeast corner, and the "A" Street alignment (sample S-1). Location S-1 is in an area where the soil has been disturbed due to installation of the water lateral and is considered to be a non-pond sample location.

At each location in the southern exposure area, soil borings were advanced to the water table with continuous soil cores collected from each boring. Where practical based on field conditions, ENVIRON advanced certain soil borings (P-1, P-7, P-8, A-1, and A-2) to the top of the Muddy Creek Formation to provide additional information regarding the thickness of alluvium. All borings and soil cores were logged by an ENVIRON field geologist in accordance with ASTM Standard D-2488 (ASTM 1990).

Samples to be analyzed for all chemical classes except VOCs were collected at approximately the 0-1 foot and 10-12 foot soil intervals, as well as the interval directly above the water table[2]. Soil samples were examined to determine the presence and likely extent of any capillary fringe overlying the water table to ensure that samples were collected from the lowest unsaturated horizon. Samples for VOC analysis were collected from the 0-to-1 foot horizon, the horizon directly above the water table, and at an intermediate depth that is coincident with the highest level recorded in the field with a PID, to ensure that the most heavily impacted interval was obtained. At locations where no PID detections were observed, the intermediate-depth VOC sample was collected from the 10-to-12 foot horizon. Based on the PID readings, samples for VOCs analysis were collected at intermediate depth intervals of 2-3 feet at P-7 and 12-12.5 feet at P-10. Field duplicates (DUP 1 and DUP 3) were collected from two locations at the 0-to-1 foot depth horizon in the southern exposure area, P-7 and P-5, respectively. A pair of samples was collected from the 18-20 foot depth interval at P-7; one of these was erroneously labeled as representing the 19-21 foot depth interval.

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[2] At location P-9, tool refusal and poor sample recovery associated with caliche prevented the collection of representative samples from the desired depth intervals. Samples were collected at this location from the 0-1 foot and 6-8 foot intervals.

3. Background Soil Sampling

Subsequent to the field sampling performed in May 2001, ENVIRON collected soil samples at eight locations selected to represent background conditions at the WRF expansion site. The details of this sampling effort and the resulting data are provided in Appendix E. The data from the soil samples collected at the WRF expansion site are compared to the background data set in Section B.5 of this chapter and also in the appendices.

4. Ground Water Sampling

ENVIRON attempted to collect ground water samples from nine existing ground water monitoring wells previously constructed on and adjacent to the WRF expansion site. Three of the nine wells were found to be dry, including wells B2-10 and B2-11 on the southern portion of the site and DM-4, adjacent to the southern boundary of the site. Thus, samples of ground water were collected from six locations, identified on Figure 6, including two wells in the southern exposure area (B2-8 and B2-14), two wells in the northern exposure area (PC-2 and PC-4), and two wells north of the site (wells PC-56[3] and PC-58). A field duplicate sample of ground water (DUP 6) was collected from well PC-56. The well purging and sampling logs and the well construction details for the six ground water monitoring wells that were sampled are presented in Appendix C.

B. Site Characterization Data Set

The samples described above were collected and analyzed to characterize conditions and support a risk assessment for the proposed expansion of the existing WRF. The use of the laboratory data to characterize conditions at the site is described in this section, which is supported by more complete tables, figures, and statistical analysis in Appendix D. The characteristics of the area in which the site is located are summarized in Chapter I of this report and described more completely in the references cited there.

The suite of analyses for each soil and ground water sample is summarized in Table 1, and a complete listing of the analytes determined by each laboratory method is provided in Appendix D as Table D-1. With the exception of the analysis of ground water samples for ferrous iron, which was performed by ENVIRON personnel in the field, the analyses listed in these tables were performed at off-site laboratories. All of the soil and ground water samples collected at the site were shipped to Severn Trent Laboratories, Inc. of Earth City, Missouri, but some of the analyses were performed at other laboratory locations. The laboratory reports for these analyses are presented as Adobe PDF files on the CD in Appendix D.

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[3] After completion of the site characterization, PC-56 was excluded from the risk assessment because it appears that this well is not downgradient of the WRF expansion site but is located in a separate alluvial channel west of the site.

TABLE 1
Analytical Summary Table

Parameters		Soil	Ground Water	Method
VOCs	*Plus 10 TICs*	X	X	8260
SVOCs	*Plus 20 TICs*	X	X	8270
Pesticides	Organochlorine	X	X	8081
	Organophosphorus	X	X	8141
PCBs		X	X	8082
Dioxins/Furans		X	X	8290
Perchlorate		X	X	314
Asbestos		X		PLM, Elutriator*
Cyanide		X	X	9010
Metals	Al, Fe, Zn	X	X	6010
	As, Sb, Be, Ba, Cd, Cr, Cu, Co, Pb, Mg, Mn, Mo, Ni, Se, Ag, Tl, Th, Ti, V	X	X	6020
	Chromium (VI)	X	X	7196
	Mercury	X	X	7471 (soil) 7470 (GW)
Radionuclides	Uranium-238	X	X	3050M/RP-725
	Thorium-234	X	X	3050M/RP-725
	Uranium-233/234	X	X	3050M/RP-725
	Thorium-230	X	X	3004M
	Radium 226	X	X	9315M
	Lead-214	X	X	HASL AM-02M
	Bismuth-214	X	X	HASL AM-02M
	Lead-210	X	X	HASL AM-02M
	Thorium-232	X	X	3004M/RP-725
	Radium-228	X	X	9320M
	Actinium-228	X	X	HASL AM-02M
	Thorium-228	X	X	3004M/RP-725
	Radium-224	X	X	HASL AM-02M
	Lead-212	X	X	HASL AM-02M
	Bismuth-212	X	X	HASL AM-02M
	Thallium-208	X	X	HASL AM-02M
	Uranium-235/236	X	X	3050M/RP-725
	Potassium-40	X	X	HASL AM-02M
	Cesium-137		X	HASL AM-02M
Physical/ Chemical Indicators	CEC	X		9081
	TOC	X		USEPA 9060
	Dry Bulk Density	X		ASTM D1188
	Bulk Density	X		ASTM D3550
	Soil Moisture	X		ASTM D2216-98
	Grain size	X		ASTM D422

TABLE 1
Analytical Summary Table

Parameters		Soil	Ground Water	Method
Physical/ Chemical Indicators	Total Dissolved Solids		X	160.1
	Specific Conductance		X	120
	Turbidity		X	180
	PH		X	150
	Hardness		X	130
	Alkalinity		X	310
	Cations (Ca, Mg, Na,K)		X	6010
	Anions (Cl, F, NO3, PO4, SO4)		X	300
	Ferrous Fe		X	Hach Kit

Note:
* - ENVIRON had contracted with the laboratory to analyze the soil samples for asbestos using transmission electron microscopy (TEM). The laboratory, however, analyzed the soil samples using a polarized light microscopy (PLM) method. All of the samples were non-detect using this method. To corroborate these results, NDEP requested that ENVIRON collect additional asbestos data and perform a more refined analysis using the elutriator methodology, as discussed in Section B.3 of Chapter II.

At the request of NDEP, ENVIRON collected a second set of soil samples at the WRF site on October 18, 2002. These samples were collected to provide additional information regarding the amounts of releasable asbestos in the surface soils at the WRF expansion site. Analysis of these samples is discussed in Section B.3 of this chapter.

1. Development of the Chemical Data Base

The chemical data received from the laboratory were compiled into a single data base that was used to characterize chemical conditions at the site. The chemical data base includes results of the analysis of 7 ground water samples and 74 soil samples (including field duplicates) for more than 200 chemical constituents. The complete chemical data base includes all of the chemical data reported by the laboratory, including results obtained by analyzing quality control samples (laboratory blanks and duplicates as well as blanks and duplicates submitted from the field). The results of the physical and chemical indicator analyses listed at the end of Table 1 are not included in the chemical data base, but are discussed separately in the next section (B.2) of this chapter. The complete chemical data base is provided in an electronic form as an Excel file on the CD in Appendix D. A printed copy of the chemical data base for ground water and soil is provided as Tables D-8 and D-9, respectively, in Appendix D. The printed copy includes only the data that were used to characterize conditions at the WRF expansion site; for clarity, the data from the laboratory's QC analyses are not printed.

In addition to the analytes listed in Table D-1, the laboratory reported data for a number of tentatively identified compounds (TICs) associated with the analyses for volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs). Because both the identification and quantitation of these chemicals is uncertain, the TIC data are not included in the chemical data base. The TICs are tabulated and discussed in more detail in the uncertainties section (Chapter IX) of this report.

The samples were analyzed for radionuclides from the uranium-238 and thorium-232 decay chains, as well as for potassium-40, uranium-235/236 (combined), and cesium-137 (ground water only). The two decay chains, which are illustrated by figures provided in Appendix D, include a number of other radionuclides that are not measured directly by the laboratory methods used in this investigation. In conducting this risk assessment, the activity of each of these unmeasured decay products in each sample was estimated by assuming that the decay product was in secular equilibrium with its parent isotope. This assumption, which is very commonly used, is appropriate because the half-lives of the unmeasured decay products are much shorter than those of the parent isotopes and because the samples represent wastes that are several years old (giving time for any artificially enriched decay product that was not directly measured to decay away).

Because they were not measured directly, the activities of the unmeasured decay products are not reported in the chemical data base. In addition, the activity of uranium-235 has been assumed in this report to equal the combined uranium-235/236 measurement. This assumption is made because the concentration of uranium-236 present in natural uranium is extremely low compared to the uranium-235 concentration.

The chemical data were reviewed and qualified by the laboratory in a manner consistent with the laboratory's standard operating procedures (SOPs). These procedures resulted in the classification of each sample concentration as either non-qualified (i.e., the identity and concentration of the constituent are validated) or qualified (i.e., the concentration or identity of the constituent may not be reliable under certain circumstances discussed in the bullets below). The qualifiers (or "flags") that were assigned by the laboratory include:

- a U-qualifier, which indicates the chemical was not detected at the method detection limit (MDL).

- a B-qualifier applied to data for organic chemicals to indicate that the result is qualitatively invalid because the analyte was also detected in a laboratory method blank.

- a J-qualifier applied to data for organic chemicals to indicate that the reported concentration is higher than the MDL but below the reporting limit (RL). The laboratory's reporting limit is analogous to the sample quantitation limit (SQL) described by the USEPA in *Risk Assessment Guidance for Superfund* (USEPA 1989).

- a B-qualifier applied to data for inorganic chemicals to indicate that the reported concentration is higher than the MDL but below the RL. When applied to data for inorganic chemicals, the B-flag indicates that the concentration is estimated; it corresponds to the J-flag applied to data for organic chemicals.

- a CON-qualifier[4], which indicates that the data were obtained by a laboratory confirmation analysis.

[4] This qualifier is only applied to select 2,3,7,8-TCDF results. Duplicate results for confirmatory samples are not presented in the laboratory data reports.

- a Q-qualifier[5], which indicates an elevated reporting limit due to high analyte levels.

The electronic chemical data base provided on CD includes the flags as reported by the laboratory. With the following exceptions, the printed form of the data base provided in Appendix D (Tables D-8 and D-9) matches the electronic form provided on CD:

- Results from analysis of laboratory-generated quality control samples (including method blanks, duplicate analyses, and check samples) were not used to characterize the soil and ground water conditions beneath the WRF site. Therefore, these data were not printed in Tables D-8 and D-9.

- Concentrations marked by the laboratory with a U-flag, indicating that the analyte was not detected above the applicable method detection limit, are printed as "ND" (for non-detect) followed by the MDL and a U-flag.

- Data for inorganic chemicals marked by the laboratory with a B-flag to indicate that the concentrations were estimated are printed with a J-flag in Appendix D. This step was taken to avoid confusion regarding the meaning of the B-flags.

- The laboratory reported thorium-232 results based on (1) a daughter product analysis (reported as Thorium 232DA) and (2) a direct analysis (reported as Thorium-232). Both results appear in the electronic data base, but only the results based on the direct analysis of thorium 232 are printed in Tables D-8 and D-9.

In preparation for the risk assessment, ENVIRON reviewed the data and documentation in more detail. This review is the basis for the data usability analysis that is presented in Appendix F and discussed in Section C of this chapter.

2. Summary of Physical and Indicator Chemical Data

The data obtained by analyzing the soil samples for the physical and indicator chemical parameters listed at the end of Table 1 are summarized in Table 2. A listing of the data for each sample is provided as Table D-2 in Appendix D. Because these analyses include bulk density, they are only meaningful when performed on undisturbed cores.

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[5] This qualifier is only applied to select perchlorate results.

Table 2
Summary of Physical and Chemical Indicator Parameters
Measured in Soil Samples[1]

Physical Parameter	Units	Minimum	Maximum	Average
Bulk Density	Lbs/ft^3	72.0	142.8	110.8
Dry Bulk Density	Lbs/ft^3	66.9	136.2	101.5
Moisture Content	Percent	2.0	39.0	8.8
Total Organic Carbon	mg/kg	313	>44,200	6,504
Cation Exchange Capacity	MEQ/100g	1.0	26.0	9.1
% Sand and Gravel	Percent	47.1	90.9	80.8
% Silt	Percent	6.7	47.1	15.9
% Clay	Percent	<1.2	7.3	3.4

Notes:
1 – ENVIRON was not able to obtain undisturbed soil cores and/or bulk samples at all depth intervals during the May 2001 field characterization program. Therefore, physical and indicator chemical data are available for 66 of the 74 total soil samples.
2 – The percent clay was estimated from the grain-size analysis and hydrometer data for each sample.
MEQ – milli-equivalents.

The nature of the soils encountered at some locations prevented collection of undisturbed cores, so the physical and indicator chemical analyses were performed on 66 samples (including one field duplicate). In both tables, the grain size distribution is characterized as the percentage of soil particles in each of three grain-size categories (sand and gravel, silt, and clay). The grain size distribution reports obtained from the laboratory (which are included on the CD in Appendix D) do not list a percentage for the specific grain size (2 microns) that distinguishes silt from clay. Therefore, the percentages of clay reported in ENVIRON's tables were estimated from the available hydrometer data.

The data presented in Table D-2 were collected to provide a more complete characterization of the soils and to provide information that may be needed for site-specific modeling related to exposure to vapors (e.g., the Johnson and Ettinger model) and migration to ground water. The data indicate that the soils at the WRF expansion site are generally classified as loamy sands using the USDA soil texture classification system. This is consistent with the descriptions of the native soils provided in the *Soil Survey of the Las Vegas Valley Area, Nevada* (USDA, Soil Conservation Service, undated).

The laboratory reports for the indicator chemical analyses conducted on the ground water samples are summarized in Table 3, and the results for the individual samples are provided in Table D-3 (Appendix D). As noted previously, the ferrous iron measurements were performed in the field, not by the laboratory; ferrous iron was not detected in any of the ground water samples. The quality of the ground water data is evaluated in Appendix F.

3. Asbestos

All of the soil samples collected by ENVIRON during the May 2001 site characterization program were analyzed for asbestos content by EMSL Analytical, Inc. of Westmont, New Jersey (EMSL Analytical). ENVIRON had contracted with EMSL Analytical to analyze the soil samples for asbestos using transmission electron microscopy (TEM) methods as specified in USEPA Method 600/R-93/116. EMSL Analytical, however, analyzed the soil samples using a polarized light microscopy (PLM) method identified by the laboratory as "EPA Protocol for Screening Soil and Sediment Samples for Asbestos Content Used by USEPA Region 1 Laboratory (Rev May 24, 1994) Modified by EMSL (September 1999)." All of the results of the asbestos analyses were reported as "none detected" without a method detection limit or reporting limit. According to EMSL Analytical, the method involves counting the number of asbestos fibers observed on a standard grid and determining the volume of each fiber. A standard density is used to convert the asbestos volume to mass, and the analytical results are

TABLE 3
Summary of Chemical Indicator Parameters
Measured in Ground Water Samples

Parameter	Units	Minimum	Maximum	Average
TDS	mg/L	204	9,440	6,125
Conductivity	Umhos/cm	9,610	12,600	10,670
Turbidity	NTU	< 0.42	1,330	< 207.88
PH	std units	6.9	7.7	7.5
Hardness	mg/L	3,150	36,000	8,186
Alkalinity	mg/L	66	198	119
Chloride	mg/L	8.1	2,830	1,701.2
Fluoride	mg/L	0.13	1.1	0.39
Nitrate	mg/L	9.2	39.4	20.6
Phosphate (as P)	mg/L	< 1.8	< 3.5	< 2.0
Sulfate	mg/L	570	3,870	2,254
Calcium	mg/L	518	749	647
Magnesium	mg/L	269	570	353
Potassium	mg/L	33	108	66
Sodium	mg/L	861	1,390	1,094
Ferrous Fe[1]	mg/L	ND	ND	ND

Notes:
Based on data from 7 ground water samples, including one field duplicate.
The quality of the ground water data is evaluated in Appendix F.
TDS - Total dissolved solids
1 - Ferrous iron was measured in the field but was not detected (ND)

reported as percent asbestos by weight. The method has a minimum detection limit of one fiber, and the standard reporting limit for this analysis is 0.1 percent asbestos. The laboratory reports for the asbestos analysis using the PLM-based method are provided on the CD in Appendix D.

Although the conventional PLM-based analytical method used for the soil samples has historically been relied upon by USEPA to evaluate potential exposure to asbestos, this analytical method is best suited as a screening method for determining the presence or absence of asbestos in soil (USEPA Region 1, 1997). Because the results of the PLM analyses were all non-detect, ENVIRON was not able to perform a meaningful risk assessment for exposure to asbestos in soils at the WRF expansion site. In September 2002, NDEP requested that ENVIRON collect additional asbestos data that would allow more accurate characterization of asbestos levels and estimated risks at the site, in order to corroborate the results of the PLM analysis. The methods used in the asbestos risk assessment are described in *Methodology for Conducting Risk Assessments at Asbestos Superfund Sites – Part 1: Protocol* (Berman and Crump 1999). Use of this risk assessment method requires estimation of the amount of releasable asbestos in the soil by analytical methods described in *Modified Elutriator Method for the Determination of Asbestos in Soils and Bulk Material* (Berman and Kolk 2000). The analytical method described by Berman and Kolk is referred to herein as the "elutriator method."

ENVIRON collected additional samples from the WRF expansion site on October 18, 2002. One grab sample of surface soil was collected at or near[6] each of the 26 previously sampled locations. Great care was taken to excavate the same volume of material at each sampling location. The soil was excavated using a decontaminated stainless steel trowel to form a hole that was 7.5 inches square and 3 inches deep. All of the material excavated at each location was processed through a 3/8-inch (9.5 mm) sieve in the field; ENVIRON field personnel used gloved hands to break up any friable particles. Both size fractions (fine and coarse) were collected in large Ziploc bags and weighed on a spring scale. The coarse fraction of each sample (i.e., the material retained on the 3/8-inch sieve) was discarded in the field. The fine material collected at each location was labeled, double-bagged, and shipped to an off-site laboratory by express courier under chain-of-custody procedures. Sampling equipment and sieves were cleaned between sampling locations by wiping with paper towels and dry brushing to remove all visible particles.

[6] In a few cases, the precise location used in the May 2001 sampling event could not be identified with certainty in the field in October 2002. The October 2002 sampling locations represent the best professional judgment of the field personnel regarding the locations sampled in May 2001.

The grab samples of fine material were composited and analyzed by the elutriator method at EMS Laboratories in Pasadena, California. This work was performed under the direction of Anthony Kolk, the co-author of the publication that describes the elutriator method (Berman and Kolk 2000). Each grab sample was weighed and homogenized, then split into two subsamples before further processing. One subsample of each grab sample was archived for possible future analyses; the other was used to form composite samples.

Seven composite samples were formed at the laboratory from the homogenized grab samples of fine material. The final compositing plan was developed during a series of telephone calls in November 2002. Wayne Berman (of Aeolus, Inc.) and Paul Black (of Neptune and Company, Inc.) represented the NDEP in these discussions; the City of Henderson was represented by Mark Hawley of ENVIRON. By mutual agreement, the grab samples were grouped on the basis of exposure area (northern and southern) and previous land use (ponds, ditches, and other) and assigned to seven composite samples. Sample S-1 was not assigned to a composite because it does not appear to represent a significant portion of either exposure area. This sample was collected at a location between one of the former ponds (UR-1 in Figure 3) and the adjacent Beta ditch. The soils at this location were disturbed by road building activity after the site characterization sampling event (May 2001) but before the October 18, 2002 sampling event.

Each composite sample was formed, homogenized, and processed with the elutriator using the methods described by Berman and Kolk (2000). Each of the seven composite samples includes portions of from two to five grab samples collected from the same exposure area and land use category. The amount of each grab sample included in each composite is proportional to the normalized weight percent of fine material excavated at each sampling location. The proportions used in preparing the composite samples are shown in Table 1 of the EMS laboratory report, which is provided in Appendix P.

As explained in the laboratory report, operation of the elutriator produces air filters that retain samples of the dust generated by agitating the soils. For each composite sample, three filters were prepared and one filter was examined using transmission electron microscopy (TEM). For each filter examined, the number of grid openings counted was sufficient to achieve an analytical sensitivity of 1×10^6 structures per gram of dust. Although the sensitivity of the methods cannot be compared directly,

calculations[7] suggest that the elutriator analysis is much more sensitive to the presence of asbestos than the earlier PLM analysis. When structures with dimensions that qualified them as possible asbestos fibers were found, their composition and characteristics were determined by energy-dispersive X-ray and electron diffraction methods. The data obtained by the laboratory analyses are summarized in Table 2 of the EMS laboratory report in Appendix P.

4. Overview of the Chemical Data

Tag maps that show the concentrations of the chemicals detected in soil or ground water at each sampling location are provided in Appendix D. The six tag maps provide an overview of the sampling results from the May 2001 site characterization program for:

- Chemicals in soil that are the greatest contributors to total risk at the site;
- Metals detected in soil;
- Measured radionuclides in soil;
- Dioxins and furans in soil;
- Perchlorate and pesticides detected in soil; and
- Chemicals detected in ground water.

On each tag map, the analytical results for all soil depths sampled during the site characterization program are provided in a table ("tag") associated with each sampling location. No tag map was produced for VOCs and SVOCs in soils because they were not included in the final risk calculations. With one exception, the data are presented as they appear in the printed version of the chemical data base (i.e., flagged with the data qualifiers used by ENVIRON and with the field duplicates reported separately). The exception is that in preparation for the risk assessment, the concentrations of the 17 dioxin/furan congeners were used to generate a single dioxin value (the toxicity equivalent, or TEQ) for each soil sample by the method described in section B.1 of Chapter VI of this report. The TEQ value for each sample is reported on the tag maps along with the concentrations for the 17 congeners.

Additional discussion of the results of the site characterization is provided in the following sections, including a comparison with soil and ground water benchmarks (e.g.,

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[7] Under the Berman and Crump (1999) methodology, the smallest asbestos structure of concern is 5 μm long and no more than 1 μm in diameter, with a mass of approximately 1×10^{-5} μg. At the stated sensitivity of 1×10^{6} structures/g of dust, the mass of asbestos would be about 10 μg/g of dust if all of the structures were of the minimum size. This corresponds to 0.001 percent of the mass of the dust. The detection limit of the PLM analysis was reported as approximately 0.1 percent by weight. This indicates that the elutriator analysis is much more sensitive to the presence of asbestos than the earlier PLM analysis.

USEPA Region 9 Preliminary Remediation Goals), a statistical analysis of the data set, and an analysis of potential hot spots.

a. Soils

In total, 83 of the chemicals for which the soil samples were analyzed were detected in at least one sample. The detected chemicals include 7 VOCs, 3 SVOCs, 23 metals, 17 dioxin/furan congeners, 14 pesticides, perchlorate, and 18 radionuclides. The results obtained for the chemicals detected in soils are summarized and compared to a set of risk-based benchmarks in Table 4. For each chemical, this table lists the number of soil samples analyzed (including field duplicates), the number of and percentage of detections, the ranges of concentrations and MDLs reported by the laboratory, and a benchmark concentration. An expanded table that provides the same information for all chemicals (including those that were not detected in any of the soil samples) is provided in Appendix D as Table D-4.

The benchmarks used in these tables are the preliminary remediation goals (PRGs) established by USEPA Region 9 for exposure to soils in industrial scenarios. Industrial PRGs have not been established for some of the detected chemicals. The other available benchmarks for these chemicals, including those provided by the USEPA in *Soil Screening Guidance for Radionuclides: User's Guide* (USEPA 2000b), were developed for residential exposure scenarios and are not considered appropriate for the WRF expansion site. As shown in Table 4, arsenic is the only chemical found in soils at the WRF expansion site at levels that exceed the industrial PRGs. None of the MDLs reported for any of the chemicals (including those that were not detected) exceeded the industrial PRGs.

b. Ground Water

Table 5 provides a summary of the results obtained by chemical analysis of the ground water samples, along with benchmarks. The chemicals detected in ground water include 5 VOCs, 1 SVOC, 21 metals, 2 pesticides, perchlorate, total cyanide, and 9 radionuclides. Table 5 addresses each of the chemicals that was detected in at least one of the ground water samples. This table lists the number of ground water samples analyzed (including field duplicates), the number of and percentage of detections, the

TABLE 4
Summary of Sampling Data for Chemicals in Soil

Chemical	Units	# of Samples*	# of Detects	% of Samples with Detect	Maximum Detect	Minimum Detect	Maximum MDL for Nondetects	Minimum MDL for Nondetects	Region 9 Industrial Soil PRG	# of Detects Exceeding Benchmarks	# of MDLs Exceeding Benchmarks
VOCs and SVOCs											
Acetone	ug/kg	74	71	96	31	2.8	3	2.8	6000000	0	0
Chloroform	ug/kg	74	4	5	21	2.5	0.32	0.24	12000	0	0
Ethylbenzene	ug/kg	74	1	1	1.2	1.2	1.5	0.89	20000	0	0
Methylene chloride	ug/kg	74	28	38	17	1.1	0.77	0.53	21000	0	0
Tetrachloroethene	ug/kg	74	2	3	4.5	2	0.48	0.36	3400	0	0
Toluene	ug/kg	74	4	5	3.7	1.4	0.89	0.54	520000	0	0
Xylenes (total)	ug/kg	74	3	4	3.9	1.8	1.8	1.1	420000	0	0
Butyl benzyl phthalate	ug/kg	74	1	1	80	80	44	28	100000000	0	0
Di-n-butyl phthalate	ug/kg	74	1	1	130	130	100	63	62000000	0	0
Phenol	ug/kg	74	1	1	120	120	97	60	100000000	0	0
Metals											
Aluminum	mg/kg	74	74	100	19000	5260			100000	0	0
Antimony	mg/kg	74	1	1	1.3	1.3	0.26	0.16	410	0	0
Arsenic	mg/kg	74	74	100	35.9	1.3			2	62	0
Barium	mg/kg	74	74	100	1100	26.4			67000	0	0
Beryllium	mg/kg	74	74	100	0.93	0.27			1900	0	0
Cadmium	mg/kg	74	74	100	0.43	0.033			450	0	0
Chromium (total)	mg/kg	74	74	100	36.3	4.2			450	0	0
Cobalt	mg/kg	74	74	100	10	2.6			1900	0	0
Copper	mg/kg	74	74	100	43.1	8.5			41000	0	0
Iron	mg/kg	74	74	100	25500	7180			100000	0	0
Lead	mg/kg	74	74	100	379	4.3			750	0	0
Magnesium	mg/kg	74	74	100	79500	4270				0	0
Manganese	mg/kg	74	74	100	2030	132			19000	0	0
Mercury	mg/kg	74	46	62	0.096	0.0077	0.011	0.0072	310	0	0
Molybdenum	mg/kg	74	74	100	7.2	0.12			5100	0	0
Nickel	mg/kg	74	74	100	18.2	5.4			20000	0	0
Selenium	mg/kg	74	74	100	2.5	0.13			5100	0	0
Silver	mg/kg	74	74	100	0.67	0.053			5100	0	0
Thallium	mg/kg	74	74	100	1.1	0.03			67	0	0
Thorium	mg/kg	74	74	100	10.4	3.7				0	0
Titanium	mg/kg	74	74	100	1500	233				0	0
Vanadium	mg/kg	74	74	100	57.5	18.4			7200	0	0
Zinc	mg/kg	74	74	100	108	19.1			100000	0	0

TABLE 4
Summary of Sampling Data for Chemicals in Soil

Chemical	Units	# of Samples*	# of Detects	% of Samples with Detect	Maximum Detect	Minimum Detect	Maximum MDL for Nondetects	Minimum MDL for Nondetects	Region 9 Industrial Soil PRG	# of Detects Exceeding Benchmarks	# of MDLs Exceeding Benchmarks
Dioxins/Furans											
1,2,3,4,6,7,8-HpCDD	pg/g	74	10	14	50	3	2.7	0.25		0	0
1,2,3,4,6,7,8-HpCDF	pg/g	74	17	23	320	3.7	2.4	0.2		0	0
1,2,3,4,7,8,9-HpCDF	pg/g	74	12	16	160	3.1	2.8	0.18		0	0
1,2,3,4,7,8-HxCDD	pg/g	74	1	1	3.6	3.6	1.5	0.16		0	0
1,2,3,4,7,8-HxCDF	pg/g	74	14	19	170	2.8	2.8	0.15		0	0
1,2,3,6,7,8-HxCDD	pg/g	74	3	4	10	3.4	2.1	0.22		0	0
1,2,3,6,7,8-HxCDF	pg/g	74	12	16	110	3.1	2.8	0.12		0	0
1,2,3,7,8,9-HxCDD	pg/g	74	3	4	8.9	3.1	1.7	0.23		0	0
1,2,3,7,8,9-HxCDF	pg/g	74	3	4	20	3.4	2.3	0.15		0	0
1,2,3,7,8-PeCDD	pg/g	74	1	1	6.4	6.4	1.5	0.29		0	0
1,2,3,7,8-PeCDF	pg/g	74	11	15	85	2.9	2.7	0.19		0	0
2,3,4,6,7,8-HxCDF	pg/g	74	5	7	28	2.8	2.6	0.14		0	0
2,3,4,7,8-PeCDF	pg/g	74	7	9	45	4	2.6	0.19		0	0
2,3,7,8-TCDD	pg/g	74	1	1	2.1	2.1	0.72	0.17	16	0	0
2,3,7,8-TCDF	pg/g	74	16	22	51	0.56	0.83	0.12		0	0
Dioxins/Furans TEQ**	pg/g	72	72	100	81.7	0.33614				0	0
OCDD	pg/g	74	24	32	200	5.5	5.4	0.56		0	0
OCDF	pg/g	74	22	30	4000	5.9	4.9	0.65		0	0
Pesticides											
4,4'-DDD	ug/kg	74	2	3	3.4	2.2	6.7	0.65	10000	0	0
4,4'-DDE	ug/kg	74	10	14	150	2.1	1.4	0.9	7000	0	0
4,4'-DDT	ug/kg	74	9	12	69	1.8	7.4	0.71	7000	0	0
alpha-Chlordane	ug/kg	74	1	1	12	4.7	4.7	0.46	6500	0	0
beta-BHC	ug/kg	74	8	11	20	2.8	7.5	0.73	1300	0	0
Dieldrin	ug/kg	74	3	4	4.3	1.9	6.1	0.59	110	0	0
Endosulfan II	ug/kg	74	1	1	6	4.4	6.6	0.64	3700000	0	0
Endosulfan sulfate	ug/kg	74	1	1	8.7	8.7	5.6	0.54	3700000	0	0
Endrin	ug/kg	74	1	1	21	5.9	5.9	0.57	180000	0	0
Endrin aldehyde	ug/kg	74	2	3	13	2.5	12	1.2	180000	0	0
Endrin ketone	ug/kg	74	1	1	2.8	2.8	5.6	0.54	180000	0	0
gamma-Chlordane	ug/kg	74	1	1	8.1	4.2	10	0.98	6500	0	0
Heptachlor epoxide	ug/kg	74	2	3	5.5	2.7	4.9	0.48	190	0	0
Methoxychlor	ug/kg	74	2	3	27	6.9	14	1.3	3100000	0	0

TABLE 4
Summary of Sampling Data for Chemicals in Soil

Chemical	Units	# of Samples*	# of Detects	% of Samples with Detect	Maximum Detect	Minimum Detect	Maximum MDL for Nondetects	Minimum MDL for Nondetects	Region 9 Industrial Soil PRG	# of Detects Exceeding Benchmarks	# of MDLs Exceeding Benchmarks
Other* **											
Perchlorate	ug/kg	74	72	97	59900	34.5	21.1	20.8	100000	0	0
Radionuclides											
Uranium 238	pCi/g	74	74	100	4.45	0.58				0	0
Thorium 234	pCi/g	74	33	45	4.5	1.14	2.6	0.9		0	0
Uranium 234	pCi/g	74	74	100	4.6	0.6				0	0
Thorium 230	pCi/g	74	74	100	4.6	0.8				0	0
Radium 226	pCi/g	73	60	82	4	0.38	0.39	0.23		0	0
Lead 214	pCi/g	74	74	100	4.7	0.56				0	0
Bismuth 214	pCi/g	74	74	100	4.43	0.6				0	0
Lead 210	pCi/g	74	22	30	6.9	2.1	3.6	1.2		0	0
Thorium 232	pCi/g	74	74	100	1.79	0.78				0	0
Radium 228	pCi/g	74	74	100	3.00	0.74				0	0
Actinium 228	pCi/g	74	70	95	2	0.8	1	0.79		0	0
Thorium 228	pCi/g	74	74	100	1.82	0.61				0	0
Radium 224	pCi/g	74	63	85	9.6	2	2.9	2.1		0	0
Lead 212	pCi/g	74	74	100	1.52	0.67				0	0
Bismuth 212	pCi/g	74	18	24	2.7	1.97	3.4	1.8		0	0
Thallium 208	pCi/g	74	73	99	0.59	0.23	0.3	0.3		0	0
Potassium 40	pCi/g	74	74	100	31	15.5				0	0
Uranium 235	pCi/g	74	41	55	0.21	0.048	0.19	0.042		0	0

Notes:
* - Number of samples includes field duplicates
** - The method used to calculate TEQs is discussed in Section B.1 of Chapter VI.
*** - Asbestos in soil was analyzed for using the PLM method. Every sample was indicated as "none detected" (approximate detection limit of 0.1 %). ENVIRON is in the process of conducting additional analyses for asbestos using a refined method.

TABLE 5
Summary of Sampling Data for Chemicals Detected in Ground Water

Chemical	Units	# of Samples	# of Detects	% of Samples with Detect	Maximum Detect	Minimum Detect	Maximum MDL for Nondetects	Minimum MDL for Nondetects	Benchmarks				# of Detects Exceeding Benchmarks	# of NDs with MDLs Exceeding Benchmarks
									MCL	Freshwater AWQC[a]	Region 9 Tap Water PRG	Other		
VOCs and SVOCs														
Acetone	ug/L	6	3	50	3	2.7	2.6	2.6			610			
Carbon tetrachloride	ug/L	6	2	33	1.6	1.1	0.65	0.65	5		0.17		2	4
Chloroform	ug/L	6	4	67	150	19	0.24	0.24	80[b]		6.2		4	
Tetrachloroethene	ug/L	6	2	33	3.3	1	0.36	0.36	5		0.66		2	
Toluene	ug/L	6	1	17	0.72	0.72	0.54	0.54	1000		720			
bis(2-Ethylhexyl)phthalate	ug/L	7	1	14	2.7	2.7	1.3	1.3			4.8			
Metals														
Aluminum	ug/L	7	7	100	82600	58.2				87[c]	36000	50-200[d]	7	6
Arsenic	ug/L	7	6	86	142	55.9	0.22	0.22	10	150	0.045		6	1
Barium	ug/L	7	6	86	1150	12.1	2	2	2000		2600			
Beryllium	ug/L	7	1	14	5.1	5.1	0.1	0.1	4		73		1	
Cadmium	ug/L	7	6	86	3.5	0.5	0.12	0.12	5	57[e]	18			
Chromium (hexavalent)	ug/L	7	4	57	97.3	66	4.5	4.5		11	110		4	
Chromium (total)	ug/L	7	7	100	85	0.73			100	2733[e]	55000[f]			
Cobalt	ug/L	7	7	100	0.37	0.02					730			
Copper	ug/L	7	1	14	71.9	71.9	19.5	19.5		386[e]	1500	1000[d], 1300[g]		
Iron	ug/L	7	7	100	68500	99.9				1000	11000	300[d]	4	
Lead	ug/L	7	3	43	37	0.52	0.43	0.43		129[e]		15[g]	1	
Magnesium	ug/L	7	7	100	570000	269000								
Manganese	ug/L	7	7	100	1130	0.34					880	50[d]	3	
Molybdenum	ug/L	7	6	86	824	83.4	2	2			180		4	
Nickel	ug/L	7	6	86	63.6	19.4	2	2		2160[e]	730[h]			
Selenium	ug/L	7	6	86	128	7.3	0.4	0.4	50	5	180		6	
Silver	ug/L	7	4	57	1.1	0.065	0.062	0.062			180	100[d]		
Thorium	ug/L	7	1	14	24.1	24.1	0.96	0.96						
Titanium	ug/L	7	7	100	1830	1.2								
Vanadium	ug/L	7	7	100	158	0.16					260			
Zinc	ug/L	7	5	71	262	5.6	4.2	4.2		4938[e]	11000	5000[d]		
Pesticides														
alpha-BHC	ug/L	7	2	29	0.27	0.24	0.02	0.02			0.011		2	5
beta-BHC	ug/L	7	2	29	0.1	0.096	0.02	0.02			0.037		2	
Other														
Perchlorate	ug/L	7	7	100	256000	5250					3.6	18[i]	7	
Total Cyanide	ug/L	7	1	14	2.9	2.9	2.5	2.5	200	5.2	720			

TABLE 5
Summary of Sampling Data for Chemicals Detected in Ground Water

Chemical	Units	# of Samples	# of Detects	% of Samples with Detect	Maximum Detect	Minimum Detect	Maximum MDL for Nondetects	Minimum MDL for Nondetects	Benchmarks				# of Detects Exceeding Benchmarks	# of NDs with MDLs Exceeding Benchmarks
									MCL	Freshwater AWQC[a]	Region 9 Tap Water PRG	Other		
Radionuclides														
Lead 210	pCi/L	7	1	14	260	260	230	170						6
Radium 226	pCi/L	7	7	100	1.61	0.32	0.29	0.27	5[j]				5	
Radium 228	pCi/L	7	3	43	4.7	0.77	1.2	0.88		15[l]				7
Thorium 228	pCi/L	7	2	29	1.93	0.32	0.6	0.36						
Thorium 230	pCi/L	7	7	100	7.5	0.74								
Thorium 232	pCi/L	7	3	43	2.1	0.14	0.44	0.2						
Uranium 234	pCi/L	7	7	100	33.3	6.4			20[k]				3	
Uranium 235	pCi/L	7	7	100	1.54	0.36								
Uranium 238	pCi/L	7	7	100	22	4.7								

Notes:
This tables includes data from all wells sampled during the site characterization program, including well PC-56, which is not included in the risk assessment because this well is not downgradient of the WRF expansion site.
Thus, the exposure point concentrations in ground water that were used in the risk assessment (Table 21) do not rely on the data from mnoitoring well PC-56.
A blank space indicates that a value was not identified
a - EPA National Recommended Water Quality Criteria for freshwater aquatic life (continuous concentration)
b - Total for trihalomethanes
c - when pH is between 6.5 and 9
d - Secondary MCL
e - Adjusted for average site water hardness of 8,186 mg/L
f - PRG for chromium III
g - EPA action level
h - For nickel soluble salts
i - Cal DHS/Cal EPA and state of Nevada recommended action level; USEPA is currently considering a revised draft refernce dose with a drinking water equivivent of 1 µg/L
j - MCL is for combined radium 226 + 228
k - Proposed MCL - the current MCL for total uranium is 30 µg/L
l - MCL value for adjusted gross alpha which includes the sum of Pb-210, Ra-226, Ra-228, Th-228, Th-230, and Th-232 activities

ranges of concentrations and MDLs reported by the laboratory, and the benchmark concentrations. An expanded table that provides the data obtained from each sample (including a field duplicate sample) is provided in Appendix D as Table D-5.

The ground water benchmarks listed in Table 5 include the primary and secondary drinking water standards, Region 9 tap water PRGs, and freshwater ambient water quality criteria. As shown in the table, these benchmarks are exceeded by the reported concentrations of several chemicals including 3 VOCs, 9 metals, 2 pesticides, and perchlorate. The three benchmarks for radionuclides, which are not specific to individual isotopes, are also exceeded. Note that USEPA has proposed a revised reference dose for perchlorate that, if adopted, will likely result in a risk-based benchmark lower than the current level of 18 μg/L.

The ground water data obtained for the WRF expansion project will be considered in more detail at a later date in conjunction with a regional characterization of ground water conditions. Wide-spread contamination of the shallow ground water aquifer has previously been shown in the area of the WRF expansion property (Kerr-McGee 2001). It is believed that much of the contamination is associated with sources upgradient of the WRF expansion site, including the BMI Complex.

5. Evaluation of Chemical Data from Soil Samples

The chemical data obtained from the soil samples collected at the WRF expansion site were evaluated using maps (bubble plots) and statistical analysis to characterize the site. These supporting materials are provided in Appendix D. These data were also compared to the data obtained from the background soil sampling described in Appendix E. The analyses were prepared using a data set in which non-detects are represented by concentrations set equal to half of the MDL reported by the laboratory, and field duplicates are averaged to provide a single concentration for each sampling location and depth.

a. Preparation of the Soils Data Set

The data set used in statistical analysis of the soils data was developed from the chemical data base using the following protocols:

- Data flagged as estimated by the laboratory (i.e., organic chemical data marked with a J-flag and inorganic chemical data marked with a B-flag) and data marked with a CON-flag or a Q-flag were treated as unqualified data.

- Data marked by the laboratory with a U-flag (i.e., as non-detects) were represented by one-half the MDL reported by the laboratory.

- Data for organic chemicals marked with a B-qualifier by the laboratory were evaluated using the protocol prescribed by the USEPA in *Risk Assessment Guidance for Superfund* (USEPA 1989). Because none of the B-flagged data for organic chemicals exceeded the limits set in the USEPA protocol, these data were treated as non-detects and represented by one-half the MDL reported by the laboratory.

- Radionuclide activity results reported as negative numbers were treated as non-detects and represented by one-half the MDL reported by the laboratory.

- Only the activity data obtained from the direct measurements was used for thorium 232. The data from the decay product analysis (reported as Thorium 232DA) were not evaluated.

Representative concentrations for the sample locations represented by field duplicates were calculated as follows:

- When an analyte was detected in both duplicate samples, the average of the reported concentrations (or activities) for that analyte was used.

- When an analyte was detected in only one of the two duplicate samples, the concentration (or activity) reported for that sample was used. The non-detect result is not reflected in the value used to represent the duplicate sampling location.

- If both reported results were non-detects, the MDLs were averaged and one-half of the resulting value was used to represent the analyte concentration (or activity) at the duplicate sampling location.

Field duplicate samples were collected at sample locations P-5 (0-1') (DUP 3); P-7 (0-1') (DUP 1); and P-17 (0-1') (DUP 2). In addition, samples identified as P-7 (18-20') and P-7 (19-21') were incorrectly labeled in the field and actually represent the same sampling location and sampling interval (18-20 feet below ground surface). Data from the two resulting samples were managed as field duplicates.

The resulting data set contains concentration or activity values for 67 chemicals at 70 soil sample locations in 26 soil borings. Dioxins are represented by the calculated TEQ value rather than by the concentration data for the 17 individual congeners.

b. Statistical Analysis of the Soils Data Set

Summary statistics for the 67 chemicals are provided in Table 6. This table summarizes the statistical analysis presented in Appendix D for each of the chemicals detected in soils. The details of the statistical analysis are provided in output generated using the JMP software package (version 3.1, SAS Institute 1995). The analysis presented in Appendix D includes graphical depictions of the distribution of sample data (including a histogram, a quantile box plot, an outlier box plot, and a normal quantile plot). The quantiles, moments, and other characteristics of the sample data are provided, as are the results of a Shapiro-Wilk test for normality of the distribution represented by the sample values. As shown in Table 6, the hypothesis of normality is rejected[8] for all but six of the 67 chemicals detected in soils. This result is not surprising; concentration data collected during site investigations are often positively skewed, and are commonly assumed to be log-normally distributed. The six chemicals for which the data are consistent with a normal distribution include two metals (aluminum and beryllium) and four radionuclides (potassium 40, thorium 232, lead 212, and thallium 208). Most of the VOCs, SVOCs, and pesticides were detected at only a few of the 70 soil sampling locations at the WRF expansion site. This is also true for antimony, bismuth 212, and lead 210. The statistical analyses for all of the chemicals were performed using one-half the MDL to represent the non-detects. For chemicals that were detected in only a few samples, the statistics tend to reflect the detection limits achieved by the laboratory more than the actual variation, which cannot be characterized precisely by statistical analysis of the available data.

The possibility of systematic differences among groups defined by historical land use (pond, ditch, or other) and sampling depth zone (top, middle, or bottom) was investigated using nonparametric analysis of variance (ANOVA). These analyses may help to determine the importance of waste disposal in determining the current concentrations of chemicals in the soils at various locations. The importance of historical land use was evaluated by ANOVA after assigning each soil sample location to one of three categories. These categories are Pond (46 soil samples collected in 17 former ponds locations), Ditch (13 soil samples collected at 5 ditch sampling locations identified by the A and B prefixes), and Other (11 soil samples collected at 4 locations identified by the E and S prefixes). The strength of the relationship between depth and concentration or

[8] All of the hypothesis tests presented in Appendix D are evaluated at the five percent level of significance.

TABLE 6
Summary Statistics for Chemicals Detected in Soils
Values Assigned Using One-Half MDL for Non-Detects

Chemical	Units	Number of Sample Locations[1]	Number of Detections[2]	Minimum Value	Maximum Value	Mean Value	Standard Deviation	Coefficient of Variation (Percent)	Consistent with Normal Distribution?	Significant Differences among Land Use Groups?	Significant Differences among Depth Zones?
VOCs and SVOCs											
Acetone	ug/kg	70	13	1.35	13.5	2.496	2.593	104			X
Chloroform	ug/kg	70	3	0.12	21	0.533	2.567	482			X
Ethylbenzene	ug/kg	70	1	0.445	1.2	0.497	0.095	19			X
Methylene chloride	ug/kg	70	5	0.265	1.3	0.351	0.223	63			X
Tetrachlorethene	ug/kg	70	2	0.18	4.5	0.282	0.555	197			X
Toluene	ug/kg	70	2	0.27	2	0.336	0.242	72			X
Xxylenes	ug/kg	70	1	0.55	1.8	0.601	0.155	26			X
Butyl benzyl phthalate	ug/kg	70	1	14	80	15.764	7.879	50			X
Di-n-butyl phthalate	ug/kg	70	1	31.5	130	35.493	11.773	33			X
Phenol	ug/kg	70	1	30	120	33.725	10.796	32			X
Metals											
Aluminum	mg/kg	70	70	5260	19000	11074.286	2546.465	23	X		X
Antimony	mg/kg	70	1	0.08	1.3	0.104	0.145	140			X
Arsenic	mg/kg	70	70	1.3	35.9	6.376	6.049	95		X	X
Barium	mg/kg	70	70	43.8	1100	245.443	127.307	52			X
Beryllium	mg/kg	70	70	0.27	0.93	0.532	0.125	23	X		X
Cadmium	mg/kg	70	70	0.033	0.43	0.118	0.065	55		X	X
Chromium	mg/kg	70	70	4.2	36.3	10.344	5.694	55			
Cobalt	mg/kg	70	70	2.6	10	6.906	1.733	25			X
Copper	mg/kg	70	70	8.5	43.1	13.866	5.207	38			X
Iron	mg/kg	70	70	7180	23500	17363.929	3714.209	21			X
Lead	mg/kg	70	70	4.8	379	17.320	45.573	263			X
Magnesium	mg/kg	70	70	4270	79500	12039.571	9060.217	75		X	
Manganese	mg/kg	70	70	132	2030	427.093	242.705	57		X	X
Mercury	mg/kg	70	44	0.0036	0.096	0.020	0.024	116			
Molybdenum	mg/kg	70	70	0.12	7.2	1.029	0.978	95		X	X
Nickel	mg/kg	70	70	5.4	18.2	12.615	2.409	19		X	
Selenium	mg/kg	70	70	0.13	2.5	0.340	0.297	87			
Silver	mg/kg	70	70	0.053	0.67	0.130	0.081	62			X
Thallium	mg/kg	70	70	0.03	1.1	0.097	0.131	135		X	X
Thorium	mg/kg	70	70	3.7	10.4	6.554	1.492	23			
Titanium	mg/kg	70	70	233	1500	516.286	154.151	30			X
Vanadium	mg/kg	70	70	18.4	57.5	27.976	6.793	24			
Zinc	mg/kg	70	70	19.1	108	42.441	12.480	29		X	X
Dioxins/Furans											
Dioxins (TEQ)	pg/g	70	29	0.33614	81.7	2.908	10.277	353			
Pesticides											
4,4'-DDD	ug/kg	70	2	0.325	3.4	0.464	0.485	104			X
4,4'-DDE	ug/kg	70	10	0.45	74	2.808	9.884	352			X
4,4'-DDT	ug/kg	70	9	0.355	69	2.508	9.480	378		X	X
alpha-Chlordane	ug/kg	70	1	0.23	4.7	0.341	0.557	163			X
beta-BHC	ug/kg	70	8	0.365	20	1.050	2.557	244			X
Dieldrin	ug/kg	70	3	0.295	4.3	0.494	0.719	146			X

TABLE 6
Summary Statistics for Chemicals Detected in Soils
Values Assigned Using One-Half MDL for Non-Detects

Chemical	Units	Number of Sample Locations[1]	Number of Detections[2]	Minimum Value	Maximum Value	Mean Value	Standard Deviation	Coefficient of Variation (Percent)	Consistent with Normal Distribution?	Significant Differences among Land Use Groups?	Significant Differences among Depth Zones?
Endosulfan II	ug/kg	70	1	0.32	4.4	0.446	0.539	121			X
Endosulfan sulfate	ug/kg	70	1	0.27	8.7	0.447	1.022	229			X
Endrin	ug/kg	70	1	0.285	21	0.622	2.476	398			X
Endrin aldehyde	ug/kg	70	2	0.6	13	0.906	1.548	171			X
Endrin ketone	ug/kg	70	1	0.27	2.8	0.363	0.361	100			X
gamma-Chlordane	ug/kg	70	1	0.49	4.2	0.640	0.570	89			X
Heptachlor epoxide	ug/kg	70	2	0.24	5.5	0.398	0.707	177			X
Methoxychlor	ug/kg	70	2	0.65	27	1.226	3.232	264			X
Perchlorate											
Perchlorate	ug/kg	70	68	10.4	59900	4534.071	8542.661	188		X	
Radionuclides											
Actinium 228	pCi/g	70	66	0.395	2	1.303	0.305	23			
Bismuth 212	pCi/g	70	4	0.9	2.7	1.124	0.322	29			
Bismuth 214	pCi/g	70	70	0.6	4.43	1.113	0.605	54		X	X
Lead 210	pCi/g	70	4	0.6	6.9	1.360	0.814	60			X
Lead 212	pCi/g	70	70	0.67	1.52	1.159	0.151	13	X		X
Lead 214	pCi/g	70	70	0.56	4.7	1.054	0.635	60			X
Potassium 40	pCi/g	70	70	15.5	31	24.650	2.831	11	X		
Radium 224	pCi/g	70	57	1	9.6	3.136	1.668	53			
Radium 226	pCi/g	70	50	0.115	3.81	1.284	1.085	85			
Radium 228	pCi/g	70	70	0.74	2.998	1.328	0.293	22			
Thallium 208	pCi/g	70	69	0.15	0.59	0.427	0.069	16	X		
Thorium 228	pCi/g	70	70	0.61	1.82	1.345	0.234	17			X
Thorium 230	pCi/g	70	70	0.8	4.6	1.329	0.559	42			X
Thorium 232	pCi/g	70	70	0.82	1.79	1.352	0.198	15	X		X
Tthorium 234	pCi/g	70	20	0.45	4.5	0.964	0.603	63			
Uranium 234	pCi/g	70	70	0.6	4.6	1.327	0.593	45		X	X
Uranium 235	pCi/g	70	34	0.021	0.2	0.076	0.042	55			
Uranium 238	pCi/g	70	70	0.58	4.45	1.132	0.525	46		X	X

Notes:
1 - Number of sample location/depth interval combinations at which samples were analyzed for the chemical; field duplicates are not counted as separate samples here. Samples were collected at 14 locations in the SEA (3 samples from each of 13 locations and 2 samples from 1 location) and 12 locations in the NEA (2 samples from each of 7 locations and 3 samples from each of 5 locations). Samples were collected at various depth intervals at each location, as discussed in Sections II.A.1 and II.A.2 for the NEA and SEA, respectively.
2 - Number of the 70 sample location/depth interval combinations at which the chemical was detected.

activity was investigated by ANOVA after assigning each sample to one of three depth categories. The categories include Top (26 samples, all from the 0-1 foot interval); Middle (26 samples, generally from the 4-5 foot interval in the northern exposure area and the 10-12 foot interval in the southern exposure area); and Bottom (18 samples collected immediately above the water table).

The ANOVA by land use category identified significant differences for 13 of the 67 detected chemicals. These 13 include eight metals (arsenic, cadmium, magnesium, manganese, molybdenum, nickel, thallium, and zinc); one pesticide (DDT); perchlorate; and three radionuclides (uranium 238, uranium 234, and bismuth 214). These results are generally consistent with the fact that the ponds and ditches were used for disposal of wastes generated by the various operations at the BMI industrial complex.

The ANOVA by depth category identified significant differences for all but 18 of the 67 detected chemicals. The 18 chemicals that did not appear to vary significantly with depth include seven metals (chromium, magnesium, mercury, nickel, selenium, thorium, and vanadium); total dioxins (TEQ); perchlorate; and nine of the 18 measured radionuclides (thorium 234 and radium 226 from the U-238 chain; radium 228, actinium 228, radium 224, bismuth 212, and thallium 208 from the Th-232 chain; potassium 40, and uranium 235). With the exception of total dioxins and perchlorate, all of these chemicals may be native to the soils in the area.

In combination, no significant differences with either land use category or depth category were detected for total dioxins, five metals, and nine radionuclides. Conversely, significant differences were identified by both ANOVAs for six metals (including arsenic), DDT, and three radionuclides. The differences (or lack of differences) among these categories for the chemicals that are significant in the risk assessment are addressed in more detail in Appendix G.

c. Evaluation of Patterns and Potential Hot Spots in the Soils Data Set

The possibility of important spatial trends and patterns in the values for individual chemicals was investigated using the bubble plots provided in Appendix D. These plots illustrate the variations in the concentration or activity values for each chemical by using a dot to represent each sampling location. The size of each dot is proportional to the value assigned to the sampling location. Because samples were collected at multiple (two or three) depth intervals in each boring, multiple dots are shown for each boring location. At each boring location, the dot closest to the top of the map (i.e., farthest north) is located at the actual boring location; the dots that represent the deeper samples at the same boring are offset to allow representation of all of the samples on one plot. The

bubble plots were developed using the Surfer 7© software package (version 7.02, Golden Software 2000).

The bubble plots allow visual identification of areas with one or more samples that have anomalous values because the size of the dot that represents each sample is proportional to the concentration or activity value in that sample. The chemicals that were detected in most or all of the samples can be identified by the information in Table 6. Review of the bubble plots for these chemicals led to the following general observations:

- The spatial variation of the concentration/activity values for these chemicals does not exhibit consistent, gradual trends (e.g., a gradual increase from south to north across the site).

- The values for most of these chemicals exhibit relatively little variation, as reflected in the coefficients of variation reported in Table 6.

- The bubble plots for the chemicals that exhibit greater variation tend to be dominated by just a few relatively high values. These chemicals include lead, mercury, molybdenum, thallium, and perchlorate. This observation applies to a lesser degree to arsenic, magnesium, selenium, and radium 226. Dioxins were detected at only 29 of the 70 sample locations, but this observation applies to the total dioxin bubble plot as well.

- Comparisons of the bubble plots for these chemicals suggest that some sampling locations have anomalous concentrations of multiple chemicals. Conditions at these potential multi-chemical hot spots are characterized below using tables based on ranks.

The few relatively high values that dominate the bubble plots for some of the frequently detected chemicals may be considered anomalous. These values are considerably higher than the rest of the values for the same chemical but they may not be significant to the risk assessment because, as shown in Table 4, the only chemical for which the risk-based benchmarks for soil was exceeded is arsenic. Arsenic levels exceeded the benchmark at nearly all of the sampling locations, so the few anomalous values are not the only samples that are significant to the risk assessment. The variation in the concentration/activity values for the chemicals of significance in the risk assessment is evaluated in greater detail in Appendix G.

Many of the chemicals (including most of the organic chemicals, antimony, bismuth 212, and lead 210) were detected in only a few samples. In general, these detections are represented on the bubble plots (provided in Appendix D) for these chemicals by the largest dots. Because these chemicals were only detected in a few samples, the sampling locations at which they were detected may be considered anomalous.

Table 7 summarizes the results of an analysis for potential multi-chemical hot spots. This analysis was conducted by ranking all of the detected values for each chemical in descending order (i.e., with the highest value ranked #1) and assigning the ranks to the samples in which the concentration/activity values were measured. Table D-7 in Appendix D shows all of the ranks assigned to all of the samples. Note that when ties occur, the Excel spreadsheet function (RANK) used to rank the values assigns the same rank to all of the tied observations. Thus, if there are two equal observations that are third highest for a specific chemical, both are assigned the rank of 3. Therefore, for any particular chemical there may be multiple observations with the same rank, and the sum of the ranks varies from one chemical to another.

To facilitate the interpretation of the ranks presented in Table D-7, the 67 detected chemicals were organized into three groups composed of the 25 organic chemicals (VOCs, SVOCs, pesticides, and dioxins), the 24 inorganic chemicals (metals and perchlorate), and the 18 radionuclides. The number of highest (#1) ranks and top 10% ranks assigned to each sample location in each group and for all three groups combined is shown in Table D-7. These counts were used to identify locations of the anomalous concentrations listed in Table 7. Each sample that has at least one #1 rank or at least two top 10% ranks in one group is included in the table. Of the 26 samples that meet these criteria, the following stand out:

- Sample B-2 (0-1') has the highest rank for five of the organics (all pesticides) and copper, and also has top 10% ranks for four other metals.

- Sample P-11 (0-1') has the highest rank for three organics (toluene, xylenes, and a pesticide) iron, and lead 212. It also has top 10% ranks for methylene chloride, molybdenum, and thorium232.

- Sample A-1 (16-18') ranks highest in 12 chemicals including chloroform and tetrachloroethene, two metals, and eight radionuclides (seven from the U-238 chain and radium 224). It has top 10% levels of five other metals, including arsenic (rank #3).

TABLE 7
Potential Multi-Chemical Hot Spots Identified by Analysis of Ranks

Exposure area	NEA	NEA	NEA	NEA	NEA	NEA	NEA	NEA	NEA
LCODE	D	O	O	P	P	P	P	P	P
DCODE	T	T	B	T	M	T	T	T	T
Boring location	B-2	E-2	E-2	P-11	P-11	P-12	P-14	P-15	P-16
Depth	0-1'	0-1'	6-8'	0-1'	4-5'	0-1'	0-1'	0-1'	0-1'
# Organics Detected in Sample:	6	1	2	8	1	1	0	5	0
# Highest (#1) Ranks in Sample:	5	0	1	3	0	1	0	0	0
# Top 3 (10%) Ranks in Sample:	5	0	1	4	0	1	0	1	0
# Inorganics Detected in Sample:	23	22	23	23	22	23	22	23	23
# Highest (#1) Ranks in Sample:	1	0	0	1	1	3	0	1	1
# Top 3 (10%) Ranks in Sample:	5	0	0	2	4	5	0	2	1
# Radionuclides Detected in Sample:	15	16	15	14	13	14	14	15	16
# Highest (#1) Ranks in Sample:	0	1	0	1	0	0	1	1	0
# Top 2 (10%) Ranks in Sample:	0	1	0	2	0	1	1	1	0
Totals for All Chemicals:									
# of 67 Chemicals Detected in Sample:	44	39	40	45	36	38	36	43	39
# Highest (#1) Ranks in Sample:	6	1	1	5	1	4	1	2	1
# of Top 10% Ranks in Sample:	10	1	1	8	4	7	1	4	1

TABLE 7
Potential Multi-Chemical Hot Spots Identified by Analysis of Ranks

Exposure area	NEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA
LCODE	O	D	D	D	D	P	P	P	P
DCODE	B	B	T	T	B	T	B	T	M
Boring location	S-2	A-1	A-2	B-1	B-1	P-10	P-10	P-3	P-3
Depth	18-20'	16-18'	0-1'	0-1'	19-21'	0-1'	16.5-17.5'	0-1'	10-12'
# Organics Detected in Sample:	2	2	7	2	1	13	1	1	0
# Highest (#1) Ranks in Sample:	0	2	3	0	0	7	0	0	0
# Top 3 (10%) Ranks in Sample:	2	2	7	0	0	10	0	0	0
# Inorganics Detected in Sample:	22	22	23	23	22	23	23	22	23
# Highest (#1) Ranks in Sample:	0	2	0	12	0	0	0	0	0
# Top 3 (10%) Ranks in Sample:	0	7	1	16	3	1	0	0	0
# Radionuclides Detected in Sample:	14	15	13	15	14	14	15	16	13
# Highest (#1) Ranks in Sample:	0	8	0	0	0	0	1	2	1
# Top 2 (10%) Ranks in Sample:	0	8	0	0	4	0	1	2	1
Totals for All Chemicals:									
# of 67 Chemicals Detected in Sample:	38	39	43	40	37	50	39	39	36
# Highest (#1) Ranks in Sample:	0	12	3	12	0	7	1	2	1
# of Top 10% Ranks in Sample:	2	17	8	16	7	11	1	2	1

TABLE 7
Potential Multi-Chemical Hot Spots Identified by Analysis of Ranks

Exposure area	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA
LCODE	P	P	P	P	P	P	P	P
DCODE	T	B	M	T	M	B	T	M
Boring location	P-4	P-5	P-6	P-7	P-7	P-7	P-8	P-9
Depth	0-1'	16-18'	10-12'	0-1'	10-12'**	18-20'	0-1'	6-8'
# Organics Detected in Sample:	4	1	0	4	3	3	0	1
# Highest (#1) Ranks in Sample:	1	0	0	2	1	0	0	0
# Top 3 (10%) Ranks in Sample:	2	1	0	3	1	1	0	1
# Inorganics Detected in Sample:	23	23	22	23	22	23	22	22
# Highest (#1) Ranks in Sample:	0	1	1	0	0	0	0	0
# Top 3 (10%) Ranks in Sample:	0	1	2	1	1	2	3	0
# Radionuclides Detected in Sample:	13	14	15	14	16	14	14	14
# Highest (#1) Ranks in Sample:	0	1	0	0	0	0	0	1
# Top 2 (10%) Ranks in Sample:	0	2	0	0	3	1	0	1
Totals for All Chemicals:								
# of 67 Chemicals Detected in Sample:	40	38	37	41	41	40	36	37
# Highest (#1) Ranks in Sample:	1	2	1	2	1	0	0	1
# of Top 10% Ranks in Sample:	2	4	2	4	5	4	3	2

- Sample B-1 (0-1') has the highest levels of 12 metals including arsenic, and has top 10% levels of four more metals. It does not have high levels of any of the organics or radionuclides.

- Sample P-10 (0-1') has the highest ranks for di-n-butyl phthalate, phenol, and five pesticides including DDD. It also has ranks in the top 10% for acetone, DDT, and methoxychlor.

Although locations of anomalous concentrations (relative to other areas of the site) were identified by this analysis of ranks, the reader should keep in mind that arsenic is the only chemical that was detected in soils at levels that exceed the appropriate risk-based benchmarks. This fact is demonstrated by the comparison of data to the Region 9 industrial PRGs presented in Table 4. Two of the five locations with relatively high concentrations are anomalous primarily for their high levels of pesticides. Both are surface samples, one from a ditch (B-2) and one from a pond (P-10). Another location with anomalous concentrations, B-1 (0-1'), is a surface ditch sample with elevated levels of many metals, including arsenic. The only location with anomalously high concentrations of multiple radionuclides is A-1 (16-18'), a deep ditch sample that also has the highest levels of chloroform and tetrachloroethene. This is also the only deep location with anomalously high concentrations. The only location with anomalous concentrations of multiple VOCs identified by this analysis is the surface sample at P-11, which has high levels of toluene, xylenes, and methylene chloride.

d. Comparison to Background Data

The chemical data obtained from soil samples collected at the background sampling locations are summarized in Table 8. The background sampling and analysis program and the resulting data are described in detail in Appendix E. The chemical data from the WRF expansion site soil samples were compared to the background data to identify chemicals that appear to be present at elevated levels. Because this comparison is important to the risk assessment, it was performed separately for each of the two exposure areas (northern and southern). Each comparison is based on a nonparametric test for differences between the populations represented by the background samples and the samples collected at the WRF expansion site. The nonparametric test procedure used in this evaluation is the Wilcoxon Rank Sum test. This procedure is used to test whether the values in one population are consistently larger or smaller than the values in another population and can be interpreted as a test of the null hypothesis that the means of the two

TABLE 8
Summary Statistics for Chemicals Detected in Background Soils
Values Assigned Using One-Half MDL for Non-Detects

Chemical	Units	Number of Sample Locations[1]	Number of Detections[2]	Minimum Value	Maximum Value	Mean Value	Standard Deviation	Coefficient of Variation (Percent)	Consistent with Normal Distribution?
Metals									
Aluminum	mg/kg	16	16	6820	12700	10036.250	1817.683	18	X
Antimony	mg/kg	16	0	0.0197	0.0197	0.0197	0.000	NC	NC
Arsenic	mg/kg	16	16	2.1	4.3	3.038	0.583	19	X
Barium	mg/kg	16	16	198	561	335.688	105.791	32	X
Beryllium	mg/kg	16	16	0.25	0.5	0.375	0.076	20	X
Cadmium	mg/kg	16	16	0.052	0.16	0.105	0.028	26	X
Chromium	mg/kg	16	16	4.3	12.4	7.694	2.083	27	X
Cobalt	mg/kg	16	16	3.9	7.8	5.684	1.442	25	
Copper	mg/kg	16	16	7.8	16.3	10.613	2.281	21	X
Iron	mg/kg	16	16	7520	15000	11656.250	2562.543	22	X
Lead	mg/kg	16	16	7	23.5	15.081	5.601	37	X
Magnesium	mg/kg	16	16	4630	9090	6890.625	1582.169	23	X
Manganese	mg/kg	16	16	223	615	446.250	98.342	22	X
Mercury	mg/kg	16	16	0.013	0.027	0.020	0.004	20	X
Molybdenum	mg/kg	16	16	0.17	0.44	0.293	0.081	28	X
Nickel	mg/kg	16	16	7.8	15.4	10.659	1.788	17	X
Selenium	mg/kg	16	12	0.02335	0.26	0.128	0.077	60	X
Silver	mg/kg	16	16	0.019	0.083	0.049	0.019	39	X
Thallium	mg/kg	16	16	0.1	0.4	0.180	0.081	45	
Thorium	mg/kg	16	16	4.6	7.7	5.891	0.925	16	X
Titanium	mg/kg	16	16	235	473	355.719	73.055	21	X
Vanadium	mg/kg	16	16	14.6	25.5	20.525	4.351	21	
Zinc	mg/kg	16	16	23	52.4	39.609	10.412	26	X

TABLE 8
Summary Statistics for Chemicals Detected in Background Soils
Values Assigned Using One-Half MDL for Non-Detects

Chemical	Units	Number of Sample Locations[1]	Number of Detections[2]	Minimum Value	Maximum Value	Mean Value	Standard Deviation	Coefficient of Variation (Percent)	Consistent with Normal Distribution?
Dioxins/Furans									
Dioxins (TEQ)	pg/g	16	10	0.0002915	0.004225	0.002	0.001	62	X
Pesticides									
Eight surface soil samples were analyzed for pesticides, but none were detected. See Appendix E for additional details.									
Perchlorate									
Perchlorate	ug/kg	16	9	9.35	402.5	60.044	101.250	169	
Radionuclides									
Actinium 228	pCi/g	16	16	1.11	2.05	1.595	0.298	19	X
Bismuth 212	pCi/g	16	4	0.44	1.72	0.793	0.403	51	
Bismuth 214	pCi/g	16	16	0.57	1.22	0.873	0.183	21	X
Lead 210	pCi/g	16	1	0.85	1.9	1.155	0.241	21	
Lead 212	pCi/g	16	16	0.94	1.47	1.261	0.174	14	X
Lead 214	pCi/g	16	16	0.62	1.23	0.845	0.149	18	X
Potassium 40	pCi/g	16	16	23.6	34.4	28.356	2.702	10	X
Radium 224	pCi/g	16	15	1	6.7	3.253	1.357	42	X
Radium 226	pCi/g	16	16	1.03	2.15	1.480	0.309	21	X
Radium 228	pCi/g	16	16	1.02	1.88	1.386	0.189	14	X
Thallium 208	pCi/g	16	16	0.33	0.59	0.483	0.083	17	X
Thorium 228	pCi/g	16	16	1.07	2.14	1.579	0.284	18	X
Thorium 230	pCi/g	16	16	0.88	1.38	1.130	0.168	15	X
Thorium 232	pCi/g	16	16	1.1	1.93	1.518	0.239	16	X
Thorium 234	pCi/g	16	1	0.55	1.49	0.665	0.225	34	
Uranium 234	pCi/g	16	16	0.53	1.11	0.772	0.166	22	X
Uranium 235	pCi/g	16	9	0.019	0.116	0.061	0.032	52	X
Uranium 238	pCi/g	16	16	0.45	1.07	0.763	0.173	23	X

Notes:
NC - the statistic was not calculated because the chemical was not detected in the background samples
1 - Number of sample location/depth interval combinations at which samples were analyzed for the chemical; field duplicates are not counted as separate samples here. Samples were collected at 2 depth intervals at each of 8 background locations, as discussed in Appendix E.
2 - Number of the 16 sample location/depth interval combinations at which the chemical was detected.

populations are equal (Gilbert 1987). In this context, each Wilcoxon Rank Sum test was interpreted as a test of the null hypothesis that the mean concentration in soils at the WRF expansion site is less than or equal to the mean background concentration. The details of the comparisons for the exposure areas are provided in Appendix E. These comparisons were performed for all of the chemicals that were commonly detected in both data sets. The background soil samples were not analyzed for VOCs or SVOCs, and no pesticides were detected in the background samples. A few of the other chemicals (antimony, bismuth 212, thorium 234, and lead 210) were detected in five or fewer of the 16 background soil samples. Therefore, the comparison was not performed for these chemicals.

As shown in Table E-5 (Appendix E), both of the exposure areas appear to be elevated with respect to background for dioxins, perchlorate, twelve of the metals, and two of the radionuclides. The only two radionuclides found at elevated levels in both exposure areas are uranium 238 and uranium 234, which is a decay product of uranium 238. The northern exposure area also appears to be elevated for aluminum, chromium, and uranium 235; the southern exposure area also appears to be elevated for lead, mercury, bismuth 214, lead 214, and thorium 230. These results are based on interpretation of 78 statistical hypothesis tests (two each for 39 chemicals) at a five percent level of significance, so some false rejections of the null hypothesis are likely. While individual tests are not necessarily conclusive, the pattern and number of elevated levels indicate that soils in both exposure areas have been affected by wastes associated with the BMI industrial complex. The nature and disposal of these wastes is addressed in the conceptual model described in Chapter III of this report. A more detailed comparison to background for the chemicals of greatest significance in the risk assessment is provided in Appendix G.

C. Data Usability and Data Adequacy

The data usability (DU) analysis is a multi-step process that is designed to maximize the usability of environmental analytical data collected during site characterization activities in the risk assessment. This process, which was developed by the USEPA, is applied to ensure that the site data meet the needs of the risk assessment and to identify potential uncertainty issues associated with the data that may require further review or discussion in the risk assessment. The approach to conducting a DU analysis is described in USEPA's *Guidance for Data Usability in Risk Assessment, Parts A and B* (USEPA 1992b,c) and consists of six criteria, a summary of which was provided as an appendix to the work plan (ENVIRON 2001). The six criteria are:

Criterion I - Availability of Information Associated with Site Data
Criterion II - Documentation Review
Criterion III - Data Sources
Criterion IV - Analytical Methods and Detection Limits
Criterion V - Data Review
Criterion VI - Data Quality Indicators

Each of these six DU criteria is discussed individually in Appendix F. An overview of the results of the DU analysis is provided below.

- Sufficient information was available to perform the DU analysis, including site descriptions, analytical methods, chemical and physical parameter data, laboratory QA/QC narratives, and laboratory QC results.

- Although several discrepancies between the contents of the coolers received and the accompanying chain-of-custody forms were noted by the laboratory, all samples analyzed by the laboratory were correlated to the correct geographic location at the site. All sample discrepancies were cleared by ENVIRON prior to analysis.

- The DU review indicates that the analytical techniques used in the site characterization process are appropriate to identify the chemicals of potential concern in the risk assessment for each medium being evaluated, and field measurements of physical parameters were adequately collected.

- The analytical methods used are approved USEPA methods and are the most appropriate methods for the respective chemical constituent classes. In general, the detection limits obtained by the analytical laboratory are sufficiently below regulatory benchmarks or levels of concern. Although Table 5 shows that some of the MDLs in the ground water samples exceed some of the benchmarks, the only MDLs that exceeded an MCL were for lead 210.

- Acetone and methylene chloride were routinely detected in trip blanks. Applying the methodology recommended by USEPA (1989) for chemicals detected in trip blanks, the detection of acetone and methylene chloride in several samples was assumed to be due to non-site-related contamination.

- Several metals and radionuclides were detected, generally at low concentrations, in field blank samples. This was apparently due to the presence of dusty conditions at the site; thus, it is not surprising that some metals and radionuclides were detected. The contaminants in the field blank samples were assumed to be site related, and the presence of these chemicals in site samples was not qualified.

- No significant data usability issues were noted based on a review of field duplicate results. The concentrations of chemicals detected in field duplicates were averaged with the concentrations in the original samples as part of the data analysis portion of the risk assessment.

- The calibration of instrumentation used to perform the laboratory analyses was verified by STL, which reported that the equipment was properly calibrated for the analytical methods being performed.

- The Data Quality Indicators (precision, accuracy, representativeness, completeness, and comparability) were reviewed, as summarized below:

  Precision – No significant issues related to precision were noted based on ENVIRON's review. A detailed review of the DU analysis for precision is presented in Appendix F.

  Accuracy – ENVIRON's review of accuracy included an analysis of holding times and sample temperatures; laboratory control sample (LCS) percent recovery; MS/MSD percent recovery (organics); spike sample recovery (inorganics); surrogate spike recovery; and blank sample results. No significant DU issues were identified based on this review.

  Representativeness – A review of the representativeness of the data set identified some potential sources of bias. These sources of bias are a result of the sampling design. As explained in Appendix F, these sources are not likely to result in a significant underestimation of the actual exposure concentrations.

  Completeness – No significant data usability issues were identified relating to completeness. All of the analytical data collected was determined to be usable in the risk assessment.

Comparability - Comparability is not a concern within the context of this risk assessment because all of the data used was collected during a single site characterization program (no historical site data was used in the risk calculations). All of the chemical analyses for each analyte and medium were conducted by the same laboratory and method. The data review presented in Appendix F did not identify any reasons to qualify the comparability of the data within this data set.

The adequacy of the site characterization data collected by ENVIRON in May 2001 for use in the risk assessment was evaluated, as recommended by USEPA (2000a). ENVIRON's findings regarding the data adequacy are summarized below. A more detailed discussion of the data adequacy analysis techniques applied is provided in Appendix G.

The data adequacy analysis presented in Appendix G leads to the conclusion that the data set is sufficient to support a no-further-action decision for soils at the WRF expansion site. This evaluation is based on assumed values for the cumulative risk action levels and tolerable probabilities of decision errors; these criteria were not specified during the planning stage of this investigation. The final determination of these factors is a risk management decision that will be made by the appropriate regulatory agencies. The action levels assumed in this report include the following: 1×10^{-6} for cumulative chemical cancer risks; a hazard index of one for cumulative chemical non-cancer risks; and 3×10^{-4} for cumulative radionuclide cancer risks. These levels were selected because they are consistent with USEPA recommendations in the National Contingency Plan (NCP) and other guidance documents (USEPA 1997c; USEPA 1991a,b), as discussed in Sections A and B of Chapter VII for carcinogens and noncarcinogens, respectively, and in Section D of Chapter VIII for radionuclides.

The data set is used in this risk assessment to characterize the concentrations of chemicals in the media to which the populations of interest may be exposed. In general terms, the adequacy of the data set is determined by the level of uncertainty in the risk estimates that results from an incomplete characterization of these media. The data adequacy analysis in Appendix G indicates that the probability that the risk associated with any chemical in soil exceeds the assumed action levels is small (about 5 percent). Because the exceedence probabilities are based on RME exposure patterns, the decision error probabilities are considerably lower. The worst-case (5 percent) probability relates to arsenic (which is present primarily as a result of background conditions) and to an assumed carcinogenic risk action level of 1×10^{-6} (which is the lower end of the range of acceptable risk established in the National Contingency Plan). For this reason, ENVIRON believes that the soils data set for each of the 14 chemicals is adequate.

D. Comparison of May 2001 Data with Data Collected Previously

As summarized in the *Site Characterization and Risk Assessment Work Plan* (ENVIRON 2001), soil sampling had been conducted at the WRF expansion site by others prior to ENVIRON's field program. An overview of the historical soil sampling data is presented in Table 9.

A comparison of the previously collected data with the data from the May 2001 site characterization program (Table 4) indicates that the historical data do not differ significantly from the recently collected data. For example, historical perchlorate concentrations ranged from 0.05 mg/kg to 37 mg/kg. In the May 2001 data, perchlorate concentrations range from 0.0345 mg/kg to 59.9 mg/kg. In addition, the ranges of arsenic and lead concentrations from the historical data are within the corresponding ranges from the May 2001 data. Other metals show a similar pattern, as indicated in Figure 7. One notable exception is mercury. The maximum concentration of mercury detected in the May 2001 site characterization program is below the minimum detected concentration in the historical data. It should be noted, however, that the historical data include only two detections. Furthermore, both the historical and May 2001 maximum mercury concentrations are more than three orders of magnitude below the industrial soil PRG for mercury, as shown in Figure 7. For the pesticides, the distribution of detections is very similar between the May 2001 data and the previously collected data. A similar group of pesticides was detected in both historical and the recent sampling, and the most commonly detected compounds are the same in both sets of data (beta-BHC, 4,4'-DDE, and 4,4'-DDT). A comparison of the historical maximum/minimum concentrations of these pesticides with the maximum/minimum concentrations measured in May 2001 is provided in Figure 7.

Although the historical radionuclide and dioxin/furan data are limited, the available historical data are similar to the concentrations observed in the May 2001 sampling event, as indicated from a comparison of the values in Table 4 with values in Table 9.

Historical ground water data sets from wells installed on or near the WRF site were provided in two of the documents reviewed by ENVIRON. These data sets are summarized in Table 10. The only historical data collected from wells on the WRF site was for perchlorate, which was measured in water samples collected from a number of on-site and downgradient wells in 1998 (Kerr-McGee 1998). The only nearby upgradient well for which data were found is DM-4, which is adjacent to the southern boundary of the site. This well was dry when ENVIRON attempted to sample it in May 2001, but data from earlier sampling events in this well were obtained from the *Soil/Groundwater Nexus Report* submitted to the NDEP in

TABLE 9
Summary of Historical Soil Sampling Data

Chemical	Units	# of Samples	# of Detects	% of Samples with Detect	Maximum Detect	Minimum Detect	Average Detect	Maximum MDL for Nondetects	Minimum MDL for Nondetects	Region 9 Industrial PRG	Detects Exceeding Benchmarks	MDLs Exceeding Benchmarks
Metals												
Antimony	mg/kg	20	3	15%	1.2	0.66	0.953	0.5	0.5	410	0	0
Arsenic	mg/kg	41	33	80%	12	2.9	5.62	25	20	1.6	33	0
Barium	mg/kg	33	25	76%	720	120	283			67000	0	0
Beryllium	mg/kg	17	16	94%	1.4	0.77	1.03	1.25	1.25	1900	0	0
Cadmium	mg/kg	33	3	9%	0.54	0.36	0.44	13	0.34	450	0	0
Chromium	mg/kg	33	26	79%	69	9.6	20.2			450	0	0
Copper	mg/kg	17	17	100%	130	12	28.2			41000	0	0
Lead	mg/kg	41	41	100%	140	4.9	33.8			750	0	0
Manganese	mg/kg	28	28	100%	1200	170	492			19000	0	0
Mercury	mg/kg	33	2	6%	0.2	0.13	0.165	0.12	0.09	310	0	0
Nickel	mg/kg	17	17	100%	29	7.5	15.2			20000	0	0
Thallium	mg/kg	20	2	10%	0.63	0.58	0.605	5	0.5	67	0	0
Vanadium	mg/kg	33	25	76%	80	33.1	48.9			7200	0	0
Zinc	mg/kg	17	17	100%	140	25	51.5			100000	0	0
Perchlorate												
Perchlorate	µg/kg	58	27	47%	37000	50	3980	40000	0.0017	100000	0	0
Pesticides												
alpha-BHC	µg/kg	42	3	7%	7.4	1.1	3.63	500	1.7	360	0	0
beta-BHC	µg/kg	42	21	50%	49	0.75	12.8	500	1.8	1300	0	0
D-BHC	µg/kg	42	4	10%	15	3.2	10.2	500	1.7		0	0
gamma-Chlordane	µg/kg	42	2	5%	2.1	1.1	1.6	500	1.7	6500	0	0
Chlordane	µg/kg	42	1	2%	180	180	180	2000	20	6500	0	0
4,4'-DDD	µg/kg	42	1	2%	5.4	5.4	5.4	500	3.3	10000	0	0
4,4'-DDE	µg/kg	42	31	74%	2200	0.91	97	5.1	3.3	7000	0	0
4,4'-DDT	µg/kg	42	20	48%	2100	1.2	132	15	3.3	7000	0	0
Dieldrin	µg/kg	42	5	12%	9.9	1.5	6.46	500	3.3	110	0	1
VOCs and SVOCs												
Acetone	µg/kg	18	4	22%	5.6	4.2	4.98	13	10	6000000	0	0
Chloroform	µg/kg	18	2	11%	2.9	2.7	2.8	6.5	5.1	120000	0	0
Di-n-butyl phthalate	µg/kg	15	3	20%	16000	10000	12700	800	670	62000000	0	0
Phenol	µg/kg	15	1	7%	590	590	590	1400	670	100000000	0	0
Dioxins/Furans												
2,3,7,8-TCDD TEQ*	pg/g	1	1	100%	3	3	3			16		
Radionuclides												
Uranium-238	pCi/kg	3	3	100%	2.2	1.02	1.55				0	0
Uranium-234	pCi/kg	3	3	100%	2.58	0.9	1.76				0	0
Thorium-230	pCi/kg	3	2	67%	1.54	1.08	1.31	NA	NA		0	0
Radium-226	pCi/kg	3	2	67%	0.85	0.194	0.522	NA	NA		0	0
Thorium-232	pCi/kg	3	3	100%	1.73	1.48	1.61				0	0
Radium-228	pCi/kg	3	3	100%	1.45	1.25	1.35				0	0
Thorium-228	pCi/kg	3	3	100%	2.28	1.53	1.8				0	0
Uranium-235/236	pCi/kg	3	2	67%	0.112	0.049	0.081	NA	NA		0	0

Note:
* - The methodology used to calculate TEQs is discussed in Section B.1 of Chapter VI.

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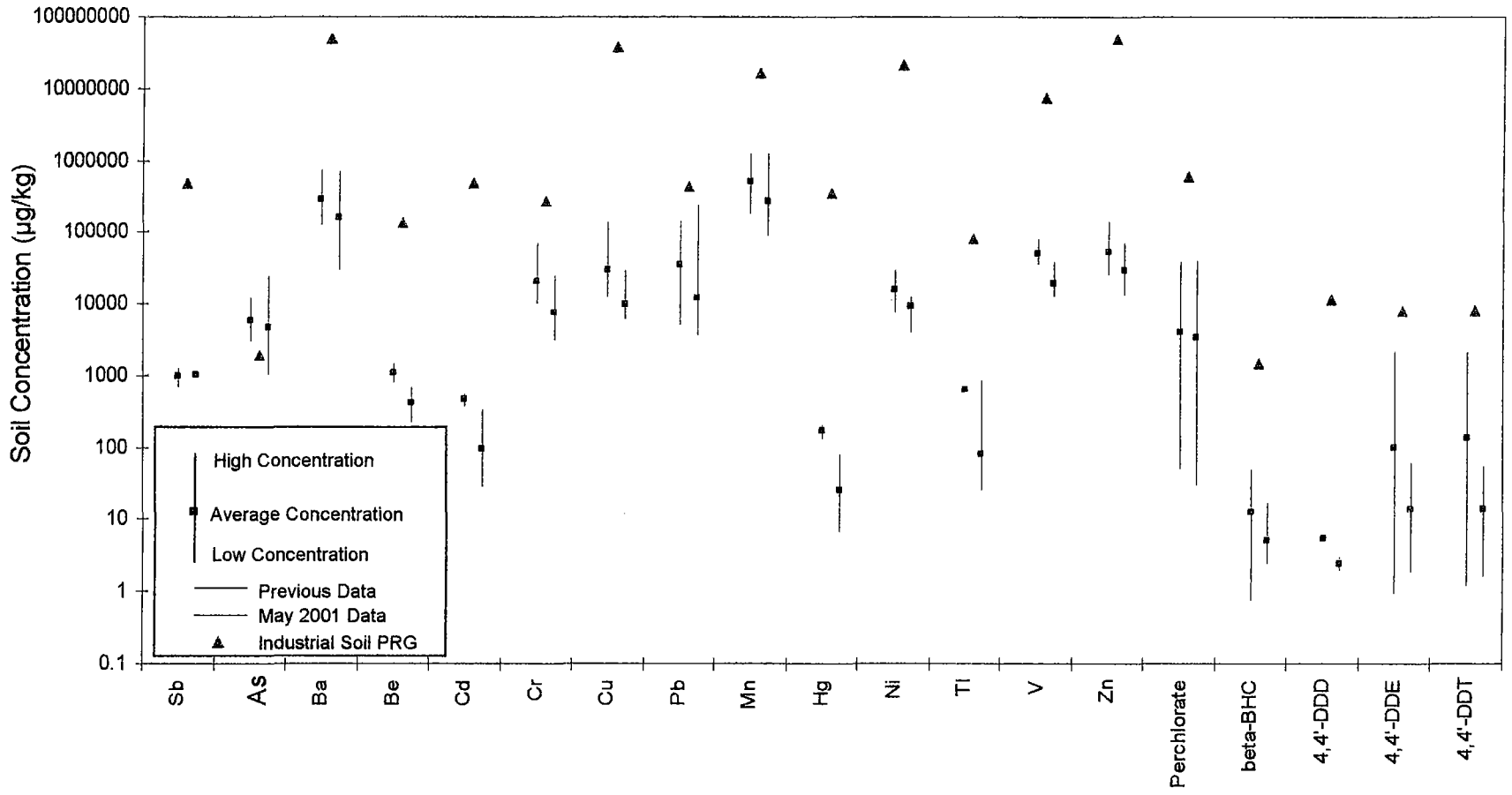

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COMPARISON OF CURRENT AND HISTORICAL SOIL SAMPLING DATA
WRF EXPANSION SITE, HENDERSON, NEVADA

Figure
7

December 2000 by ERM (2000b) on behalf of Basic Remediation Company (BRC). The tables in this report provide data from eight sampling events conducted at well DM-4 between November 1995 and November 1997. The historical data from well DM-4 for the chemicals detected in the ENVIRON ground water samples are summarized in Table 10 along with the historical perchlorate data from the on-site wells. The ground water data from the samples collected by ENVIRON in May 2001 (summarized in Table 5) are generally consistent with the historical data in Table 10.

E. Initial Evaluation of Potential Migration from Soils to Ground Water

Several of the chemicals that have been detected in soil at the site during the May 2001 site characterization program were also detected in ground water beneath the property. To provide an initial indication of whether the chemicals present in soils at the WRF expansion site could also contribute to ground water degradation, ENVIRON compared the maximum detected concentrations of chemicals in soil for the WRF expansion site with the most conservative of the USEPA's generic soil screening levels (SSLs) for migration to ground water. This comparison is summarized in Table 11.

The maximum detected concentrations in soil at the WRF expansion site for many chemicals (including 2 VOCs, 8 metals, 2 pesticides, and 13 radionuclides) exceed the SSL values, as indicated by the shading in Table 11. Thus, it is possible that soils at the WRF expansion site could be adversely affecting ground water beneath the site. The SSLs for arsenic, chromium, and seven of the radionuclides were exceeded at all 70 sampling locations, and all of the detected concentrations of methylene chloride, beta-BHC, and dieldrin exceeded the SSLs for these compounds. These results indicate that the impacts to ground water by migration of chemicals from the soil may be significant throughout the WRF expansion site; the problem is not restricted to a few small areas.

As discussed in Chapter I of this report, a complete evaluation of the potential impacts of migration of chemicals from the soil on human health and the environment needs to be addressed within a framework that accounts for regional ground water quality and the NDEP's associated regulatory strategy. Development of the WRF expansion area is not expected to interfere with further investigation or remediation efforts that address existing or potential impacts to ground water.

As indicated by "NA" in the table, USEPA has not developed generic SSL values for some of the chemicals detected in soil at the WRF expansion site. The most significant of these chemicals is likely to be perchlorate. As shown in Figure 8, Kerr-McGee (2000) developed isoconcentration contours for perchlorate emanating from the BMI complex and traveling downgradient toward the Las Vegas Wash. Although Kerr-McGee did not develop contours for the WRF expansion site, the concentrations of perchlorate in ground water detected in the

TABLE 10
Summary of Historical Ground Water Sampling Data

Chemical	Units	# of Samples	# of Detects	% of Samples with Detect	Maximum Detect	Minimum Detect	Maximum MDL for Nondetects	Minimum MDL for Nondetects
Monitoring Well DM-4 (8 sampling events)								
Metals								
Iron	mg/L	7	7	100%	44	1.1		
Magnesium	mg/L	7	7	100%	880	360		
VOCs and SVOCs								
Bromodichloromethane	µg/l	7	0	0%			<5	<5
Carbon Tetrachloride	µg/l	7	0	0%			<5	<5
Chloroform	µg/l	7	7	100%	90	45		
1,1-Dichloroethane	µg/l	7	0	0%			<5	<5
Methylene chloride	µg/l	7	1	14%	9	9	<5	<5
Tetrachloroethylene	µg/l	7	0	0%			<5	<5
1,1,1-Trichloroethane	µg/l	7	0	0%			<5	<5
Trichloroethylene	µg/l	7	0	0%			<5	<5
Pesticides								
a-BHC	µg/l	5	0	0%			<0.1	<0.1
b-BHC	µg/l	5	0	0%			<0.1	<0.1
d-BHC	µg/l	5	0	0%			<0.1	<0.1
g-BHC	µg/l	5	0	0%			<0.1	<0.1
Heptachlor epoxide	µg/l	5	0	0%			<0.1	<0.1
4,4'-DDT	µg/l	5	0	0%			<0.1	<0.1
Endosulfan I	µg/l	5	0	0%			<0.1	<0.1
Radionuclides								
Radium 226	pCi/L	2	1	50%	0.4 ± 0.3	0.4 ± 0.3	<0.3	<0.3
Radium 228	pCi/L	2	2	100%	2.1 ± 1.6	1.1 ± 0.9		
Thorium 228	pCi/L	2	0	0%			<0.4	<0.4
Thorium 230	pCi/L	2	0	0%			<0.4	<0.4
Thorium 232	pCi/L	2	0	0%			<0.4	<0.4
Uranium (total)	mg/L	2	2	100%	0.0227	0.0210		
Monitoring Wells PC-1, PC-2, PC-4, PC-56, PC-58 (1 sampling event each)								
Perchlorate	µg/l	5	5	100%	64000	1070		

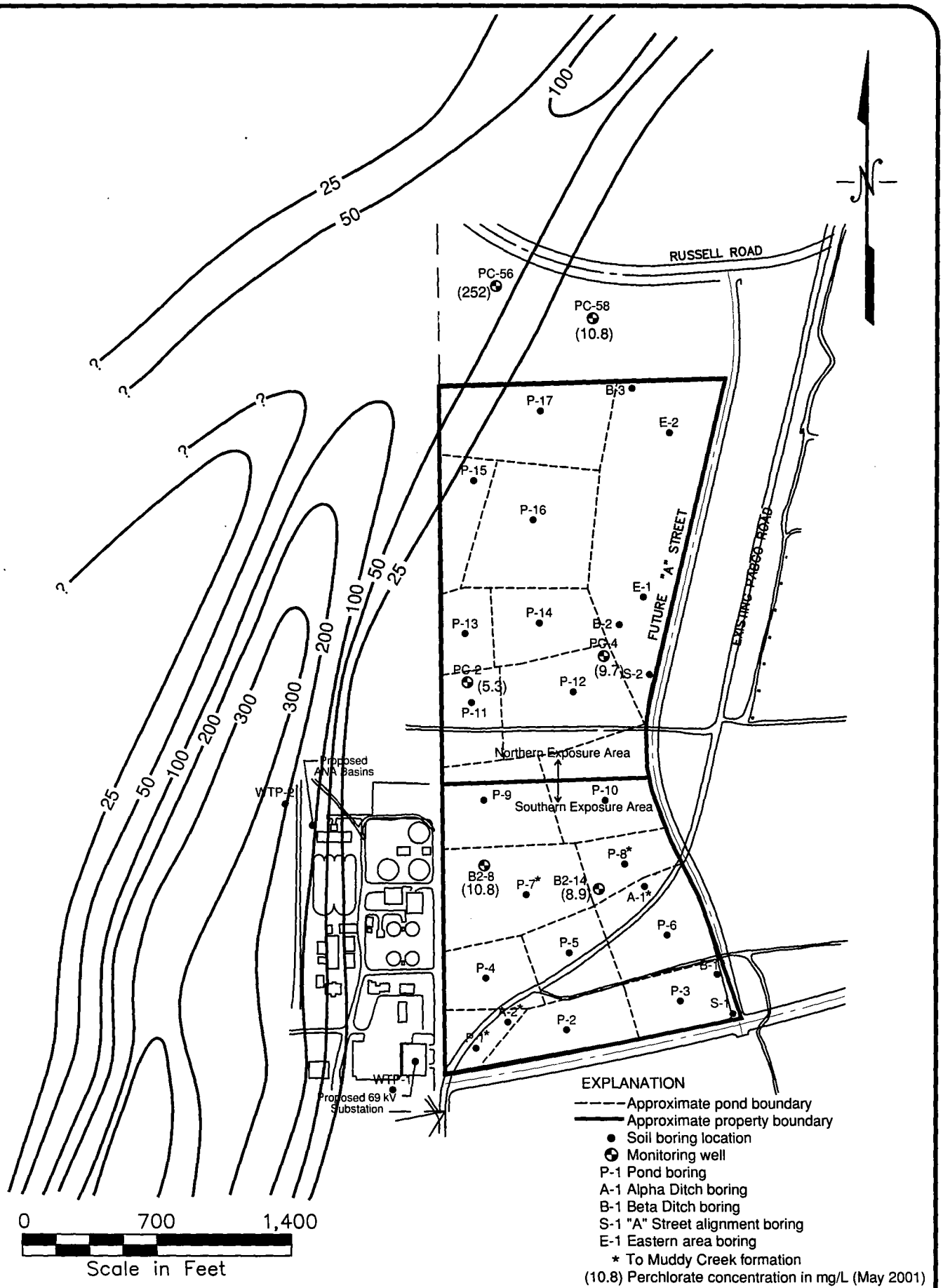
TABLE 11
Comparison of Soils Data from WRF Expansion Site
to USEPA Generic SSLs for Migration to Ground Water

Chemical	Detected in On-site Ground Water	USEPA Generic SSL for DAF = 1	Maximum Soil Concentration	Number of Detections Exceeding the SSL for DAF=1
Organic Compounds		ug/kg	ug/kg	
Acetone	Yes	800	13.5	0
Chloroform	Yes	30	21	0
Ethylbenzene		700	1.2	0
Methylene chloride		1	1.3	5
Tetrachloroethene	Yes	3	4.5	1
Toluene	Yes	600	2	0
Xylenes		9,000	1.8	0
Butyl benzyl phthalate		810,000	80	0
Di-n-butyl phthalate		270,000	130	0
Phenol		5,000	120	0
Metals		ug/kg	ug/kg	
Aluminum	Yes	NA	19,000,000	NA
Antimony		300	1,300	1
Arsenic	Yes	1,000	35,900	70
Barium	Yes	82,000	1,100,000	68
Beryllium		3,000	930	0
Cadmium	Yes	400	430	1
Chromium (total)	Yes	2,000	36,300	70
Cobalt	Yes	NA	10,000	NA
Copper		NA	43,100	NA
Iron	Yes	NA	23,500,000	NA
Lead	Yes	400,000	379,000	0
Magnesium	Yes	NA	79,500,000	NA
Manganese	Yes	NA	2,030,000	NA
Mercury		NA	96	NA
Molybdenum	Yes	NA	7,200	NA
Nickel	Yes	7,000	18,200	67
Selenium	Yes	300	2,500	31
Silver	Yes	2,000	670	0
Thallium		40	1,100	65
Thorium	Yes	NA	10,400	NA
Titanium		NA	1,500,000	NA
Vanadium	Yes	300,000	57,500	0
Zinc	Yes	620,000	108,000	0
Dioxins/Furans			pg/g	
Dioxins/Furans TEQ		NA	81.7	NA
Pesticides		ug/kg	ug/kg	
4,4'-DDD		800	3.4	0
4,4'-DDE		3,000	74	0
4,4'-DDT		2,000	69	0
alpha-Chlordane		500	4.7	0
beta-BHC		0.1	20	8
Dieldrin		0.2	4.3	3
Endosulfan II		900	4.4	0
Endosulfan sulfate		900	8.7	0
Endrin		50	21	0
Endrin aldehyde		50	13	0
Endrin ketone		50	2.8	0
gamma-Chlordane		500	4.2	0
Heptachlor epoxide		30	5.5	0
Methoxychlor		8,000	27	0

TABLE 11
Comparison of Soils Data from WRF Expansion Site
to USEPA Generic SSLs for Migration to Ground Water

Chemical	Detected in On-site Ground Water	USEPA Generic SSL for DAF = 1	Maximum Soil Concentration	Number of Detections Exceeding the SSL for DAF=1
Perchlorate		ug/kg	ug/kg	
Perchlorate	Yes	NA	59,900	NA
Radionuclides		pCi/g	pCi/g	
Potassium 40		NA (1)	31.00	NA
Uranium 235	Yes	.012 (2)	0.20	34
U-238 chain:				
Uranium 238	Yes	0.012 (2)	4.45	70
Thorium 234		0.012 (3)	4.50	20
Uranium 234	Yes	0.012	4.60	70
Thorium 230	Yes	0.3	4.60	70
Radium 226	Yes	0.016 (2)	3.81	50
Lead 214		0.016 (3)	4.70	70
Bismuth 214		0.016 (3)	4.43	70
Lead 210	Yes	0.00055 (2)	6.90	4
Th-232 Chain:				
Thorium 232	Yes	0.3	1.79	70
Radium 228		0.059 (2)	3.00	70
Actinium 228		0.059 (3)	2.00	66
Thorium 228	Yes	3.3 (2)	1.82	0
Radium 224		3.3 (3)	9.60	24
Lead 212		3.3 (3)	1.52	0
Bismuth 212		3.3 (3)	2.70	0
Thallium 208		3.3 (3)	0.59	0

Notes:
Shading identifies chemicals for which the maximum value exceeds the SSL for migration to ground water
NA indicates that USEPA has not provided a generic SSL for migration to ground water for this chemical
(1) USEPA 2000b states that this SSL cannot be calculated because a default Kd has not been specified for K-40
(2) This SSL is established for the named radionuclide and its decay products
(3) This SSL is established for the named radionuclide as a decay product



..\acad\012131A\perchlorate Distribution.dwg

ENVIRON

PERCHLORATE DISTRIBUTION IN GROUNDWATER
(AS DEVELOPED BY KERR-McGEE)
PROPOSED WRF EXPANSION PROPERTY

Figure
8

samples collected by ENVIRON in May 2001 are generally consistent with Kerr-McGee's representation. The perchlorate concentrations measured at the WRF expansion site in May 2001 are approximately two to three orders of magnitude lower than the concentrations detected by Kerr-McGee within the main body of the perchlorate plume, which appears to pass to the west of the WRF expansion site.

As discussed in Chapter I of this report, NDEP has requested that BEC complete an evaluation of possible impacts to regional ground water quality, which will include a characterization of hydrogeological conditions in the alluvial aquifer at the WRF expansion site. Given that a more refined analysis of leaching has been proposed, the comparison in Table 11 is based on the SSLs developed for a dilution-attenuation factor (DAF) of one, which is likely to be excessively conservative for the WRF expansion site, and is intended for screening purposes only. It is anticipated that the future leaching analysis will involve development of site-specific soil screening levels for migration to ground water.

III. RISK ASSESSMENT APPROACH

A. Risk Assessment Process

The risk assessment approach described in this report is consistent with current USEPA guidance on risk assessment, including primarily USEPA's *Risk Assessment Guidance for Superfund* (RAGS; USEPA 1989). The foundation for this guidance comes from well established chemical risk assessment principles and procedures developed for the regulation of environmental contaminants and is consistent with the process used by the National Research Council (NRC 1983, 1993) and USEPA (1986a). Consistent with this guidance, the general outline of the approach applied in this risk assessment consists of the following four components:

1. Hazard Identification, in which the chemical substances of potential concern at the site are identified;

2. Exposure Assessment, in which the magnitude of chemical exposure is estimated based upon exposure assumptions and characteristics of the population being exposed;

3. Toxicity Assessment, in which the relationship between dose and response is evaluated for each COPC to derive toxicity values that can be used to estimate the incidence of adverse effects occurring at different exposure levels; and

4. Risk Characterization, in which numerical estimates of risk are calculated for each substance being considered in the assessment using the toxicity information and exposure estimates derived in the previous steps.

Application of this process provides a means for evaluating and documenting public health risks associated with environmental exposures. As emphasized by the Office of Science and Technology Policy (OSTP 1985) and USEPA (1986a), with respect to carcinogenic risk assessments, these assessments also involve a number of assumptions and forms of extrapolation that have not been verified by traditional scientific means. These assumptions and forms of extrapolation include animal models of carcinogenesis or tumorigenic potential. Substantial uncertainty exists about how accurate these models are in predicting the likelihood of carcinogenesis or tumor formation in humans. Nevertheless, the risk assessment approach has been accepted by USEPA and other regulatory agencies as providing a rational basis to act in the absence of complete experimental information by adopting a series of conservative assumptions to ensure maximum health protection. Risk assessments performed in this manner are designed to place a realistic upper-bound estimate on risk.

Similarly, risk assessment methods developed for the noncarcinogenic effects of chemicals incorporate various conservative (i.e., health-protective) assumptions. Noncarcinogenic risk assessment is not intended to provide a demarcation between "safe" and "unsafe" levels of exposure. Rather, the approach taken by risk assessors is to ensure that a substantial margin of safety exists between those exposure levels at which toxicity has been demonstrated and potential site-related exposure levels. Thus, the risks estimated using these risk assessment methods are not actuarial (i.e., the risk estimates cannot be used to predict the actual number of individuals who might experience health consequences as a result of exposure). Given the conservative nature of the numerous assumptions employed, actual health risk is almost certainly less than that described using the methods of risk assessment.

The following chapters discuss the various steps of the risk assessment process with respect to the WRF expansion site. The evaluation of chemicals and radionuclides is being conducted separately; thus, Chapters IV through VII are devoted to the four steps of the chemical risk assessment process (Hazard Identification, Exposure Assessment, Toxicity Assessment, and Risk Characterization, respectively) and Chapter VIII addresses the risk assessment of radionuclides. Chapter IX discusses potential limitations and uncertainties associated with the risk assessment as a whole.

B. Conceptual Site Model

One of the objectives of the site characterization activities conducted in May 2001 by ENVIRON was to collect sufficient information to check and revise, as necessary, the conceptual site model (CSM) developed for the site in the *Site Characterization and Risk Assessment Work Plan* (ENVIRON 2001). To address this objective, the soil sampling results summarized in Appendix D were reviewed, as discussed in Section II.B. Few trends arise from a review of the data grouped in this manner. Generally, metals, perchlorate, and radionuclides appear to be distributed throughout the soil column.

VOCs and SVOCs were rarely detected in soil samples collected at the site. These classes of compounds were not detected in a sufficient number of samples to indicate distribution of contaminants throughout the soil column. If these compounds had been transported to the site historically, most have volatilized or degraded over time, as expected. The possible exceptions to this pattern are tetrachloroethene and chloroform, which were detected in only a very limited number of soil samples and only in the deepest samples. Both tetrachloroethene and chloroform have been detected in ground water beneath the site; thus, it is possible that these compounds are present due to migration in ground water from sources located upgradient of the WRF expansion site. These chemicals were not detected in shallower samples indicating that upward migration of volatile constituents from the ground water through the soil column is not occurring to a significant extent. A more detailed review of chemical concentrations by depth is provided in

Appendix D and summarized in Table 6. In addition, a discussion of specific sampling locations that could represent multiple-chemical hot spots is provided in Section B.5.c of Chapter II.

Based on ENVIRON's review, the CSM presented in the work plan (ENVIRON 2001) was revised, as presented below. Revised CSM figures are presented as Figures 9 and 10.

Revised Conceptual Site Model

In the *Site Characterization and Risk Assessment Work Plan* (ENVIRON 2001) for the WRF expansion site, ENVIRON developed a conceptual site model (CSM) to describe the suspected sources of contamination and associated chemical transport mechanisms, and to identify potential exposure scenarios. This CSM was revised based on the results of the site characterization program conducted in May 2001 and is provided in the following sections.

1. Contaminant Source and Primary Transport Mechanisms

Process effluent from the BMI Complex, along with cooling water and storm water, were conveyed to the site through the Alpha and Beta Ditches from the early 1940s until approximately 1976. The following representative BMI companies, among others, have discharged process effluent to the Lower Ponds:

Stauffer Chemical Company discharged process effluent to the Lower Ponds from 1946 to 1970. Although information regarding the characteristics and volume of Stauffer's discharges is limited, the wastewater generated at the plant is reported to have included: 1) effluent from the BHC plant consisting of cooling water containing organic compounds; 2) effluent from the caustic plant containing tank car washings, filter and floor washings, and cell liquor 3) cooling tower blowdown; 4) dilute caustic and salt solutions from tank washings in the caustic, brine, and cell renewal operations; and 5) process wastewater containing organic compounds (Geraghty & Miller 1993). In addition, Stauffer reported in 1980 that asbestos waste generated from the reconditioning of "Hooker" cells used in production might have been discharged to the ponds. Asbestos was used in these cells as a coating on the cathodes, which required periodic removal and replacement.

Montrose Chemical Corporation reportedly disposed of an estimated quantity of 163,500 tons of liquid wastes in the BMI Ponds (including both the Upper and Lower Ponds) between 1947 and 1975 (Geraghty & Miller 1993). Liquid waste streams discharged by Montrose to the Lower Ponds included sulfuric acid, hydrochloric acid, and sulfonated metabolites of DDT. Hydrochloric acid wastes reportedly contained various polychlorinated benzenes.

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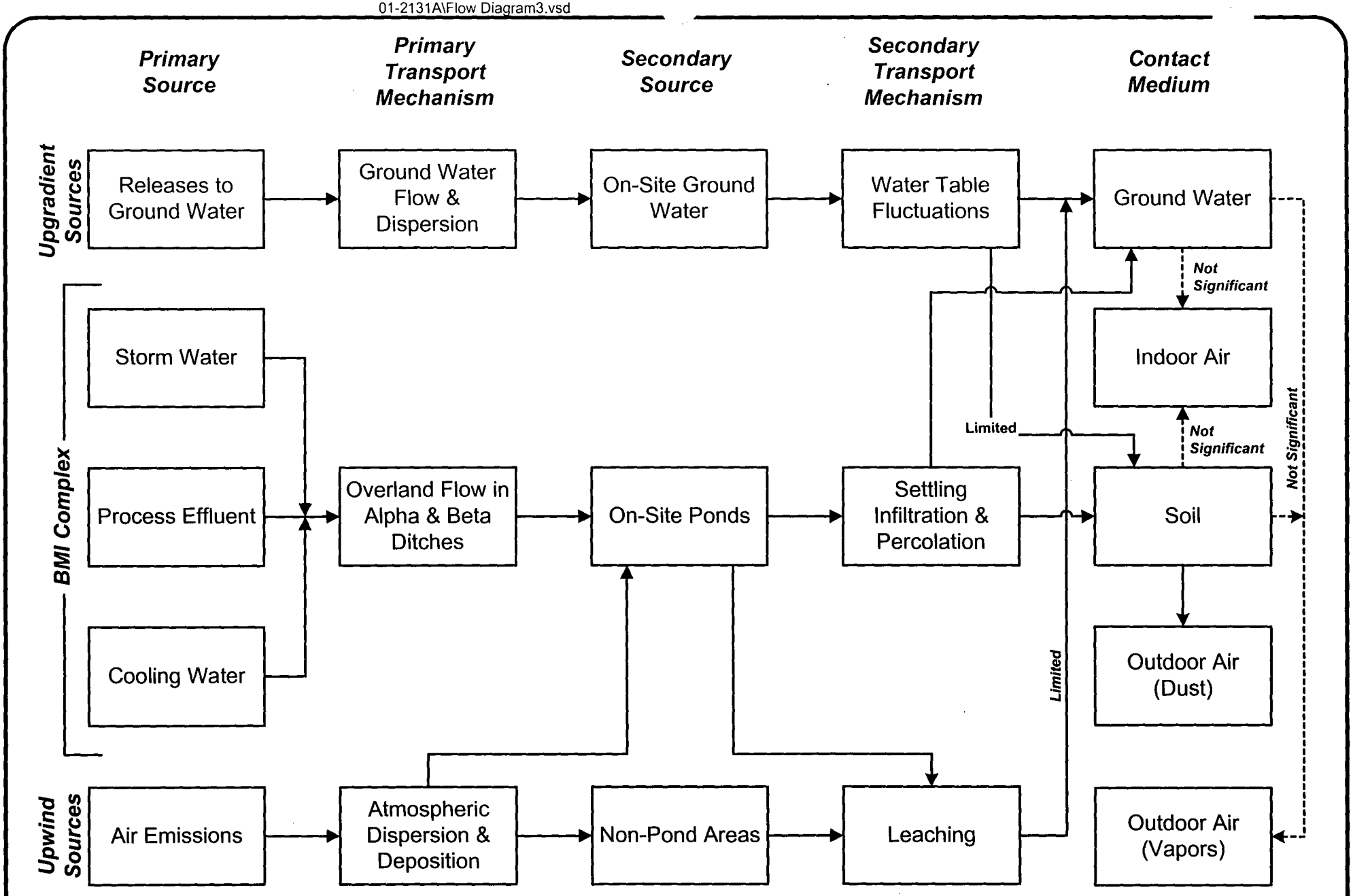

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CSM FIGURE - CONTAMINANT TRANSPORT MECHANISMS

Figure 9

Contact Medium	Exposure Route	During WRF Construction: Construction Worker (South)‡	During WRF Construction: Off-Site Worker	During WRF Construction: Off-Site Resident	Post WRF Construction: Trespasser (North)	Post WRF Construction: Indoor Worker (North & South)	Post WRF Construction: Maintenance Worker (North & South)	Post WRF Construction: Off-Site Worker	Post WRF Construction: Off-Site Resident	Post WRF Construction: Construction Worker (North)
Ground Water	Ingestion	●**	I	I	I	I	●	I	I	●**
	Dermal Contact	●**	I	I	I	I	●	I	I	●**
Indoor Air	Inhalation	I	I	I	I	●* ***From Ground Water Only***	I	I	I	I
Soil	Ingestion	●	I	I	●	Not Significant	●	I	I	●
	Dermal Contact	●	I	I	●	Not Significant	●	I	I	●
Outdoor Air (Dust)	Inhalation	●	●	●	●	Not Significant	●	●	●	●
Outdoor Air (Vapors)	Inhalation	● ***From Ground Water Only***	●* ***From Ground Water Only***	●* ***From Ground Water Only***	●* ***From Ground Water Only***	Not Significant	●* ***From Ground Water Only***	●* ***From Ground Water Only***	●* ***From Ground Water Only***	● ***From Ground Water Only***

NOTE: For on-site exposure populations, the exposure area (i.e., north or south) is indicated in parentheses.

* These pathways are apparently incomplete based on the results of the site characterization program, but are theoretically possible routes of exposure.

I = Incomplete pathway

‡ Based on proposed site plans, almost the entirety of work associated with the construction of the WRF will be conducted in the southern exposure area. The northern exposure area will be used only for staging of equipment; thus, the extent of exposure in the northern exposure area during WRF construction will be very limited and is not evaluated quantitatively in the assessment. However, in the future (after completion of the WRF) construction activities could occur in the Northern Exposure Area. This exposure scenario is evaluated as a "Post-WRF Construction" scenario.

** During WRF construction, dewatering is planned; thus exposure to construction workers is expected to be very limited. For the individual involved in dewatering pipeline maintenaance, exposure to ground water could occur, assuming no PPE is used.

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CSM FIGURE - EXPOSURE POPULATIONS AND PATHWAYS

Figure 10

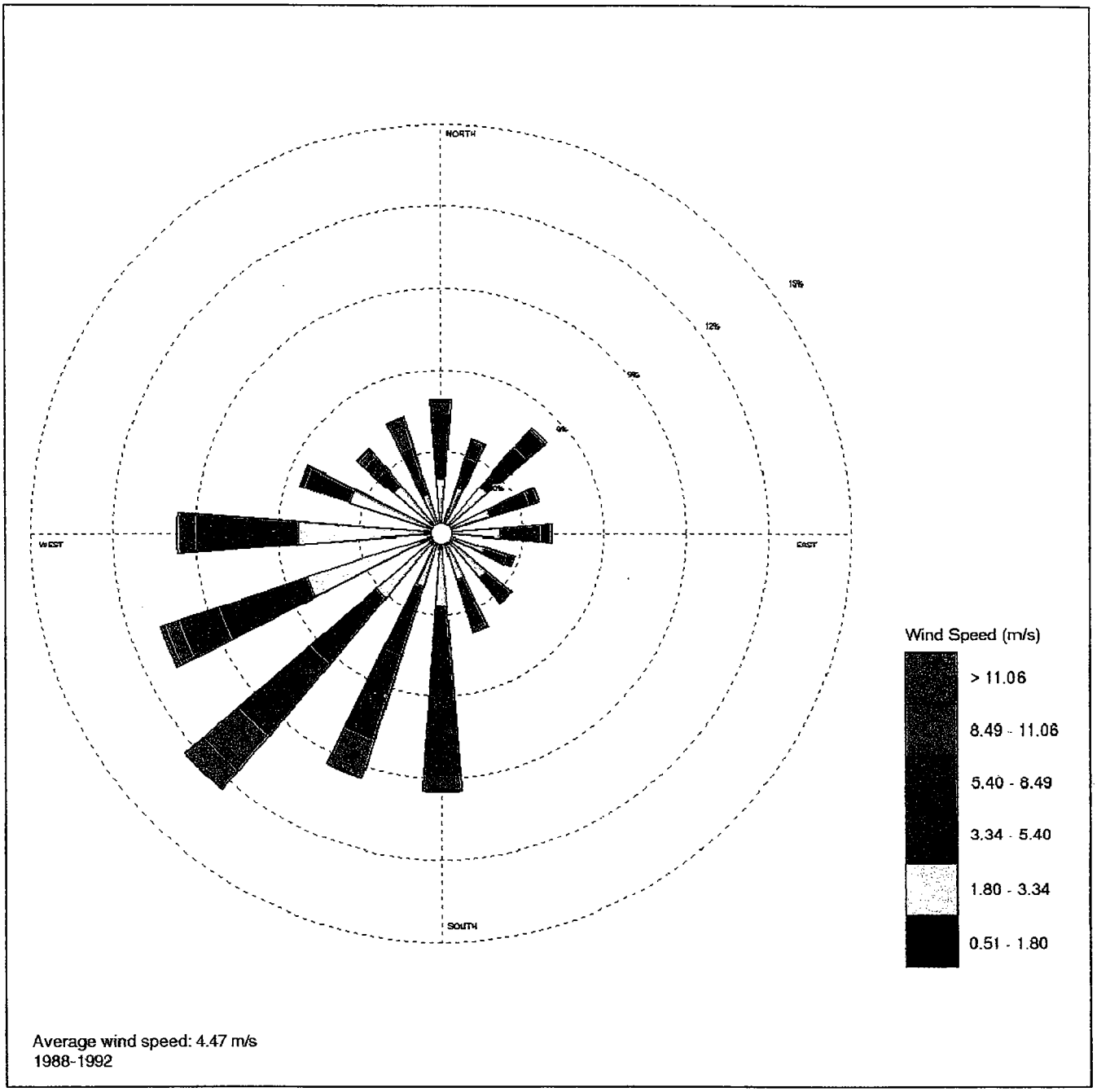
Kerr-McGee Chemical Corporation discharged (along with its predecessors) waste streams consisting of salts and filter cake sluicings to the BMI Ponds. Kerr McGee has indicated, however, that most of its wastes were routed to the Upper Ponds and that discharges to the Lower Ponds were small and infrequent (Geraghty & Miller 1993). Constituents likely present in the discharged materials include calcium carbonate, calcium sulfate, sodium chloride, potassium chloride, potassium perchlorate, hexavalent chromium, magnesium, manganese, zinc, nickel, copper, cobalt, and lead.

Titanium Metals Corporation (TIMET) began manufacturing titanium metal products, including ingots, titanium tetrachloride, titanium sponge, and a magnesium chloride concentrate, in the BMI Complex in the early 1950s. The operations conducted included chlorination, purification, reduction, crushing, leaching, and magnesium recovery processes. Liquid effluents, which may have been discharged to the Upper and Lower ponds included spent caustics, leach liquor, other process water, sludge dryer waste, and cooling water.

It should be noted that a specific historical source of low levels of arsenic observed in soil and ground water at the site has not been identified. However, it is clear that many heavy metals were present in process wastewaters discharged from the BMI Complex and transported to the site via the Alpha and Beta Ditches. It is likely, therefore, that arsenic, although not identified as being a primary constituent in process effluent, was transported to the site primarily by these surface water conveyances. Such a transport and deposition mechanism for arsenic (and other heavy metals) is consistent with the CSM, and with the results of the field sampling program.

The liquid wastes generated by the BMI Complex were discharged to the Lower Ponds and allowed to infiltrate or evaporate. Based on a review of historical aerial photographs of the site, it appears that most (or all) of the former pond cells at the site were used, to varying degrees, for wastewater disposal. These photographs indicate that use of specific individual pond cells tended to be intermittent throughout the history of operations (USEPA 1980), although it is likely that pond cells closer to the BMI Complex (i.e., the Upper Ponds) may have been used to a greater extent than those to the north.

In addition to the transport of chemicals by overland flow of wastewater, other possible mechanisms of transport of contaminants to the site include deposition of airborne chemicals emitted from upwind sources and ground water transport of chemicals released from upgradient sources. The BMI Complex is located generally upwind of the WRF expansion site, as indicated by the wind rose for Las Vegas Airport (Figure 11), and



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NOTE: Display indicates direction from which the wind is blowing.

ENVIRON

WIND ROSE
McCARRAN INTERNATIONAL AIRPORT, LAS VEGAS

Figure
11

is in the general upgradient direction from the site, with respect to ground water flow. The potential sources of contaminants at the site and the associated primary transport mechanisms are illustrated graphically in Figure 9.

2. Secondary Contaminant Transport Mechanisms

The movement of chemicals at the site has changed over time due to changes in the use of the property. An overview of contaminant transport mechanisms during its period of use historically, currently in its undeveloped state, and in the future under the City's proposed use of the site is presented in the following sections of the CSM.

a. Historical Conditions

Chemical constituents in wastewater transported to the ponds would either volatilize, settle to the bottom of the ponds, or infiltrate to the subsurface after being discharged to the ponds, depending on the physical-chemical characteristics of the constituent. A large portion of any volatile organic compounds (VOCs) and possibly semi-volatile organic compounds (SVOCs) discharged to the ponds would be expected to volatilize to the atmosphere. Remaining VOCs and SVOCs would be expected to undergo various physical, chemical, or biological processes, including biodegradation, chemical transformation, or photodegradation. These processes would collectively reduce the overall mass of such contaminants in the water phase of the ponds. As indicated by the results of the site characterization program very few volatile and semi-volatile chemicals were detected in soils at the site and typically at low concentrations.

The hydraulic characteristics of the ponds (i.e., relatively quiescent surface water impoundments) would have been expected to allow certain constituents (primarily insoluble metals and other inorganics) to settle to the floor of the ponds as sediment. Depending on the chemical characteristics of the pond, soluble metals could also precipitate out of solution as solid particles and settle to the pond floor. For these reasons, contaminants at the site are expected to be present primarily in those areas of the site previously occupied by pond cells.

Chemicals may also be present in the Alpha and Beta Ditches. Previous sampling results are available for five ditch locations on the site. In addition, location ADB-07 is located immediately south of the site in the Alpha Ditch. Certain metals had higher average concentrations in the ditches than in the ponds; however, no apparent pattern or trend was observed in the previous soil sampling data. A detailed analysis of the data set obtained from ENVIRON's May 2001 site characterization effort is provided in Section B of Chapter II of this report and Appendices D and G. In addition, the results of the sampling are depicted on

figures ("tag maps") provided in Appendix D, which show the distribution of chemicals in soil at the site. An overview of these tag maps is provided in Section B.4 in Chapter II.

The analysis of the soil sampling data indicates that any systematic differences between concentrations in soils in the ditches and soils in the former ponds are not significant in the context of this risk assessment. The samples collected in the ditches and former ponds appear to be different from the samples collected outside of those areas. This is consistent with the expectation that the primary transport mechanism for the chemicals of concern was surface water flow through the ditches to the ponds. The chemicals that contribute most significantly to the cumulative risk estimates (i.e., arsenic and perchlorate) are generally found at higher levels in the ditches and former ponds than in areas that were not used for waste disposal, as noted in Appendices D and G.

Chemicals not attenuated in the pond sediment would be transported downward through the soil column. The more mobile chemicals would tend to infiltrate deeper into the soil column and a portion of these chemicals could eventually reach the underlying water table.

Airborne contaminants deposited on the ground surface at the site would have remained on the ground surface or would have leached through the soil column to varying extents. In addition, shallow ground water entering the site from the south likely contains contaminants from the BMI Complex (or other upgradient sources) as there is extensive data showing groundwater contamination migrating to hydraulically downgradient areas from the plant site proper. Historical aerial photographs indicate that, in the southernmost part of the site, the water table may have (at times) risen to the ground surface level (USEPA 1980). This could have resulted in chemical constituents being deposited in what is now the vadose zone via a shallow ground water transport pathway. There is evidence that certain chemicals (including tetrachloroethene and chloroform) have been deposited within the capillary fringe just above the water table based on the results of the May 2001 site characterization program. There is no evidence, however, that these volatile chemicals have migrated upward through the soil column to shallower soils.

It should be noted that the atmospheric and ground water transport mechanisms are expected to have been much less significant than the surface water transport pathway based on the reported long-term use of the ponds and the volume of wastewater discharged to the ponds.

b. Current Conditions

The site is no longer receiving wastewater from the BMI Complex and, in general, remains dry; however, limited deposition from atmospheric sources may be continuing. Transport of chemicals to the site from upgradient sources via ground water transport may also be occurring. Since 1976 when use of the ponds and ditches on the site ceased, significant vegetation has grown across much of the site and surficial soils have crusted over, limiting the potential for wind-blown dust. In addition, the entire perimeter of the site has been fenced. Although most of the former structures (i.e., ponds, berms, and ditches) are still evident, some changes are apparent. The Alpha Ditch is still evident across the southern portion of the site, and the Beta Ditch is also present but has been covered in some locations for the construction of access roads[9], effectively cutting off any possible flow of storm water at these locations. Furthermore, the portion of the Beta Ditch that begins just north of the site and continues to the north toward Las Vegas Wash has been filled entirely. Thus, under current site conditions, transport of chemicals off-site from overland flow (erosion and runoff) is not expected to occur to a significant extent.

c. Future Site Use

The City of Henderson is proposing to construct an expansion of its existing WRF on the site. The site will be divided into two primary areas. The southern portion of the site (Southern Exposure Area) will house the proposed expansion of the WRF and associated structures; thus, extensive excavation and construction activities will be required in this area. The northern portion of the site (Northern Exposure Area) will be used as an equipment storage and staging area during the construction process and will only require some minor grading (estimated to be the top 5 feet of soil).

After the WRF is constructed, the northern portion will remain undeveloped, although development for WRF or Public Works Department operational purposes may occur at some point in the future. A plan of the proposed WRF in the southern exposure area is provided in Figure 5.

The proposed WRF facility will consist of numerous unit processes for the physical, chemical, and biological treatment of municipal wastewater. The primary structures proposed for the facility include equalization basins, biological nutrient removal (BNR) basins, an emergency storage basin, an ultraviolet (UV)

[9] It should be noted that the extent of filling of the Beta Ditch in the vicinity of the WRF expansion site is not significant and is limited to several access roadways to the site. Soil sampling conducted by ENVIRON in the Beta Ditch was not conducted in areas that were filled.

disinfection chamber, clarifiers, solids processing operations, and various ancillary structures (e.g., pump houses, pipelines, administration building). With the exception of the emergency storage basin, all structures proposed for the facility's unit operations are to be constructed of reinforced concrete. Maximum depth of excavation required for construction of the proposed structures is estimated at approximately 30 feet (accounting for appropriate foundation construction). Design specifications will require that all excavations be properly dewatered prior to construction of the WRF structures, such that a separation distance of at least 24 inches be maintained between the bottom of the excavation and the ground water table (Black and Veatch 2000b). It is expected that water removed from the excavation area will be piped to an off-site location for discharge under a state-issued discharge to surface water permit (i.e., NPDES), with pretreatment, as necessary. Black & Veatch (2001) has estimated that the dewatering system will operate for a period of approximately 1.5 years. It is assumed for the purposes of this assessment that no discharge of contaminated ground water will occur due to dewatering efforts (i.e., pretreatment will be applied, if necessary). Before contaminated ground water is pumped and discharged, pretreatment methods shall be reviewed with NDEP, Bureau of Water Pollution Control and Bureau of Corrective Action. Long-term contact with this water by receptors at the site, therefore, is unlikely but may occur periodically during maintenance to the pipeline and dewatering system.

With respect to the emergency storage basin, design plans call for the basin to be constructed with a soil cement floor, underlain by compacted soil, a geotextile, and a filter fabric. According to Black & Veatch (2001), the emergency storage basin will be used very infrequently. From an analysis[10] of ten years of available in-flow data to the current WRF, Black & Veatch (2001) indicates that on only one day during this ten-year period would there have been sufficient flow to require the use of the emergency storage basin (if it had been present during that period). Black & Veatch estimates that the frequency of use of the emergency storage basin that will be constructed as part of the WRF expansion will be similar to this past (estimated) frequency. Thus, it is unlikely that this infrequent use of the basin will result in significant infiltration and leaching of any material in the underlying soil to ground water.

The majority of the southern portion of the site will be covered with buildings or paved. Those areas within the southern portion of the site that will

[10] The analysis performed by Black & Veatch to determine the frequency of use of the proposed emergency storage basin was not memorialized in a written report. When a leaching analysis is performed for the WRF site, the in-flow data that was reviewed by Black & Veatch will be provided to NDEP.

not be paved will primarily be covered with landscaping stone. Only very limited areas will be covered with grass. In areas of grass and in raised planters, imported top soil will be used (Black & Veatch 2001) to varying depths. During construction, the northern portion of the site is to be used as a contractor staging area for equipment and excavated soil. Soil staged on the northern area of the site will be covered or otherwise protected from possible weathering and human exposure.

3. Summary of Transport Mechanism

Based on the discussion presented above, the following general conclusions may be drawn regarding the potential distribution of chemical constituents at the site:

Primary Transport Mechanisms

- Surface water transport of industrial wastewater from the BMI Complex represents the primary mechanism by which chemical constituents have been transported to the site.

- Transport of chemicals by ground water from upgradient sources (i.e., the BMI Complex) also represents a possible transport mechanism by which constituents have been transported to shallow ground water at the site.

- Pollutants emitted from upwind sources of emissions to the atmosphere may have been transported to the site and deposited on the ground surface. This transport mechanism likely represents the least significant source of contaminant transport to the site.

Secondary Transport Mechanisms

- Chemical constituents deposited on the ground surface likely would have volatilized, settled to the bottom of the ponds, or infiltrated to the subsurface, depending on the physical-chemical characteristics of the constituent. Thus, the highest concentrations of chemical constituents in soil would likely be present toward the ground surface, with decreasing concentrations at depth. This pattern is observed at many of the sample locations, particularly at those exhibiting the highest levels. There is limited evidence of VOCs and SVOCs in soils at the site, indicating that these types of chemicals have evaporated, degraded, or were never present to a significant extent at the site.

- Certain chemicals in ground water may have been transferred from ground water to soils just above the water table. There is some limited evidence that this has occurred at the WRF expansion site.

- Ground water underlying the site could have been affected by chemical constituents infiltrating from the overlying pond cells.

- Although the upward migration of volatile chemicals from subsurface soils and from ground water to the ambient air is theoretically possible, the results of the May 2001 field program do not indicate that such migration is occurring to a significant extent (i.e., chemicals detected in soils at the water table and in ground water were not detected in shallow soils).

- Current surface-level sources of contaminant transport (e.g., erosion and runoff) are likely limited given the current topographic conditions at the site. Wind-blown dust emissions are, however, a possible transport mechanism.

4. Potential Exposure Scenarios

Based on the discussion provided above, the possible exposure scenarios for the current and future use of the site are identified below and illustrated in Figure 10.

During Construction of the WRF Expansion

Southern Exposure Area

- Off-site workers and residents may be exposed to dust from excavation activities and dust blown from the northern exposure area. Excavation activities are expected to involve the entire soil column to a maximum depth of approximately 30 feet. Vapor emissions from soil and off-site transport appears to be insignificant given the limited detection of volatile chemicals in soil. Migration of volatile constituents from ground water to the ground surface is expected to be very limited or nonexistent given the limited evidence of VOC migration upward through the soil column.

- During construction activities, workers may be exposed to chemicals in soil through incidental ingestion and dermal contact. It is anticipated that construction workers may be exposed to soils throughout the entire soil column during construction activities. Exposure to vapors emitted from soil and ground water

could also occur but is expected to be limited. Construction workers may also be exposed to dust from both the southern and northern areas of the site. It is not expected that most construction workers will be exposed to ground water because all excavations in the work area will be dewatered. However, a construction worker who is involved in maintenance of the dewatering system could be exposed to chemicals in ground water due to unexpected leaks and splashing that might result in incidental ingestion and dermal contact with ground water. If necessary, this type of exposure could be limited through the use of PPE during pipeline maintenance activities.

Northern Exposure Area

- Off-site workers and residents may be exposed to dust generated from grading and wind erosion. Wind-blown dusts will likely be generated from surficial (0 to 1 foot) soil; whereas, deeper soils (up to 5 feet below ground surface) may generate airborne dust during grading activities. Emissions of vapors from soil appear to be insignificant given the limited number of detected volatile constituents in soil at the site. Furthermore, emissions of vapors from ground water to the atmosphere also appear to be insignificant or nonexistent given the limited evidence of upward migration of VOCs through the soil column.

- Based on the proposed construction plans for the WRF expansion site, most of the activities associated with WRF construction will occur in the southern exposure area; however, there will be a limited number of activities that will occur in the northern exposure area (e.g., grading of the ground surface). Exposures that might occur in the northern part of the site during WRF construction will be significantly less than exposures to workers in the southern part of the site. Thus, for the purposes of this assessment a single WRF construction worker scenario is evaluated for the southern exposure area. Any exposure that occurs in the northern exposure area during WRF construction is assumed to be encompassed within this WRF construction worker scenario.

After Construction of the WRF Expansion

Southern Exposure Area

- Theoretically, an indoor worker at the WRF could be exposed to volatile chemicals emitted in the vapor phase from soil and ground water that migrate into

the buildings. However, there were only limited VOC detections in soil during the site characterization program, and there is limited evidence that the upward movement of chemicals from ground water is occurring. Thus, this pathway appears to be insignificant.

- A maintenance worker at the WRF may be exposed through incidental ingestion of and dermal contact with soil. It is expected that most exposure by a worker would be to surficial (0 to 1 foot) soils; although deeper soils could be brought to the surface due to construction activities. Exposure to vapors emitted from soil and ground water to the ground surface is expected to be limited (as noted above). Although highly unlikely, it is possible that a maintenance worker could come in contact with shallow ground water during periodic excavation or trenching activities.

Northern Exposure Area

- A trespasser may be exposed through incidental ingestion of and dermal contact with soil and through inhalation of wind-blown dust. Wind-blown dusts will be generated from surficial soils (0 to 1 foot); although deeper soils could be brought to the surface due to grading. Emissions of vapors from soil and ground water are expected to be very limited or nonexistent (as discussed above).

- Off-site workers and residents may be exposed to wind-blown dust. Wind-blown dusts will be generated from surficial soils (0 to 1 foot); although deeper soils could be brought to the surface due to grading. Emissions and off-site transport of vapors from soil and ground water are expected to be very limited or nonexistent (as discussed above).

- If the northern portion of the site is developed by the City, a construction worker in the north could be exposed through incidental ingestion of and dermal contact with soil, and inhalation of dust/vapors. There currently are no plans to develop this portion of the property, and any future development by the City would be likely limited to "surface use" (e.g., parking lots, warehouses, equipment storage), requiring only limited construction activity. If the City chose to construct structures that required excavation, it is assumed that dewatering (as is being required by the City in the southern exposure area) would be performed; thus, an individual maintaining the dewatering pipeline could be exposed to ground water due to incidental ingestion and dermal contact associated with unexpected leaks or

splashing. This type of exposure could be eliminated through the use of PPE. Construction workers not involved in dewatering pipeline maintenance are unlikely to come into contact with ground water.

- After development of the northern portion of the site, a maintenance worker could be exposed through incidental ingestion of and dermal contact with soil. It is expected that most exposure by a worker would be to surficial (0 to 1 foot) soils; although deeper soils could be brought to the surface due to grading. Exposure to vapors emitted from soil and ground water to the ground surface is expected to be limited (as noted above). Exposure to wind-blown dust (if the entire northern exposure area were not developed or paved) could also occur. It is possible that a maintenance worker could also come in contact with shallow ground water (through dermal contact and incidental ingestion) during periodic excavation or trenching activities. The depth to ground water in the two monitoring wells sampled in the northern exposure area was 19 feet and 24 feet below ground surface, respectively. However, in the two monitoring wells north of the site (350 to 500 feet from the northern boundary), ground water was observed at a depth of between 6 feet and 7 feet below ground surface. In addition, in the three soil borings located nearest the northern boundary of the site (i.e., P17, B3, and E2), soil was observed to be "wet" at the bottom of the bore hole (8.5 feet, 5 feet, and 8 feet, respectively). The wet soils observed in these bore holes may be associated with the capillary fringe. As an average for the northern exposure area, a depth to ground water of 14 feet is used in the risk assessment as an approximate average of the various ground water measurements collected in this area of the site and the off-site wells.

- Once developed, an indoor worker could be exposed to volatile chemicals emitted in the vapor phase from soil and ground water that migrate into any buildings that may be constructed. There were only limited VOC detections in soil during the site characterization program, and there is limited evidence that the upward movement of chemicals from ground water is occurring. Thus, this pathway appears to be insignificant.

5. Ecological Habitats

Ecological habitats on the site are unlikely to be significant given the lack of water, the presence of a complete perimeter fence, and the small area encompassed by the site (i.e., species would likely spend only a limited period of time at the site). Furthermore, any populations currently present will be limited in the future upon

construction of the WRF expansion. The nearest ecological habitats to the site of any significance are a bird preserve, located north of the current WRF and west of the northern portion of the site; Las Vegas Wash, which flows from west to east approximately ½-mile north of the site; and a wetlands area approximately 1,000 feet north of the site. It is likely that ground water that passes beneath the site discharges to the wetlands and Las Vegas Wash. There are no current surface water discharges from the site to these potential habitats, nor are any planned for the future. Thus, surface water pathways of exposure for ecological populations in these areas are not expected.

It is possible that ecological populations could be exposed to chemicals in ground water that discharges into Las Vegas Wash or the adjacent wetlands. As indicated by the preliminary leaching analysis summarized in Chapter II, it is possible that the WRF expansion site could be contributing to ground water contamination beneath the site and, hence, in the wetlands and Las Vegas Wash, which are likely hydraulically connected with ground water. It is highly unlikely, however, given the direction of ground water flow, that the site would be contributing to concentrations in the bird preserve to the west of the site. Table D-5 (in Appendix D) provides a comparison of detected ground water concentrations for wells on the site and north of the site with AWQC for freshwater. As indicated in Table D-5, several metals, including aluminum, iron, hexavalent chromium, and selenium, exceed the corresponding freshwater AWQC. Given this possible exposure pathway for ecological population, a discussion of possible ecological effects due to ground water is provided in Section D of Chapter VII.

Although it is possible that surficial soils could be blown from the site and deposit within the wetlands, bird preserve, or on Las Vegas Wash, this pathway is likely limited, given that after development the entire southern portion, and possibly the northern portion of the site, will be paved or covered with buildings. If the northern portion of the site is not developed immediately, the City will be required, under Clark County Air Quality Regulations, to eliminate wind-blown fugitive dust emissions[11] from the unused portion of the site through control measures (e.g., dust suppressants, paving, vegetation). Additional discussion of potential ecological exposure to wind-blown dust is provided in Section D of Chapter VII.

[11] Clark County Air Quality Regulations require dust emissions control for disturbed vacant land. An overview of the regulations and recommended control measures is provided in Appendix J.

IV. HAZARD IDENTIFICATION

A. Overview

Sampling of soil and ground water at the WRF expansion site was conducted by ENVIRON in May 2001. The data collected as part of this effort serve as the basis for the human health risk assessment. As discussed in Chapter II, the samples collected during the site characterization program were analyzed for a broad range of analytes, including VOCs, SVOCs, metals and other inorganic compounds (i.e., perchlorate and cyanide), pesticides, radionuclides, dioxin/furans, PCBs, and asbestos. In total, laboratory analyses were conducted on the samples for more than 200 individual constituents. Many of these chemicals were not detected or may pose an insignificant risk due to low concentrations. In order to focus the risk assessment on those substances that are expected to pose the greatest concern, a subset of all the chemicals for which analyses were performed, referred to as Chemicals of Potential Concern (COPCs), was identified for quantitative evaluation in the risk assessment. This chapter summarizes the process applied in organizing the data in a form appropriate for the risk assessment and describes the process used to identify the COPCs that are evaluated quantitatively in the risk assessment.

B. Identification of Chemicals of Potential Concern

One of the first steps of the risk assessment process is the identification of COPCs at the site. USEPA guidance (USEPA 1989) recommends that the risk assessment focus on the most significant chemicals within a particular medium based on frequency of detection, concentration, and toxicity. Preliminarily, all chemicals that were detected in samples collected from the site during the May 2001 field program were considered as COPCs. Individual sets of COPCs were developed for soil and ground water at the site, as described in the following sections.

1. COPCs in Soil

An initial list of COPCs was identified from the May 2001 site characterization data based solely on those chemicals that were detected in at least one soil sample. This list of COPCs includes 7 VOCs, 3 SVOCs, 23 metals, 17 dioxin/furan congeners, 14 pesticides, 18 radionuclides, and perchlorate. The 65 non-radioactive chemicals are listed in Table 12; the radionuclides are addressed in Chapter VIII.

ENVIRON conducted an additional review of the analytical results for the seven VOCs and three SVOCs detected at the site in order to focus the assessment on those chemicals most likely to pose a concern at the site, as recommended by USEPA (1989). USEPA's *Risk Assessment Guidance for Superfund* (USEPA 1989) indicates that several factors, such as toxicity, frequency of detection, background concentrations, blank contamination, and nutrient information can be taken into consideration when evaluating

TABLE 12
Non-Radionuclide Chemicals Detected in Soil at the WRF Expansion Site

Pesticides	Metals		Dioxins/Furans
4,4'-DDD*	Aluminum*	Magnesium*	1,2,3,4,6,7,8-HpCDD*
4,4'-DDE*	Antimony*	Manganese*	1,2,3,4,6,7,8-HpCDF*
4,4'-DDT*	Arsenic*	Mercury*	1,2,3,4,7,8,9-HpCDF*
alpha-Chlordane*	Barium*	Molybdenum*	1,2,3,4,7,8-HxCDD*
beta-BHC*	Beryllium*	Nickel*	1,2,3,4,7,8-HxCDF*
Dieldrin*	Cadmium*	Selenium*	1,2,3,6,7,8-HxCDD*
Endosulfan II*	Chromium (total) *	Silver*	1,2,3,6,7,8-HxCDF*
Endosulfan sulfate*	Cobalt*	Thallium*	1,2,3,7,8,9-HxCDD*
Endrin*	Copper*	Thorium*	1,2,3,7,8,9-HxCDF*
Endrin aldehyde*	Iron*	Titanium*	1,2,3,7,8-PeCDD*
Endrin ketone*	Lead	Vanadium*	1,2,3,7,8-PeCDF*
gamma-Chlordane*		Zinc*	2,3,4,6,7,8-HxCDF*
Heptachlor epoxide*			2,3,4,7,8-PeCDF*
Methoxychlor*			2,3,7,8-TCDD*
			2,3,7,8-TCDF*
			OCDD*
			OCDF*

SVOCs	VOCs	Inorganic Compounds
Buytl benzyl phthalate	Acetone	Perchlorate*
Di-n-butyl phthalate	Chloroform	Asbestos**
Phenol	Ethylbenzene	
	Methylene chloride	
	Tetrachloroethene	
	Toluene	
	Xylenes (total)	

Note:
* - COPC selected for further quantitative evaluation in the risk assessment.
** - Asbestos was not detected in the May 2001 site characterization field program (using PLM); however, it was detected in the supplemental field program in October 2002 in which soil samples were analyzed for asbestos using the elutriator method. As such, it was retained as a COPC. The risk assessment for asbestos is discussed in Chapter IX.

chemicals for possible elimination from quantitative assessment. Thus, as an initial step, the frequency of detection in the northern and southern exposure areas for each of the 10 chemicals listed in Table 13 was determined. USEPA (1989) suggests a cut-off of 5 percent, below which a chemical can reasonably be eliminated. As indicated in Table 13, ethylbenzene, tetrachlorethene, xylenes, butylbenzylphthalate, di-n-butylphthalate, and phenol are all below a 5 percent frequency of detection. Acetone and methylene chloride were detected in numerous method blank samples, indicating that the detection of these chemicals was likely the result of laboratory contamination. Finally, toluene and chloroform were detected at very low concentrations, significantly below commonly applied risk benchmark values (as indicated by the PRG values shown in Table 13). Furthermore, chloroform is present in only four samples collected from wide ranging locations (A-1, S-2, P-5, and P-7), each at the maximum sample depth (i.e., all chloroform detections were at depths of at least 16 feet below ground surface). It is likely that these detections of chloroform are associated with the ground water. Thus, given the limited extent of contamination by VOCs and SVOCs and the low concentrations of these chemicals, the likelihood of exposure to VOCs and SVOCs in soil appears very limited. Thus, the VOCs and SVOCs detected in soil were eliminated from further quantitative consideration in the risk assessment. It should be noted, however, that the VOCs that were detected in ground water are evaluated for the ground water exposure pathways (e.g., volatilization of chloroform from ground water is evaluated).

In the *Site Characterization and Risk Assessment Work Plan* (ENVIRON 2001), ENVIRON proposed to use the Region 9 PRG for lead in industrial soil (750 mg/kg) as an indication of possible concern for exposure to lead. If results of the site characterization program indicated a maximum detected concentration in lead in excess of the industrial soil PRG for lead, ENVIRON proposed to apply the USEPA non-residential blood lead model (USEPA 1996b, 1999a), which evaluates potential exposures to the most sensitive receptor for non-residential land use. The maximum lead concentration in soil detected at the site during the site characterization program was 379 mg/kg in the southern exposure area and 75 mg/kg in the northern exposure area; thus, lead was not selected as a COPC for soil.

After the elimination of VOCs, SVOCs, and lead, the remaining non-radionuclide COPCs that are evaluated quantitatively in the risk assessment include the 22 metals, 17 dioxin/furan congeners, 14 pesticides, and perchlorate, as identified in Table 12.

ENVIRON conducted supplemental soil sampling at the site in October 2002 to provide additional data to evaluate potential risks associated with asbestos. Although asbestos was not detected during the May 2001 site program (using PLM), it was detected in the October 2002 sampling program. As such, asbestos was retained as a COPC, as indicated in Table 12. The asbestos risk assessment is provided in Chapter IX.

TABLE 13
Analysis of VOCs and SVOCs Detected in Soil

Chemical	Northern Exposure Area		Southern Exposure Area		Maximum Conc. (µg/kg)	PRG (µg/kg)
	Number of Samples	Number of Detects (% of samples)	Number of Samples	Number of Detects (% of samples)		
Volatile Organic Compounds						
Acetone	30	5 (17%)	44	6 (14%)	17	6,000,000
Chloroform	30	1 (3%)	44	3 (7%)	21	2,000
Ethylbenzene	30	1 (3%)	44	0 (0%)	1.2	20,000
Methylene chloride	30	1 (3%)	44	4 (9%)	4.1	21,000
Tetrachloroethene	30	0 (0%)	44	2 (5%)	4.5	3,400
Toluene	30	3 (10%)	44	1 (3%)	7.3	520,000
Xylenes	30	1 (3%)	44	0 (0%)	1.8	420,000
Semivolatile Organic Compounds						
Butylbenzylphthalate	30	0 (0%)	44	1 (3%)	80	100,000,000
Di-n-butylphthalate	30	0 (0%)	44	1 (3%)	130	62,000,000
Phenol	30	0 (0%)	44	1 (3%)	120	100,000,000

2. COPCs in Ground Water

As part of the site characterization program, ground water samples were collected from six wells on and adjacent to the site, and laboratory analyses were conducted for VOCs (five samples), SVOCs, pesticides, PCBs, dioxins/furans, metals, inorganic compounds, and radionuclides. In selecting COPCs for ground water, however, results from one of the six wells (PC-56, located approximately 350 feet north of the northern boundary of the site) were not included because it appears that this well is not downgradient of the WRF expansion site but is located within a separate alluvial channel located primarily west of the site (see Figure 8). Thus, in the other five wells a total of 37 chemicals were detected, including 5 VOCs, 21 metals, 2 inorganic compounds, and 9 radionuclides. Although it is possible that several compounds, such as acetone and toluene could be laboratory contaminants, no additional effort was made to limit the number of COPCs in ground water; thus, all of the chemicals detected in the five ground water wells on or downgradient of the site are evaluated quantitatively in the risk assessment. The list of non-radionuclide COPCs in ground water is provided in Table 14.

TABLE 14
Non-Radionuclide Chemicals of Potential Concern (COPCs) in Ground Water at the WRF Expansion Site

Inorganic Compounds	**Metals**
Perchlorate	Aluminum
Cyanide	Arsenic
	Barium
	Beryllium
VOCs	Cadmium
Acetone	Chromium (total)
Carbon tetrachloride	Chromium (hexavalent)
Chloroform	Cobalt
Tetrachloroethene	Copper
Toluene	Iron
	Lead
	Magnesium
	Manganese
	Molybdenum
	Nickel
	Selenium
	Silver
	Thorium
	Titanium
	Vanadium
	Zinc

V. EXPOSURE ASSESSMENT

The exposure assessment component of the risk assessment involves the estimation of the magnitude of exposure (i.e., dose) for individuals who may come into contact with site contaminants. The exposure assessment process comprises several steps, which include 1) identifying the potentially exposed populations and exposure pathways; 2) estimating concentrations of chemicals in media to which individuals may be exposed; and 3) estimating the dose of chemicals from each medium to exposed individuals. The following sections describe in greater detail the methodology that was used in conducting the exposure assessment.

A. Identification of Potentially Exposed Populations and Pathways

Individuals may come into contact with chemicals at or from the site due to proposed construction activities or subsequently during future use of the site. A discussion of the populations potentially exposed to chemicals in site soils and ground water beneath the site is provided below.

1. During WRF Construction Activities

As described in Chapter I, the City of Henderson is proposing to construct on the site an expansion of its existing WRF. Construction of the WRF will require grading of the ground surface in the northern portion of the site to facilitate its use as a contractor staging area. Similar grading activities will take place in the southern portion of the site to prepare the site for construction. In addition, construction of the WRF in the southern portion of the site will require excavation to depths up to approximately 30 feet below the current ground surface (see Figure 5). After pre-construction grading is completed, the depth of excavation for construction purposes is expected to be somewhat less than 30 feet.

Based on the proposed activities to be conducted at the site as part of the construction of the WRF, construction workers are expected to be exposed to chemicals in soils through direct contact (i.e., incidental ingestion and dermal contact) and through inhalation of dust generated during excavation, truck traffic, and grading activities. In addition, construction workers may also be exposed to volatile constituents emitted from ground water. The volatile COPCs in soil are very limited and were eliminated from quantitative analysis; therefore, exposure to vapors emitted from soil is not expected to be significant. For the purposes of this assessment, the WRF construction worker is assumed to be exposed primarily in the southern exposure area; although, dust generated during grading of the northern exposure area and other construction-related activities are also considered. The limited exposures that may occur in the northern part of the site during WRF construction are expected to be significantly less than exposures in the

southern part of the site and are assumed to be encompassed by the assessment of the construction worker in the southern area of the site.

The specification documents (Black & Veatch 2000b) provided as part of the WRF construction bidding process require that all excavations be "dewatered by lowering and keeping the groundwater level [to]...24 inches or more below the bottom of the excavation." Therefore, it is assumed that long-term, direct contact with ground water by construction workers in the excavation area will not occur. The water removed from the excavation pit will be piped off-site for discharge under a state-issued discharge to surface water (i.e., NPDES) permit, with pretreatment, if necessary. Routine maintenance of the dewatering pipeline is likely to result in some level of exposure to ground water due to leaks from the system. Black & Veatch (2001) has indicated that the dewatering pipeline will be operated for a portion (approximately 1.5 years) of the entire construction duration. This periodic exposure to ground water by a worker through incidental ingestion and dermal contact, therefore, was evaluated in the risk assessment.

Excavation and grading activities will generate dust that will be transported off-site by wind. Workers at the current WRF situated adjacent to the southwestern boundary of the site and nearby residents may be exposed to dust and vapors transported off-site. It is possible that emissions of vapors from ground water may occur. This pathway is likely to be very limited or incomplete, given that evidence of significant upward migration of volatile chemicals from the ground water table through the soil column was very limited in the results of the site characterization program. To be conservative, however, exposure by off-site workers and residents to vapors from ground water is evaluated in the risk assessment. The nearest residents are located approximately one-half mile to the southwest of the WRF expansion site. The nearest residents in the predominant downwind direction are two to three miles from the site. The screening-level dispersion models used in this assessment, however, provide estimates of exposure at the fence line of the WRF expansion site.

A summary of the populations and pathways of exposure that are evaluated in the risk assessment is provided in Table 15.

2. Future Use (After Construction of the WRF)

The site will be composed of two primary areas: the southern portion of the site will house the WRF expansion, while the northern portion of the site will remain undeveloped; although development for Public Works Department purposes may occur at some point in the future.

In the southern portion of the site, most activities will be conducted inside the buildings, and a large portion of the site will be paved, effectively eliminating direct contact exposure to soil. Those areas within the southern portion of the site that will not

TABLE 15
Summary of Populations and Pathways Evaluated in the Risk Assessment of the Proposed WRF Expansion Site

Population	Exposure Area	Exposure Pathways					
		Soil			Ground Water		
		Ingestion	Dermal	Inhalation Of Dust	Incidental Ingestion	Dermal	Inhalation of Vapors
During WRF Construction							
WRF Construction Worker	South	X	X	X	X[3]	X[3]	X
Off-site Resident	Off-site	Incomplete	Incomplete	X	Incomplete	Incomplete	X[1]
Off-site Worker	Off-site	Incomplete	Incomplete	X	Incomplete	Incomplete	X[1]
Future Use – After WRF Construction							
Trespasser	North	X	X	X[4]	Incomplete	Incomplete	X[1]
Indoor Worker	South	Not significant[2]	Not significant[2]	Not significant[2]	Incomplete	Incomplete	X[1]
Indoor Worker	North	Not significant[2]	Not significant[2]	Not significant[2]	Incomplete	Incomplete	X[1]
Maintenance Worker	North	X	X	X[4]	X	X	X[1]
Maintenance Worker	South	X	X	X[4]	X	X	X[1]
Off-site Resident	Off-site	Incomplete	Incomplete	X[4]	Incomplete	Incomplete	X[1]
Off-site Worker	Off-site	Incomplete	Incomplete	X[4]	Incomplete	Incomplete	X[1]
Default Construction Worker	North	X	X	X[4]	X[3]	X[3]	X[1]

Notes:
X – Exposure by this pathway is evaluated for the indicated population. "Incomplete" indicates that the specified receptor population will not be exposed to the specified medium by this pathway.
1 – Although this pathway is believed to be incomplete or insignificant, potential exposures are evaluated in this assessment, given that ground water could be a continuing source of emissions in the future.
2 – Although assumed to be on-site, indoor workers are expected to spend most or all of the time indoors.
3 – Dewatering is being required (in the construction specifications) for the WRF expansion project in the southern exposure area. The northern portion of the site, if developed, would likely be used for surface uses (e.g., parking lot, warehouse); however, if excavation were required, dewatering would be conducted there as well. For the purposes of the risk assessment, exposure to ground water by a WRF construction worker in the southern exposure area and a future default construction worker in the northern exposure area is evaluated assuming an individual who maintains the dewatering pipeline periodically contacts ground water.
4 - Exposure to airborne dust is estimated assuming that the northern area of the site is not developed immediately and that it represents a source of dust emissions for all scenarios, with one exception. For the maintenance worker in the northern exposure area, it is assumed that the northern area is eventually developed but a portion (50%) remains undeveloped/unvegetated. ENVIRON recognizes that these are somewhat conflicting assumptions, but they are applied in this risk assessment to evaluate the scenarios conservatively.

be paved will be covered with landscaping stone. Small areas of the site will be covered with grass or decorative shrubs (Black and Veatch 2000b). Furthermore, the City intends to provide institutional controls (e.g., deed restrictions) to eliminate on-site exposure to ground water.

It is possible that certain individuals (e.g., maintenance workers) may be required to spend a portion of time performing activities that result in exposure to soil (e.g., excavation, trenching activities). Therefore, it is assumed that both incidental ingestion of soil and dermal contact with soil by a maintenance worker may occur. It should be noted, however, that extensive exposure to site-related soil is not expected because design specifications (Black & Veatch 2000b) for the WRF expansion call for the use of imported top soil in landscaped areas (turf and raised planters plantings). Maintenance workers may also be exposed to wind-blown dust from the northern portion of the site[12] and vapors from ground water. As noted above, exposure to vapors from ground water does not appear to be a completed pathway; nonetheless, this exposure scenario is evaluated in this assessment. Although highly unlikely, it is possible that a maintenance worker could come in contact with shallow ground water during periodic excavation or trenching activities.

Individuals conducting primarily indoor work could be exposed to volatile constituents that are emitted from ground water, migrate upward, and infiltrate the building through cracks in the foundation. It should be noted, however, that there is no evidence that such migration is occurring to a significant extent. There are no volatile COPCs in soil; therefore, exposure to vapors emitted from soil is not treated as a complete exposure pathway.

In the northern, undeveloped portion of the site, children may trespass and be exposed to contaminants in surface soils through incidental ingestion and dermal contact with soil. These children will also be exposed to wind-blown dust from the northern portion of the site and emissions of volatile constituents from ground water. It is assumed that the trespassing child is in the 7-to-12-year-old age range, the youngest likely age range (and thus conservative) for children to play unsupervised. In addition, the possible exposure to vapors from ground water by a trespasser is also evaluated; although this pathway is believed to be incomplete or insignificant.

Wind-blown dusts from the northern portion of the site and vapors emitted from ground water may also be carried off-site. Workers and residences located in the vicinity of the site, therefore, may be exposed via the inhalation pathway (dust and vapors).

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[12] Exposure to airborne dust is estimated assuming that the northern area of the site is not developed immediately. For the maintenance worker in the northern exposure area, it is assumed that the northern area is eventually developed, but a portion (50%) remains undeveloped/unvegetated. ENVIRON recognizes that these are somewhat conflicting assumptions, but they are applied in this risk assessment to evaluate the scenarios conservatively.

Although not currently planned, it is possible that the City may eventually develop the northern portion of the site. The City has indicated that development in this portion of the site, if conducted in the future, would not be to the extent planned for the southern portion of the site. Instead, development would be likely limited to "surface use" (e.g., parking lots, warehouses, equipment storage), requiring only limited excavation and construction activity. Given the uncertainty associated with this future scenario, however, as a default, exposure by a hypothetical future construction worker in the northern exposure area was evaluated, using the same pathways as applied for the WRF construction worker scenario in the southern exposure area.

B. Estimation of Environmental Media Concentrations

Exposure concentrations of COPCs in soil, ground water, and air (indoor and outdoor) were estimated based on site characterization data and the application of fate and transport models, when necessary. The exposure concentrations used in the risk assessment are a function of the exposure scenario and the location of exposure. A summary of the methodologies that were applied in estimating exposure concentrations is provided below. Tables 16 and 17 summarize the source of the data used to estimate exposure point concentrations for the construction and post-construction exposure scenarios, respectively.

1. Soil

Prior to construction, site preparation activities in the northern and southern portions of the site will consist primarily of grading. These site preparation activities will result in the mixing of soils within approximately the top 5 feet in the northern portion of the site and within approximately the top 10 feet in the southern portion of the site based on design documents for the proposed WRF expansion. Because the grading will likely redistribute the soil, the data obtained in May 2001 are not expected to correspond directly to post-grading concentrations at individual sample locations. This does not affect the risk assessment, however, because the exposure scenarios consider large exposure areas, not specific locations. Because grading will redistribute the soils within each exposure area, the data collected within each exposure area are considered to be representative of the near-surface soils before and after the grading is complete.

As a first step, the 95 percent upper confidence limit (95% UCL) of the mean concentration of each chemical in the soil samples collected within a specific area (as identified in Table 16 and 17) of the site was estimated. Given that the exposure scenarios differ for the northern and southern portions of the site, individual 95% UCL concentrations were developed for each of these areas and for individual exposure populations, as shown in Table 16 and 17. The approach used to calculate 95% UCL concentrations for these areas included the following:

TABLE 16
Source of Data Used to Calculate Exposure Point Concentrations for the WRF Construction Exposure Scenarios Evaluated in the Risk Assessment

Population	Exposure Area	Source of Data Used to Calculate Exposure Point Concentrations (by exposure pathway)					
		Soil			Ground Water		
		Ingestion	Dermal	Inhalation of Dust	Incidental Ingestion	Dermal	Inhalation of Vapors
WRF Construction Worker	South	Two EPC estimates were developed: 1. 95% UCL of soil samples from the top 10 ft. 2. 95% UCL of all soil samples (0 to 1 ft bgs, 10 to 12 ft bgs, and just above the water table)		Excavation and dozing dust from the SEA: EPC = 95% UCL of all soil samples (0 to 1 ft bgs, 10 to 12 ft bgs, and just above the water table) Wind-blown dust and truck traffic in the SEA Two EPC estimates were developed: 1. 95% UCL of soil samples from 0 to 1 ft bgs 2. 95% UCL of soil samples from 0 to 1 ft bgs and 0 to 12 ft bgs Wind-blown, truck traffic, and grading dust from the NEA Two EPC estimates were developed: 1. 95% UCL of surface soil samples (0 to 1 ft bgs) 2. 95% UCL of soil samples from 0 to 1 ft bgs and 4 to 5 ft bgs	Maximum concentration in exposure-area ground water		
Off-site Worker	Off-site	Incomplete	Incomplete		Incomplete	Incomplete	Maximum concentration in exposure area
Off-site Resident	Off-site	Incomplete	Incomplete		Incomplete	Incomplete	Maximum concentration in exposure area

Notes:
NEA – Northern Exposure Area
SEA – Southern Exposure Area
EPC – Exposure point concentration
bgs – below ground surface

TABLE 17
Source of Data Used to Calculate Exposure Point Concentrations for the Future (After WRF Construction) Exposure Scenarios Evaluated in the Risk Assessment

Population	Exposure Area	Source of Data Used to Calculate Exposure Point Concentrations (by exposure pathway)					
		Soil			Ground Water		
		Ingestion	Dermal	Inhalation Of Dust	Incidental Ingestion	Dermal	Inhalation of Vapors
Trespasser	North	Two EPC estimates were developed: 1. 95% UCL of surface soil samples (0 to 1 ft bgs) 2. 95% UCL of soil samples from 0 to 1 ft bgs and 4 to 5 ft bgs		Wind-blown dust from the NEA Two EPC estimates were developed: 1. 95% UCL of surface soil samples (0 to 1 ft bgs) 2. 95% UCL of soil samples from 0 to 1 ft bgs and 4 to 5 ft bgs	Incomplete	Incomplete	Max. conc. in exposure area
Off-site Resident	Off-site	Incomplete	Incomplete		Incomplete	Incomplete	Max. conc. in exposure area
Off-site Worker	Off-site	Incomplete	Incomplete		Incomplete	Incomplete	Max. conc. in exposure area
Maintenance Worker	South[1]	Two EPC estimates were developed: 1. 95% UCL for surface soil samples (0 to 1 ft bgs) 2. 95% UCL of soil samples from the top 10 ft			Maximum concentration in exposure area		
Maintenance Worker	North[2]	Two EPC estimates were developed: 1. 95% UCL of surface soil samples (0 to 1 ft bgs) 2. 95% UCL of soil samples from 0 to 1 ft bgs and 4 to 5 ft bgs			Maximum concentration in exposure area		
Default Construction Worker	North	Two EPC estimates were developed: 1. 95% UCL of surface soil samples (0 to 1 ft bgs) 2. 95% UCL of soil samples from 0 to 1 ft bgs and 4 to 5 ft bgs		Wind-blown dust, excavation, dozing, and truck traffic from the NEA Two EPC estimates were developed: 1. 95% UCL of surface soil samples (0 to 1 ft bgs) 2. 95% UCL of soil samples from 0 to 1 ft bgs and 4 to 5 ft bgs	Maximum concentration in exposure area		

TABLE 17
Source of Data Used to Calculate Exposure Point Concentrations for the Future (After WRF Construction) Exposure Scenarios Evaluated in the Risk Assessment

Population	Exposure Area	Source of Data Used to Calculate Exposure Point Concentrations (by exposure pathway)					
		Soil			Ground Water		
		Ingestion	Dermal	Inhalation Of Dust	Incidental Ingestion	Dermal	Inhalation of Vapors
Indoor Worker	North and South	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Max. conc. in exposure area

Notes:
1 –The maintenance worker in the south is exposed to wind-blown dust derived from the undeveloped northern portion of the site.
2 – The maintenance worker in the north is assumed to be exposed to wind-blown dust from a portion (50%) of the northern exposure area. The remainder of the site will be developed, and no dust emissions are expected.
EPC – Exposure point concentration
NEA – Northern Exposure Area
SEA – Southern Exposure Area
bgs – below ground surface

- The soil sampling results from the May 2001 site characterization field program were subdivided into that representing the northern exposure area and the southern exposure area. The data were grouped into a variety of data sets, each representing a different exposure scenario, as summarized in Tables 16 and 17. For locations where field duplicate samples were collected, the concentration in the field duplicate and the concentration in the original sample were averaged.

- In the northern exposure area, two estimates of exposure point concentrations were developed, one that included all the soil sampling data collected from the top 5 feet of the soil column, and a second estimated based on surficial soil samples (0 to 1 ft) alone.[13] On a chemical-by-chemical basis, the maximum of the two exposure point concentrations was used to estimate exposure and risk in this assessment. Although the use of such an approach does not represent actual exposure patterns, it is conservative and accounts for the possibility that soils will not be completely mixed during grading. The actual depth of grading (and potential exposure to soils) in the northern exposure area will vary from one point to another due to local variations in elevation. The depth range is expected to be zero to five feet, but the actual depth at each location cannot be determined with certainty from the available information. Although use of the higher of the two exposure point concentrations for each chemical violates statistical assumptions because different chemicals are represented by samples from different depth intervals, this procedure was used to account for the uncertainty in the depth of grading at each point and to provide more conservative risk estimates. The exposure point concentrations estimated for the northern exposure area were applied to all exposure scenarios associated with this area of the site.

- For the southern exposure area, exposure point concentrations were developed for construction workers, who are more likely to come into contact with soils from the entire soil column, and for all other populations, who are more likely to come into contact with soils closer to the surface, as described further below:

  - For WRF construction workers, all available soil data from the southern exposure area were used to develop a 95% UCL concentration. To ensure that risks were not underestimated, 95% UCL concentrations were also calculated using data from only the top 10 feet. For each chemical, the higher of the two estimates was used to evaluate risk. The actual depth of excavation (and

potential exposure to soil) in the southern exposure area will vary from one point to another due to differences in construction and local variations in elevation. WRF construction workers are expected to be exposed to surface soils only at some locations, and to all soils to a depth of up to 30 feet at other locations. As in the northern exposure area, the use of the higher of the two exposure point concentrations for each chemical violates statistical assumptions because different chemicals are represented by samples from different depth intervals. In the southern exposure area, this procedure was used to allow development of conservative risk estimates without characterizing conditions in smaller exposure areas defined by the expected depth of excavation.

  - For the non-WRF construction worker scenarios, soil samples collected within the top 10 feet of the soil column were used to calculate 95% UCL concentrations. A second estimate of the exposure point concentrations was calculated using data from surface data alone. The two estimates were compared, and the higher of the two was used to evaluate exposure and risk. Use of the higher of two estimates for each chemical is consistent with the procedures used for the other exposure scenarios.

- For each chemical, the data set was analyzed using the Shapiro-Wilk W-test (Gilbert 1987), as recommended by USEPA (1992a), to determine if it is consistent with a normal distribution.

- For data sets for which the null hypothesis of normality was rejected, 95% UCL concentrations were calculated by applying a nonparametric bootstrapping method; otherwise, the 95% UCL was calculated assuming normality. The nonparametric method used in this assessment is the percentile method (Efron and Tibshirani 1993), as discussed with NDEP[14] and described in detail in Section II.F of Appendix G. This procedure was used to generate 95% UCLs with 1,000 simulations for each data set for which the hypothesis of normality was rejected at the 5 percent level of significance. The 95% UCLs for data sets for which the hypothesis of normality was not rejected were generated using the formula

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[13] Soil concentrations used in the excavation and dozing dust emission models for the future default construction worker in the northern exposure area included all samples collected within the exposure area.

[14] This bootstrapping approach was discussed with and recommended by NDEP during the September 24, 2002 meeting in Carson City, Nevada.

presented in Highlight 6 of *Supplemental Guidance to RAGS: Calculating the Concentration Term* (USEPA 1992a).

In estimating 95% UCL concentrations, ENVIRON applied a value of one-half the detection limit to represent the concentration of a chemical that is not detected in an individual sample. The cumulative risk estimates are not very sensitive to the procedure used to account for non-detects because all of the chemicals that contribute significantly to the cumulative risks were detected in almost all of the samples. The only exception is dioxin (TEQ); this subject is discussed in more detail in Appendix G. For each constituent and exposure area, the calculated 95% UCL concentration was compared to the maximum detected concentration within the exposure area, and the lower of the two values was used as the exposure point concentration for exposure scenario. In this study, none of the calculated exposure point concentrations are represented by a maximum concentration (i.e., in all cases the 95% UCL was below the maximum detected concentration). A tabulation of chemical-specific exposure point concentrations in soil is provided in Table 18.

2. Indoor Air

Soil sampling data collected during the site characterization program do not indicate that significant migration of chemicals from ground water upward through the soil column is occurring. To be conservative, however, indoor air concentrations of volatile compounds in ground water that may infiltrate overlying buildings to be constructed at the site were estimated using a model developed by Johnson and Ettinger (1991), as recommended in USEPA's *Soil Screening Guidance: Technical Background Document* (USEPA 1996a). USEPA has made available on its website[15] several spreadsheets for calculating indoor air concentrations based on the Johnson & Ettinger model, including a screening model and a refined model. The screening model from the USEPA website was applied, as described in Appendix J. Based on the results of the screening modeling, more refined modeling was not deemed necessary.

Ground water sampling results from the May 2001 site characterization program were used in the screening model. Specifically, for the southern exposure area, the maximum concentration in the two monitoring wells sampled within this area was used. For the northern exposure area, the maximum concentration detected in three monitoring wells (the two within the northern exposure area and PC-58, which is approximately 350 feet north of the northern boundary of this area) was used. Samples from PC-56 were not included because it appears that this well is not downgradient of the WRF expansion site

[15] (www.epa.gov/superfund/programs/risk/airmodel/johnson_ettinger).

TABLE 18
Summary of Exposure Point Concentrations for Chemicals of Potential Concern in Soil
(Concentrations in Units of µg/kg)

Chemical	NEA 0-1'	NEA 0-5'	NEA All	SEA 0-1'	SEA 0-12'	SEA All
Metals						
Aluminum	1.37E+07	1.27E+07	1.24E+07	1.31E+07	1.23E+07	1.14E+07
Antimony	8.52E+01	8.59E+01	8.67E+01	3.44E+02	2.19E+02	1.80E+02
Arsenic	6.13E+03	7.93E+03	7.87E+03	9.85E+03	7.66E+03	8.48E+03
Barium	2.90E+05	2.72E+05	2.64E+05	4.31E+05	3.34E+05	2.89E+05
Beryllium	6.36E+02	5.89E+02	5.72E+02	6.43E+02	5.98E+02	5.66E+02
Cadmium	1.56E+02	1.41E+02	1.35E+02	1.79E+02	1.47E+02	1.41E+02
Chromium (total)	1.46E+04	1.17E+04	1.13E+04	1.43E+04	1.23E+04	1.26E+04
Cobalt	8.58E+03	7.90E+03	7.72E+03	8.48E+03	7.88E+03	7.17E+03
Copper	2.13E+04	1.80E+04	1.68E+04	1.85E+04	1.61E+04	1.44E+04
Iron	2.11E+07	1.99E+07	1.97E+07	2.02E+07	1.89E+07	1.74E+07
Magnesium	1.18E+07	1.16E+07	1.16E+07	1.12E+07	1.09E+07	1.64E+07
Manganese	5.52E+05	4.85E+05	4.67E+05	8.19E+05	6.22E+05	5.20E+05
Mercury	3.02E+01	2.67E+01	2.34E+01	2.84E+01	2.78E+01	3.05E+01
Molybdenum	1.34E+03	1.04E+03	1.04E+03	2.26E+03	1.56E+03	1.53E+03
Nickel	1.47E+04	1.36E+04	1.36E+04	1.39E+04	1.34E+04	1.30E+04
Selenium	3.82E+02	3.40E+02	3.20E+02	4.44E+02	5.84E+02	4.92E+02
Silver	1.70E+02	1.57E+02	1.52E+02	2.51E+02	1.78E+02	1.57E+02
Thallium	1.16E+02	9.53E+01	9.17E+01	3.01E+02	1.88E+02	1.60E+02
Thorium	7.63E+03	6.89E+03	6.92E+03	7.20E+03	7.35E+03	7.01E+03
Titanium	5.64E+05	5.54E+05	5.40E+05	7.57E+05	6.43E+05	5.75E+05
Vanadium	2.81E+04	2.78E+04	2.82E+04	3.38E+04	3.15E+04	3.12E+04
Zinc	5.59E+04	5.00E+04	4.80E+04	5.85E+04	4.97E+04	4.47E+04
Dioxins/Furans						
1,2,3,4,6,7,8-HpCDD	5.00E-03	4.84E-03	3.93E-03	1.21E-02	7.40E-03	5.36E-03
1,2,3,4,6,7,8-HpCDF	7.76E-03	2.26E-02	1.68E-02	7.40E-02	4.11E-02	2.90E-02
1,2,3,4,7,8,9-HpCDF	2.79E-03	6.51E-03	5.11E-03	3.60E-02	1.95E-02	1.35E-02
1,2,3,4,7,8-HxCDD	2.14E-04	2.93E-04	2.61E-04	9.66E-04	6.21E-04	5.11E-04
1,2,3,4,7,8-HxCDF	4.51E-03	1.15E-02	9.09E-03	3.88E-02	2.19E-02	1.56E-02
1,2,3,6,7,8-HxCDD	3.18E-04	9.22E-04	6.83E-04	2.43E-03	1.39E-03	1.06E-03
1,2,3,6,7,8-HxCDF	2.61E-03	5.87E-03	5.01E-03	2.55E-02	1.42E-02	9.87E-03
1,2,3,7,8,9-HxCDD	3.16E-04	8.00E-04	6.94E-04	2.17E-03	1.25E-03	9.54E-04
1,2,3,7,8,9-HxCDF	3.26E-04	9.81E-04	8.15E-04	4.54E-03	2.48E-03	1.81E-03
1,2,3,7,8-PeCDD	3.06E-04	3.61E-04	3.29E-04	1.59E-03	9.77E-04	7.73E-04
1,2,3,7,8-PeCDF	2.27E-03	4.73E-03	3.82E-03	1.96E-02	1.09E-02	7.53E-03
2,3,4,6,7,8-HxCDF	3.97E-04	1.43E-03	1.21E-03	6.44E-03	3.51E-03	2.56E-03
2,3,4,7,8-PeCDF	1.17E-03	2.58E-03	2.07E-03	1.03E-02	5.56E-03	3.98E-03
2,3,7,8-TCDD	1.62E-04	1.59E-04	1.55E-04	5.89E-04	3.82E-04	3.19E-04
2,3,7,8-TCDF	1.62E-03	3.17E-03	2.53E-03	1.19E-02	6.68E-03	4.91E-03
Dioxins/Furans TEQ	2.29E-03	4.59E-03	4.11E-03	1.90E-02	1.07E-02	7.65E-03
OCDD	1.74E-02	2.07E-02	2.04E-02	5.86E-02	3.17E-02	2.28E-02
OCDF	4.68E-02	1.33E-01	1.06E-01	8.80E-01	4.65E-01	3.24E-01
Pesticides						
4,4'-DDD	7.05E-01	5.32E-01	4.98E-01	1.14E+00	8.12E-01	6.94E-01
4,4'-DDE	1.91E+01	1.08E+01	8.42E+00	9.36E+00	5.18E+00	3.98E+00
4,4'-DDT	1.78E+01	9.46E+00	7.58E+00	1.02E+01	5.52E+00	4.12E+00

TABLE 18
Summary of Exposure Point Concentrations for Chemicals of Potential Concern in Soil
(Concentrations in Units of µg/kg)

Chemical	NEA 0-1'	NEA 0-5'	NEA All	SEA 0-1'	SEA 0-12'	SEA All
alpha-Chlordane	5.05E-01	3.79E-01	3.52E-01	1.19E+00	7.75E-01	6.19E-01
beta-BHC	5.28E+00	3.19E+00	2.64E+00	2.37E+00	1.55E+00	1.19E+00
Dieldrin	6.43E-01	4.85E-01	4.51E-01	1.68E+00	1.11E+00	8.49E-01
Endosulfan II	7.00E-01	5.29E-01	4.92E-01	1.21E+00	8.43E-01	6.94E-01
Endosulfan sulfate	5.86E-01	4.41E-01	4.13E-01	2.09E+00	1.27E+00	9.73E-01
Endrin	5.47E+00	3.00E+00	2.44E+00	3.05E-01	4.48E-01	4.10E-01
Endrin aldehyde	3.92E+00	2.23E+00	2.00E+00	1.01E+00	1.02E+00	9.03E-01
Endrin ketone	5.86E-01	4.42E-01	4.13E-01	8.23E-01	6.12E-01	5.17E-01
gamma-Chlordane	1.05E+00	7.93E-01	7.40E-01	1.30E+00	1.03E+00	8.82E-01
Heptachlor epoxide	5.24E-01	3.93E-01	8.81E-01	2.56E-01	3.74E-01	3.43E-01
Methoxychlor	7.27E+00	4.13E+00	3.43E+00	2.02E+00	1.51E+00	1.28E+00
Perchlorate						
Perchlorate	1.65E+04	1.03E+04	8.61E+03	1.20E+04	7.85E+03	6.33E+03

but is located within a separate alluvial channel located primarily west of the site. A summary of the calculated indoor air concentrations is provided in Table 19.

TABLE 19
Exposure Point Concentrations in Indoor Air

Chemical	Concentration ($\mu g/m^3$)
Southern Exposure Area	
Acetone	2.21×10^{-4}
Carbon tetrachloride	1.14×10^{-2}
Chloroform	4.81×10^{-1}
Tetrachloroethene	6.47×10^{-2}
Toluene	5.87×10^{-3}
Northern Exposure Area	
Acetone	2.65×10^{-4}
Carbon tetrachloride	4.52×10^{-2}
Chloroform	6.51×10^{-1}
Tetrachloroethene	1.58×10^{-2}
Toluene	1.81×10^{-3}

3. Outdoor Air

The estimation of outdoor air concentrations is a two-step process, involving the development of emission estimates (for dust and vapors) and the modeling of atmospheric transport, as discussed below and described in greater detail in Appendix J.

a. Estimation of Emissions

The following approaches were used to estimate emissions of dust and volatile chemicals. ENVIRON recognizes that the models described below do not represent the most refined emissions models available; however, the models applied in this assessment are conservative. If estimated exposures through the inhalation pathway pose a significant risk, the use of refined models will be evaluated.

Dust Emission from Excavation, Dozing, Truck Traffic, and Grading Activities

Emission of dust from truck traffic on unpaved roads and soil handling activities (i.e., excavation, dozing, and grading) were developed based on methods recommended by USEPA (2001c) in *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites.* This USEPA document provides approaches for estimating particulate emission factors (PEFs) for truck traffic on

unpaved roads and several types of earth-moving activities, including dozing, grading, and excavation. A detailed presentation of the methodology used to estimate PM_{10} emissions resulting from these sources is included in Appendix J. The chemical-specific emission rates due to excavation and grading are tabulated in Appendix J.

Wind-blown Dust Emissions

Emissions of wind-blown dust were estimated based on the PEF approach recommended by USEPA (2001c). This approach is derived from a previous USEPA methodology (USEPA 1985) developed by Cowherd et al. and is detailed in Appendix J.

Volatile Emissions from Ground Water

Volatile emissions from ground water were estimated using an equation based on Fick's Law. The estimation of volatile emissions from ground water at the WRF expansion site is detailed in Appendix J. The chemical-specific input parameter values and the calculated chemical-specific emission rates are also presented in Appendix J.

b. Estimation of Air Concentrations

The PEF values and vapor fluxes (calculated as described in Appendix J) were used to estimate exposure point concentrations in outdoor air using default dispersion factors (referred to as Q/C values) that were developed by USEPA (2001c) based on atmospheric dispersion modeling using the Industrial Source Complex (ISC) model. The USEPA modeling was performed to predict worst-case concentrations (e.g., fence line concentrations for off-site receptors); thus, the estimated exposure point concentrations in air used in this assessment are expected to be very conservative. The estimated exposure point concentrations in outdoor air are summarized in Table 20.

4. Ground Water

The maximum detected concentration of each COPC in ground water within a given exposure area was used to evaluate exposure to ground water by construction workers and maintenance workers and exposure to vapors emitted from ground water migrating upward through the soil. For the southern exposure area, the maximum concentration in the two monitoring wells sampled within this area was used. For the northern exposure area, the maximum concentration detected in three monitoring wells (the two within the northern exposure area and PC-58, which is approximately 350 north

TABLE 20
Summary of Exposure Point Concentrations in Outdoor Air
Chemical Concentrations in µg/m³

	During WRF Construction			Future (Post WRF Construction)					
	WRF Construction Worker	Off-site Resident	Off-site Worker	Default Construction Worker	SEA Maintenance Worker	NEA Maintenance Worker	Trespassing Child	Off-site Resident	Off-site Worker
Acetone	1.33×10^{-4}	3.57×10^{-5}	3.57×10^{-5}	1.25×10^{-4}	2.14×10^{-5}	2.74×10^{-5}	2.74×10^{-5}	2.14×10^{-5}	2.14×10^{-5}
Carbon tetrachloride	1.20×10^{-2}	6.47×10^{-3}	6.47×10^{-3}	3.28×10^{-2}	5.65×10^{-3}	7.24×10^{-3}	7.24×10^{-3}	5.65×10^{-3}	5.65×10^{-3}
Chloroform	3.77×10^{-1}	1.22×10^{-1}	1.22×10^{-1}	4.93×10^{-1}	8.47×10^{-2}	1.09×10^{-1}	1.09×10^{-1}	8.47×10^{-2}	8.47×10^{-2}
Tetrachloroethene	3.81×10^{-2}	6.61×10^{-3}	6.61×10^{-3}	1.14×10^{-2}	1.97×10^{-3}	2.52×10^{-3}	2.52×10^{-3}	1.97×10^{-3}	1.97×10^{-3}
Toluene	3.67×10^{-3}	6.73×10^{-4}	6.73×10^{-4}	1.34×10^{-3}	2.31×10^{-4}	2.96×10^{-4}	2.96×10^{-4}	2.31×10^{-4}	2.31×10^{-4}
Aluminum	2.10×10^{0}	1.32×10^{-2}	1.32×10^{-2}	2.14×10^{0}	8.87×10^{-4}	5.68×10^{-4}	1.14×10^{-3}	8.87×10^{-4}	8.87×10^{-4}
Antimony	5.40×10^{-5}	3.00×10^{-7}	3.00×10^{-7}	1.34×10^{-5}	5.57×10^{-9}	3.57×10^{-9}	7.13×10^{-9}	5.57×10^{-9}	5.57×10^{-9}
Arsenic	1.50×10^{-3}	9.57×10^{-6}	9.57×10^{-6}	1.24×10^{-3}	5.14×10^{-7}	3.29×10^{-7}	6.59×10^{-7}	5.14×10^{-7}	5.14×10^{-7}
Barium	6.70×10^{-2}	4.06×10^{-4}	4.06×10^{-4}	4.53×10^{-2}	1.88×10^{-5}	1.20×10^{-5}	2.41×10^{-5}	1.88×10^{-5}	1.88×10^{-5}
Beryllium	1.00×10^{-4}	6.45×10^{-7}	6.45×10^{-7}	9.94×10^{-5}	4.12×10^{-8}	2.64×10^{-8}	5.28×10^{-8}	4.12×10^{-8}	4.12×10^{-8}
Cadmium	2.80×10^{-5}	1.74×10^{-7}	1.74×10^{-7}	2.44×10^{-5}	1.01×10^{-8}	6.48×10^{-9}	1.30×10^{-8}	1.01×10^{-8}	1.01×10^{-8}
Chromium (total)	2.20×10^{-3}	1.43×10^{-5}	1.43×10^{-5}	2.29×10^{-3}	9.48×10^{-7}	6.07×10^{-7}	1.21×10^{-6}	9.48×10^{-7}	9.48×10^{-7}
Cobalt	1.30×10^{-3}	8.52×10^{-6}	8.52×10^{-6}	1.34×10^{-3}	5.56×10^{-7}	3.56×10^{-7}	7.12×10^{-7}	5.56×10^{-7}	5.56×10^{-7}
Copper	2.90×10^{-3}	1.87×10^{-5}	1.87×10^{-5}	3.33×10^{-3}	1.38×10^{-6}	8.84×10^{-7}	1.77×10^{-6}	1.38×10^{-6}	1.38×10^{-6}
Iron	3.20×10^{0}	2.04×10^{-2}	2.04×10^{-2}	3.30×10^{0}	1.37×10^{-3}	8.77×10^{-4}	1.75×10^{-3}	1.37×10^{-3}	1.37×10^{-3}
Magnesium	1.80×10^{0}	1.21×10^{-2}	1.21×10^{-2}	1.85×10^{0}	7.66×10^{-4}	4.90×10^{-4}	9.81×10^{-4}	7.66×10^{-4}	7.66×10^{-4}
Manganese	1.30×10^{-1}	7.71×10^{-4}	7.71×10^{-4}	8.63×10^{-2}	3.58×10^{-5}	2.29×10^{-5}	4.58×10^{-5}	3.58×10^{-5}	3.58×10^{-5}
Mercury	4.50×10^{-6}	2.93×10^{-8}	2.93×10^{-8}	4.72×10^{-6}	1.96×10^{-9}	1.25×10^{-9}	2.51×10^{-9}	1.96×10^{-9}	1.96×10^{-9}
Molybdenum	3.50×10^{-4}	2.08×10^{-6}	2.08×10^{-6}	2.10×10^{-4}	8.72×10^{-8}	5.58×10^{-8}	1.12×10^{-7}	8.72×10^{-8}	8.72×10^{-8}
Nickel	2.20×10^{-3}	1.41×10^{-5}	1.41×10^{-5}	2.30×10^{-3}	9.52×10^{-7}	6.10×10^{-7}	1.22×10^{-6}	9.52×10^{-7}	9.52×10^{-7}
Selenium	9.20×10^{-5}	5.68×10^{-7}	5.68×10^{-7}	5.97×10^{-5}	2.48×10^{-8}	1.59×10^{-8}	3.17×10^{-8}	2.48×10^{-8}	2.48×10^{-8}
Silver	3.90×10^{-5}	2.35×10^{-7}	2.35×10^{-7}	2.66×10^{-5}	1.10×10^{-8}	7.05×10^{-9}	1.41×10^{-8}	1.10×10^{-8}	1.10×10^{-8}
Thallium	4.70×10^{-5}	2.67×10^{-7}	2.67×10^{-7}	1.81×10^{-5}	7.52×10^{-9}	4.81×10^{-9}	9.63×10^{-9}	7.52×10^{-9}	7.52×10^{-9}
Thorium	1.20×10^{-3}	7.48×10^{-6}	7.48×10^{-6}	1.19×10^{-3}	4.95×10^{-7}	3.17×10^{-7}	6.33×10^{-7}	4.95×10^{-7}	4.95×10^{-7}
Titanium	1.20×10^{-1}	7.28×10^{-4}	7.28×10^{-4}	8.81×10^{-2}	3.66×10^{-5}	2.34×10^{-5}	4.68×10^{-5}	3.66×10^{-5}	3.66×10^{-5}
Vanadium	5.30×10^{-3}	3.33×10^{-5}	3.33×10^{-5}	4.40×10^{-3}	1.83×10^{-6}	1.17×10^{-6}	2.34×10^{-6}	1.83×10^{-6}	1.83×10^{-6}
Zinc	9.20×10^{-3}	5.78×10^{-5}	5.78×10^{-5}	8.74×10^{-3}	3.63×10^{-6}	2.32×10^{-6}	4.65×10^{-6}	3.63×10^{-6}	3.63×10^{-6}
1,2,3,4,6,7,8-HpCDD	1.90×10^{-9}	1.08×10^{-11}	1.08×10^{-11}	7.81×10^{-10}	3.24×10^{-13}	2.08×10^{-13}	4.15×10^{-13}	3.24×10^{-13}	3.24×10^{-13}
1,2,3,4,6,7,8-HpCDF	1.20×10^{-8}	6.43×10^{-11}	6.43×10^{-11}	3.53×10^{-9}	1.46×10^{-12}	9.37×10^{-13}	1.87×10^{-12}	1.46×10^{-12}	1.46×10^{-12}
1,2,3,4,7,8,9-HpCDF	5.60×10^{-9}	3.07×10^{-11}	3.07×10^{-11}	1.02×10^{-9}	4.22×10^{-13}	2.70×10^{-13}	5.40×10^{-13}	4.22×10^{-13}	4.22×10^{-13}
1,2,3,4,7,8-HxCDD	1.50×10^{-10}	8.51×10^{-13}	8.51×10^{-13}	4.59×10^{-11}	1.90×10^{-14}	1.22×10^{-14}	2.44×10^{-14}	1.90×10^{-14}	1.90×10^{-14}
1,2,3,4,7,8-HxCDF	6.10×10^{-9}	3.37×10^{-11}	3.37×10^{-11}	1.80×10^{-9}	7.47×10^{-13}	4.78×10^{-13}	9.57×10^{-13}	7.47×10^{-13}	7.47×10^{-13}
1,2,3,6,7,8-HxCDD	3.80×10^{-10}	2.13×10^{-12}	2.13×10^{-12}	1.44×10^{-10}	5.98×10^{-14}	3.83×10^{-14}	7.66×10^{-14}	5.98×10^{-14}	5.98×10^{-14}

TABLE 20
Summary of Exposure Point Concentrations in Outdoor Air
Chemical Concentrations in µg/m³

	During WRF Construction			Future (Post WRF Construction)					
	WRF Construction Worker	Off-site Resident	Off-site Worker	Default Construction Worker	SEA Maintenance Worker	NEA Maintenance Worker	Trespassing Child	Off-site Resident	Off-site Worker
1,2,3,6,7,8-HxCDF	4.00×10^{-9}	2.19×10^{-11}	2.19×10^{-11}	9.17×10^{-10}	3.81×10^{-13}	2.44×10^{-13}	4.87×10^{-13}	3.81×10^{-13}	3.81×10^{-13}
1,2,3,7,8,9-HxCDD	3.40×10^{-10}	1.91×10^{-12}	1.91×10^{-12}	1.25×10^{-10}	5.19×10^{-14}	3.32×10^{-14}	6.64×10^{-14}	5.19×10^{-14}	5.19×10^{-14}
1,2,3,7,8,9-HxCDF	7.10×10^{-10}	3.89×10^{-12}	3.89×10^{-12}	1.53×10^{-10}	6.36×10^{-14}	4.07×10^{-14}	8.14×10^{-14}	6.36×10^{-14}	6.36×10^{-14}
1,2,3,7,8-PeCDD	2.50×10^{-10}	1.38×10^{-12}	1.38×10^{-12}	5.65×10^{-11}	2.34×10^{-14}	1.50×10^{-14}	3.00×10^{-14}	2.34×10^{-14}	2.34×10^{-14}
1,2,3,7,8-PeCDF	3.10×10^{-9}	1.68×10^{-11}	1.68×10^{-11}	7.39×10^{-10}	3.07×10^{-13}	1.96×10^{-13}	3.93×10^{-13}	3.07×10^{-13}	3.07×10^{-13}
2,3,4,6,7,8-HxCDF	1.00×10^{-9}	5.52×10^{-12}	5.52×10^{-12}	2.23×10^{-10}	9.25×10^{-14}	5.92×10^{-14}	1.18×10^{-13}	9.25×10^{-14}	9.25×10^{-14}
2,3,4,7,8-PeCDF	1.60×10^{-9}	8.88×10^{-12}	8.88×10^{-12}	4.04×10^{-10}	1.67×10^{-13}	1.07×10^{-13}	2.14×10^{-13}	1.67×10^{-13}	1.67×10^{-13}
2,3,7,8-TCDD	9.20×10^{-11}	5.17×10^{-13}	5.17×10^{-13}	2.53×10^{-11}	1.05×10^{-14}	6.71×10^{-15}	1.34×10^{-14}	1.05×10^{-14}	1.05×10^{-14}
2,3,7,8-TCDF	1.90×10^{-9}	1.03×10^{-11}	1.03×10^{-11}	4.96×10^{-10}	2.06×10^{-13}	1.32×10^{-13}	2.64×10^{-13}	2.06×10^{-13}	2.06×10^{-13}
Dioxins/Furans TEQ	3.00×10^{-9}	1.64×10^{-11}	1.64×10^{-11}	7.18×10^{-10}	2.98×10^{-13}	1.91×10^{-13}	3.82×10^{-13}	2.98×10^{-13}	2.98×10^{-13}
OCDD	9.10×10^{-9}	5.11×10^{-11}	5.11×10^{-11}	3.24×10^{-9}	1.34×10^{-12}	8.60×10^{-13}	1.72×10^{-12}	1.34×10^{-12}	1.34×10^{-12}
OCDF	1.40×10^{-7}	7.45×10^{-10}	7.45×10^{-10}	2.08×10^{-8}	8.63×10^{-12}	5.53×10^{-12}	1.11×10^{-11}	8.63×10^{-12}	8.63×10^{-12}
4,4'-DDD	1.80×10^{-7}	1.06×10^{-9}	1.06×10^{-9}	1.10×10^{-7}	4.57×10^{-11}	2.93×10^{-11}	5.85×10^{-11}	4.57×10^{-11}	4.57×10^{-11}
4,4'-DDE	1.50×10^{-6}	1.01×10^{-8}	1.01×10^{-8}	2.99×10^{-6}	1.24×10^{-9}	7.94×10^{-10}	1.59×10^{-9}	1.24×10^{-9}	1.24×10^{-9}
4,4'-DDT	1.60×10^{-6}	1.06×10^{-8}	1.06×10^{-8}	2.78×10^{-6}	1.15×10^{-9}	7.39×10^{-10}	1.48×10^{-9}	1.15×10^{-9}	1.15×10^{-9}
alpha-Chlordane	1.90×10^{-7}	1.07×10^{-9}	1.07×10^{-9}	7.89×10^{-8}	3.27×10^{-11}	2.10×10^{-11}	4.19×10^{-11}	3.27×10^{-11}	3.27×10^{-11}
beta-BHC	3.70×10^{-7}	2.64×10^{-9}	2.64×10^{-9}	8.26×10^{-7}	3.43×10^{-10}	2.19×10^{-10}	4.39×10^{-10}	3.43×10^{-10}	3.43×10^{-10}
Dieldrin	2.60×10^{-7}	1.50×10^{-9}	1.50×10^{-9}	1.00×10^{-7}	4.17×10^{-11}	2.67×10^{-11}	5.34×10^{-11}	4.17×10^{-11}	4.17×10^{-11}
Endosulfan II	1.90×10^{-7}	1.11×10^{-9}	1.11×10^{-9}	1.09×10^{-7}	4.54×10^{-11}	2.91×10^{-11}	5.81×10^{-11}	4.54×10^{-11}	4.54×10^{-11}
Endosulfan sulfate	3.30×10^{-7}	1.82×10^{-9}	1.82×10^{-9}	9.16×10^{-8}	3.80×10^{-11}	2.43×10^{-11}	4.87×10^{-11}	3.80×10^{-11}	3.80×10^{-11}
Endrin	7.30×10^{-8}	1.07×10^{-9}	1.07×10^{-9}	8.55×10^{-7}	3.55×10^{-10}	2.27×10^{-10}	4.55×10^{-10}	3.55×10^{-10}	3.55×10^{-10}
Endrin aldehyde	1.60×10^{-7}	1.39×10^{-9}	1.39×10^{-9}	6.13×10^{-7}	2.54×10^{-10}	1.63×10^{-10}	3.26×10^{-10}	2.54×10^{-10}	2.54×10^{-10}
Endrin ketone	1.30×10^{-7}	7.77×10^{-10}	7.77×10^{-10}	9.16×10^{-8}	3.80×10^{-11}	2.43×10^{-11}	4.86×10^{-11}	3.80×10^{-11}	3.80×10^{-11}
gamma-Chlordane	2.00×10^{-7}	1.25×10^{-9}	1.25×10^{-9}	1.65×10^{-7}	6.83×10^{-11}	4.37×10^{-11}	8.74×10^{-11}	6.83×10^{-11}	6.83×10^{-11}
Heptachlor epoxide	5.90×10^{-8}	3.97×10^{-10}	3.97×10^{-10}	8.19×10^{-8}	3.40×10^{-11}	2.18×10^{-11}	4.35×10^{-11}	3.40×10^{-11}	3.40×10^{-11}
Methoxychlor	3.20×10^{-7}	2.62×10^{-9}	2.62×10^{-9}	1.14×10^{-6}	4.72×10^{-10}	3.02×10^{-10}	6.04×10^{-10}	4.72×10^{-10}	4.72×10^{-10}
Perchlorate	1.90×10^{-3}	1.21×10^{-5}	1.21×10^{-5}	2.58×10^{-3}	1.07×10^{-6}	6.85×10^{-7}	1.37×10^{-6}	1.07×10^{-6}	1.07×10^{-6}

of the northern boundary of this area) was used. Results from PC-56 were not included because it appears that this well is not downgradient of the WRF expansion site but is located within a separate alluvial channel located primarily west of the site (see Figure 8). After construction is complete, use of shallow ground water is not expected for the populations being evaluated in the risk assessment; therefore, no direct exposure is anticipated, and the City has indicated it will institute controls (e.g., deed restrictions) to eliminate possible exposures to ground water, if necessary. Exposure point concentrations in ground water are summarized in Table 21.

C. Estimation of Dose

The last step in the exposure assessment process is the estimation of dose of COPCs received. Dose is expressed in terms of the mass of substance in contact with the body per unit body weight per time (mg/kg-day) and is calculated as a function of chemical concentration in the medium, contact rate, exposure frequency and duration, body weight, and averaging time. Each of these parameters (referred to as "exposure factors") can be represented by a discrete point estimate; these point estimates can be combined in an equation to estimate dose.

In an exposure assessment, it is generally necessary to provide two different estimates of the dose, one for carcinogens and a second for non-carcinogenic effects. For carcinogens, the dose is estimated by averaging the total cumulative intake over a lifetime (USEPA 1989), which is referred to as the lifetime average daily dose (LADD). The dose generally used in the assessment of non-carcinogenic effects is the average daily dose (ADD) an individual is likely to receive on any day during the period of exposure. In cases where exposure is intermittent, USEPA guidance states that it is appropriate to average the intake over the period of exposure. This distinction in the calculation of the dose for carcinogens and non-carcinogens relates to the currently held scientific opinion that the mechanisms of action of the two categories of chemicals are different. For carcinogens, the assumption is made that a high dose received over a short period of time produces a carcinogenic effect comparable to a corresponding low dose spread over a lifetime (USEPA 1989). For non-carcinogens, it is assumed that adverse effects are likely to occur only during periods of exposure when some "threshold" level is exceeded, but that latent effects will not result for any exposures at levels below the "threshold."

TABLE 21 Summary of Exposure Point Concentrations in Ground Water Concentrations in Units of µg/L		
Chemical	**NEA**	**SEA**
Acetone	3	2.8
Carbon tetrachloride	1.6	0.3
Chloroform	150	93
Tetrachloroethene	1	3.3
Toluene	0.3	0.7
Aluminum	82600	844
Arsenic	142	86.3
Barium	1150	12.1
Beryllium	5.1	0.05
Cadmium	3.5	1.1
Chromium (hexavalent)	97.3	82.3
Chromium (total)	85	60.2
Cobalt	0.4	0.03
Copper	71.9	9.8
Iron	68500	769
Lead	37	0.2
Magnesium	570000	310000
Manganese	1130	6.1
Molybdenum	824	292
Nickel	63.6	24.3
Selenium	128	47.3
Silver	1.1	0.07
Thorium	24.1	0.5
Titanium	1830	7.4
Vanadium	158	29.7
Zinc	262	5.6
Perchlorate	10800	10800
Total Cyanide	2.9	1.3

The dose equations are specific to a given exposure pathway (i), as summarized below:

Ingestion of Soil:

$$Dose\,(mg/kg\text{-}day) = \frac{CS \times IR_i \times FI \times EF_i \times BA \times ED \times 10^{-6}\,kg/mg}{BW \times AT}$$

Dermal Contact with Soil:

$$Dose\,(mg/kg\text{-}day) = \frac{CS \times SA_i \times AF \times ABS \times EF_i \times ED \times 10^{-6}\,kg/mg}{BW \times AT}$$

Inhalation of Dust/Vapors:

$$Dose\,(mg/kg\text{-}day) = \frac{CA \times IR_i \times ET \times EF_i \times ED \times 10^{-3}\,mg/\mu g}{BW \times AT}$$

Incidental Ingestion of Ground Water:

$$Dose\,(mg/kg\text{-}day) = \frac{CW \times IR_i \times EF_i \times ED}{BW \times AT}$$

Incidental Dermal Contact with Ground Water:

$$Dose\,(mg/kg\text{-}day) = \frac{DA_{event} \times SA_i \times EF \times ED}{BW \times AT}$$

The exposure factors used in the dose equations for each of the exposure scenarios being evaluated in the risk assessment are summarized as follows:

During Construction of the WRF

Table 22 – WRF Construction Worker (Southern Exposure Area)
Table 23 – Off-site Resident
Table 24 – Off-site Worker

Future (Post-WRF Construction)

Table 25 – Default Construction Worker (Northern Exposure Area)
Table 26 – Trespassing Child (Northern Exposure Area)
Table 27 – Indoor Worker (Northern and Southern Exposure Area)
Table 28 – Maintenance Worker (Northern and Southern Exposure Area)
Table 29 – Off-site Resident
Table 30 – Off-site Worker

The sources of the exposure factors presented in these tables are provided in the footnotes to the individual tables. Although not every exposure factor identified in Tables 22 through 30 represents a reasonable maximum value, ENVIRON believes that the combination of exposure factors applied in individual dose equations (identified above) results in reasonable maximum estimates of exposure. Estimated doses are tabulated in Appendix L. Several specific issues associated with the selection of exposure factors are discussed separately below:

- USEPA's *Risk Assessment Guidance for Superfund, Part E* (USEPA 2001a) provides guidance on the methodology and approaches to evaluating exposure to chemicals through the dermal contact pathway. The approaches recommended by USEPA's guidance were applied in this risk assessment. For dermal contact with soil, USEPA provide absorption factors (ABS values) that are used in calculating the dermal dose for a number of specific chemicals and chemical classes, which were used in the WRF risk assessment. For metals, USEPA provides ABS values for cadmium and arsenic only and indicates that default values for other metals are not provided because "there are too little data to extrapolate a reasonable default value." Thus, dermal exposure to metals in soil was evaluated in this assessment for arsenic and cadmium only. This approach is discussed further in Section E.3 of Chapter IX. Dermal exposure to perchlorate in soil and in groundwater was not evaluated in this assessment because USEPA's recent evaluation of perchlorate indicates that perchlorate does not pass readily through the skin (e.g., uptake of inorganic ions such as perchlorate is typically less than 10% and frequently less than 1% (USEPA 2002). Additionally, remedial actions for groundwater underlying the site will likely be based on chronic human ingestion of groundwater and/or ecological risk, which will result in more stringent perchlorate groundwater concentrations than those associated with incidental dermal contact with groundwater.

- To evaluate potential exposure to ground water by a construction worker (both the WRF construction worker in the southern exposure area and the future (default) construction worker in the northern exposure area), it was assumed that an individual who maintains the dewatering pipeline could periodically come into contact with ground water. No default exposure assumptions are available to evaluate such exposure; however, USEPA (1989) recommends a ground water ingestion rate of 50 milliliters per day during swimming. ENVIRON believes that incidental ingestion during pipeline maintenance will be significantly less than this value; thus, an ingestion rate of 5 milliliters per day was applied. It was assumed that such exposure would occur during each time the pipeline was maintained (i.e., weekly). ENVIRON believes that the combination of the exposure factors for this pathway will result in a conservative estimate of exposure to ground water for a construction worker. The uncertainties associated with this exposure

scenario are discussed in Chapter IX. It should be noted that this exposure pathway is limited to those individuals who maintain the dewatering pipeline on a regular basis; most construction workers will not participate in this activity and, thus, will not be exposed to ground water.

- The magnitude of exposure to soil at the WRF expansion site by a maintenance worker in the northern and southern exposure areas is highly dependent on a variety of site-specific factors, including 1) the fraction of soil ingested that is derived from the site (the "FI factor"), 2) the amount of pavement that is present, and 3) the bioavailability (BA) of the chemicals present in soil. NDEP has indicated that application of a site-specific FI factor would have to be reflected as a restriction on the no-further-action letter for the WRF expansion site. Thus, as a conservative measure and to maintain flexibility for the City, the FI factor for the maintenance worker scenarios was assumed to be 1.0 (i.e., all of a maintenance worker's exposure to soil was assumed to occur at the WRF site). Furthermore, the effect of pavement on exposure to soil by a maintenance worker is difficult to evaluate given the significant uncertainties regarding construction and maintenance worker activities. Thus, this factor was not considered in estimating maintenance worker exposure to soil. However, the bioavailability of a chemical is commonly considered in evaluating risks, especially for arsenic. Specifically, when exposure occurs to arsenic in soil, numerous studies have indicated that only a fraction of the arsenic in the ingested soil is actually available to be absorbed into the system (Ruby 1999; Roberts et al. 2001; Freeman et al. 1993, 1995; Groen et al. 1993; USEPA Region 10 1996; USEPA Region 8 1997). It is believed that the arsenic adheres to the soil particles or is present in a form that is less likely to be absorbed into the blood stream from the GI tract. In a review of the available literature on the subject, an internal USEPA review committee (USEPA 2001b) considered a study (Roberts et al. 2001) based on absorption of arsenic in monkeys to be the most appropriate. The range of arsenic bioavailability observed in this study was 10.7% to 24.7%. The USEPA committee selected an arsenic bioavailability of 25% based on the results of this study. Thus, for the purposes of this assessment, a bioavailability factor of 25 percent (0.25) for arsenic was applied to the two maintenance worker scenarios (northern and southern exposure areas).

- Across most of the site, typical maintenance worker activities are unlikely to result in exposure to ground water. However, soil borings along the northernmost boundary of the site (P-17, B-3, and E-2) indicated the presence of "wet" soil between 5 and 8 feet below ground surface (possibly indicating the presence of ground water or the capillary fringe associated with ground water), and in the future, it is possible that ground water levels

could rise. Thus, in certain areas of the site or if ground water were to rise, a maintenance worker could be exposed to ground water, if excavation activities were required. It is unlikely that such activities, if any, would be significant, given that if extensive digging were required the City would retain contractors to complete the work (e.g., longer-term utility excavations). Thus, it was assumed that a maintenance worker would be required to conduct minor excavation activities to a depth below ground water once per year for the estimated 25 years of employment. To evaluate the extent of exposure, the exposure pathways (e.g., ingestion and dermal contact) were assumed to be equivalent to the assumptions used for the construction worker who maintains the dewatering pipeline. Potential exposures by an individual conducting more significant excavation projects (e.g., utility excavations) are addressed in this risk assessment as part of the WRF construction worker scenarios in the southern exposure area and the future (default) construction worker in the northern exposure area, which evaluate more extensive exposure to soil and ground water.

TABLE 22
Exposure Factors for a WRF Construction Worker[a]
(Southern Exposure Area)[b]

Parameter	Value
Media Concentration	
CS = Constituent concentration in soil (mg/kg)	95% UCL or maximum[c]
CA = Constituent concentration in air ($\mu g/m^3$)	Calculated[d]
CW = Constituent concentration in ground water (mg/L)	Maximum exposure area concentration
Ingestion of Soil	
IR_{SOIL} = Soil ingestion rate (mg/day)	100[e]
FI = Fraction of soil ingested from contaminated source (unitless)	1.0[f]
BA = Bioavailability of chemical in soil (unitless)	1.0
EF_{SOIL} = Exposure frequency for soil (days/yr)	250[g]
ED_{SOIL} = Exposure duration for soil (yrs)	3[h]
Dermal Contact with Soil	
SA_{SOIL} = Skin surface area available for contact with soil (cm^2/event)	5,800[i]
AF = Soil-to-skin adherence factor (mg/cm^2)	0.1[j]
ABS = Absorption factor (unitless)[k]	SVOCs: 0.10 Arsenic 0.03 Cadmium: 0.001 Pesticides: 0.01 Dioxins/Furans: 0.03
EF_{SOIL} = Exposure frequency for soil (days/yr)	250[g]
ED_{SOIL} = Exposure duration for soil (yrs)	3[h]
Inhalation of Dust/Vapors	
IR_{AIR} = Inhalation rate (m^3/hr)	1.3[l]
ET = Exposure time (hrs/day)	8[m]
EF_{AIR} = Exposure frequency for air (days/yr)	250[g]
ED_{AIR} = Exposure duration for air (yrs)	3[h]
Incidental Ingestion of Ground Water	
IR_{GW} = Ground water ingestion rate (L/day)	0.005[n]
EF_{GW} = Exposure frequency for ground water (days/yr)	50[o]
ED_{GW} = Exposure duration for ground water (yrs)	1.5[p]
Incidental Dermal Contact with Ground Water	
DA_{event} = Absorbed dose per event (mg/cm^2-event)	see note "q" below
SA_{GW} = Skin surface area available for contact with ground water (cm^2/event)	2,000[r]
EF_{GW} = Event frequency for ground water (events/yr)	50[o]
ED_{GW} = Exposure duration for ground water (yrs)	1.5[p]
General Factors (applicable to several exposure pathways)	
BW = Body weight (kg)	70[g]
AT = Averaging time (days) Noncarcinogenic Carcinogenic	 1,095 25,550

TABLE 22
Exposure Factors for a WRF Construction Worker[a]
(Southern Exposure Area)[b]

Notes:

a - This scenario includes hypothetical exposure to ground water through periodic maintenance of the dewatering pipeline. Most construction workers will not experience this type of exposure but it is included to be conservative.

b - Most of the activities associated with construction of the WRF will occur in the southern exposure area. Exposure that occurs in the northern exposure area during construction of the WRF will be of limited duration and of significantly lower magnitude than exposures in the southern exposure area. Thus, for the purposes of this assessment, this scenario is associated with the southern exposure area.

c – Two estimates of soil concentration were developed in the risk assessment, as identified in Table 16

d – Separate estimates for dust (from on-site soil) and vapors (from on-site ground water) were developed. (Appendix J)

e – USEPA (1997a) indicates that an adult ingestion rate of 100 mg/day may be appropriate for agricultural settings. It is assumed that construction workers would be exposed to a similar extent as agricultural workers.

f – It is conservatively assumed that 100% of the construction worker's soil ingestion is derived from the site.

g – Standard USEPA (1997a) default value.

h – Black & Veatch (2001) has indicated that the period of construction for the WRF expansion is approximately three years.

i – USEPA (1997a) recommends that the skin surface area of dermal contact be 25% of the total body surface area. The total body surface area for an adult is based on a high-end estimate (USEPA 1997a).

j – USEPA (1997a) presents body-part-specific soil adherence data for construction workers. The average of the values for the individual body parts were used in the risk assessment.

k – Based on recommendations provided by USEPA (2001a).

l – Based on an hourly average for an outdoor worker (USEPA 1997a; Table 5-23)

m – It is assumed that a worker will be exposed 8 hours per day.

n – USEPA (1989; RAGS) guidance provides an incidental water ingestion rate of 0.05 L/day during swimming. It was assumed that incidental ingestion of ground water by an individual maintaining the dewatering system would be significantly less than this value; thus, a value of 0.005 L/day was applied. This assumption is discussed in the uncertainty analysis section of the risk assessment.

o – Exposure to ground water is expected to be associated with maintenance of the dewatering system, which is estimated to occur weekly by a very limited number of individual workers.

p – According to correspondence from Black & Veatch (2001), the dewatering pipeline is expected to be operated for a period of 1.5 years for the WRF expansion construction.

q – DA_{event} is a function of the concentration in ground water, the chemical-specific permeability coefficient and the event duration. The method for estimating DA_{event} differs for inorganic and organic compounds, as identified in USEPA (2001a) guidance. The USEPA-recommended methods were applied in the risk assessment. The methodology used to estimate DA_{event} is provided in Appendix H.

r – Exposure assumed to be limited to hands and lower arms (USEPA 1997a).

TABLE 23 Exposure Factors for an Off-site Resident During WRF Construction		
Parameter		**Value**
Inhalation of Dust/Vapors		
CA =	Constituent concentration in air ($\mu g/m^3$)	Calculated[e]
IR =	Inhalation rate (m^3/hr)	0.55[a]
ET =	Exposure time (hrs/day)	24[b]
EF =	Exposure frequency (days/yr)	350[c]
ED =	Exposure duration (yrs)	3[d]
BW =	Body weight (kg)	70[c]
AT =	Averaging time (days) Noncarcinogenic Carcinogenic	 1,095 25,550

Notes:
a – Based on an average adult daily inhalation rate of 13.25 m^3/day (USEPA 1997a; Table 5-23)
b – It is assumed an off-site worker will be exposed 8 hours per day.
c – Standard USEPA (1997a) default value.
d – Black & Veatch (2001) has indicated that the period of construction is approximately three years.
e – Separate estimates for dust (from on-site soil) and vapors (from on-site soil and ground water) were developed (Appendix J).

TABLE 24
Exposure Factors for an Off-site Worker During WRF Construction

Parameter		Value
Inhalation of Dust/Vapors		
CA =	Constituent concentration in air ($\mu g/m^3$)	Calculated[e]
IR =	Inhalation rate (m^3/hr)	1.3[a]
ET =	Exposure time (hrs/day)	8[b]
EF =	Exposure frequency (days/yr)	250[c]
ED =	Exposure duration (yrs)	3[d]
BW =	Body weight (kg)	70[c]
AT =	Averaging time (days) Noncarcinogenic Carcinogenic	 1,095 25,550

Notes:
a – Based on an hourly average for an outdoor worker USEPA 1997a; Table 5-23)
b – It is assumed an off-site worker will be exposed 8 hours per day.
c – Standard USEPA (1997a) default value.
d – Black & Veatch (2001) has indicated that the period of construction is approximately three years.
e – Separate estimates for dust (from on-site soil) and vapors (from on-site soil and ground water) were developed (Appendix J).

TABLE 25
Exposure Factors for a Future (Default) Construction Worker[a]
(Northern Exposure Area)[b]

Parameter	Value
Media Concentration	
CS = Constituent concentration in soil (mg/kg)	95% UCL or maximum[c]
CA = Constituent concentration in air ($\mu g/m^3$)	Calculated[d]
CW = Constituent concentration in ground water (mg/L)	Maximum exposure area concentration
Ingestion of Soil	
IR_{SOIL} = Soil ingestion rate (mg/day)	100[e]
FI = Fraction of soil ingested from contaminated source (unitless)	1.0[f]
BA = Bioavailability of chemical in soil (unitless)	1.0
EF_{SOIL} = Exposure frequency for soil (days/yr)	250[g]
ED_{SOIL} = Exposure duration for soil (yrs)	1[h]
Dermal Contact with Soil	
SA_{SOIL} = Skin surface area available for contact with soil (cm^2/event)	5,800[i]
AF = Soil-to-skin adherence factor (mg/cm^2)	0.1[j]
ABS = Absorption factor (unitless)[k]	SVOCs: 0.10 Arsenic 0.03 Cadmium: 0.001 Pesticides: 0.01 Dioxins/Furans: 0.03
EF_{SOIL} = Exposure frequency for soil (days/yr)	250[g]
ED_{SOIL} = Exposure duration for soil (yrs)	1[h]
Inhalation of Dust/Vapors	
IR_{AIR} = Inhalation rate (m^3/hr)	1.3[l]
ET = Exposure time (hrs/day)	8[m]
EF_{AIR} = Exposure frequency for air (days/yr)	250[g]
ED_{AIR} = Exposure duration for air (yrs)	1[h]
Incidental Ingestion of Ground Water	
IR_{GW} = Ground water ingestion rate (L/day)	0.005[n]
EF_{GW} = Exposure frequency for ground water (days/yr)	50[o]
ED_{GW} = Exposure duration for ground water (yrs)	1[p]
Incidental Dermal Contact with Ground Water	
DA_{event} = Absorbed dose per event (mg/cm^2-event)	see note "q" below
SA_{GW} = Skin surface area available for contact with ground water (cm^2/event)	2,000[r]
EF_{GW} = Event frequency for ground water (events/yr)	50[o]
ED_{GW} = Exposure duration for ground water (yrs)	1.0[p]
General Factors (applicable to several exposure pathways)	
BW = Body weight (kg)	70[g]
AT = Averaging time (days) Noncarcinogenic Carcinogenic	 365 25,550

TABLE 25
Exposure Factors for a Future (Default) Construction Worker[a]
(Northern Exposure Area)[b]

Notes:

a - This scenario includes hypothetical exposure to ground water through periodic maintenance of a dewatering pipeline. Most construction workers will not experience this type of exposure, but it is included to be conservative.

b – Given that most of the southern portion of the site will be developed by the WRF, this future construction worker scenario is limited to the northern exposure area.

c – Two estimates of soil concentration were developed in the risk assessment, as identified in Table 17

d – Separate estimates for dust (from on-site soil) and vapors (from on-site ground water) were developed (Appendix J).

e – USEPA (1997a) indicates that an adult ingestion rate of 100 mg/day may be appropriate for agricultural settings. It is assumed that construction workers would be exposed to a similar extent as agricultural workers.

f – It is conservatively assumed that 100% of the future construction worker's soil ingestion is derived from the site.

g – Standard USEPA (1997a) default value.

h – The City has indicated that construction in the northern portion of the site, if any, would not be as extensive as is planned for the WRF expansion. A default estimate of 1 year for construction was applied.

i – USEPA (1997a) recommends that the skin surface area of dermal contact be 25% of the total body surface area. The total body surface area for an adult is based on a high-end estimate (USEPA 1997a).

j – USEPA (1997a) presents body-part-specific soil adherence data for construction workers. The average of the values for the individual body parts were used in the risk assessment.

k – Based on recommendations provided by USEPA (2001a).

l – Based on an hourly average for an outdoor worker (USEPA 1997a; Table 5-23)

m – It is assumed that a worker will be exposed 8 hours per day.

n – USEPA (1989; RAGS) guidance provides an incidental water ingestion rate of 0.05 L/day during swimming. It was assumed that incidental ingestion of ground water by an individual maintaining the dewatering system would be significantly less than this value; thus, a value of 0.005 L/day was applied. This assumption is discussed in the uncertainty analysis section of the risk assessment.

o – Exposure to ground water is expected to be associated with maintenance of the dewatering system, which is estimated to occur weekly to a very limited number of individuals.

p – Dewatering is assumed to occur over the entire default period of construction of 1 year.

q – DA_{event} is a function of the concentration in ground water, the chemical-specific permeability coefficient and the event duration. The method for estimating DA_{event} differs for inorganic and organic compounds, as identified in USEPA (2001a) guidance. The USEPA-recommended methods were applied in the risk assessment. The methodology used to estimate DA_{event} is provided in Appendix H.

r – Exposure assumed to be limited to hands and lower arms (USEPA 1997a).

TABLE 26
Exposure Factors for a Trespassing Child
(Post-WRF Construction – Northern Exposure Area)

Parameter		Value
Media Concentration		
CS =	Constituent concentration in soil (mg/kg)	95% UCL or maximum[a]
CA =	Constituent concentration in air ($\mu g/m^3$)	Calculated[b]
Ingestion of Soil		
IR_{SOIL} =	Soil ingestion rate (mg/day)	100[c]
BA =	Bioavailability of chemical in soil (unitless)	1.0
FI =	Fraction of soil ingested from contaminated source (unitless)	1.0[d]
Dermal Contact with Soil		
SA_{SOIL} =	Skin surface area available for contact with soil (cm^2/event)	3,200[e]
AF =	Soil-to-skin adherence factor (mg/cm^2)	0.04[f]
ABS =	Absorption factor (unitless)[g]	SVOCs: 0.10 Arsenic 0.03 Cadmium: 0.001 Pesticides: 0.01 Dioxins/Furans: 0.03
Inhalation of Dust/Vapors		
IR_{AIR} =	Inhalation rate (m^3/hr)	1.2[h]
ET =	Exposure time (hrs/day)	4[i]
General Factors (applicable to several exposure pathways)		
EF =	Exposure frequency (days/yr)	50[j]
ED =	Exposure duration (yrs)	6[k]
BW =	Body weight (kg)	31[l]
AT =	Averaging time (days) Noncarcinogenic Carcinogenic	 2,190 25,550

Notes:
a – Two estimates of soil concentrations were developed in the risk assessment, as indicated in Table 17.
b – Separate estimates for dust (from on-site soil) and vapors (from on-site ground water) were developed (Appendix J).
c – Soil ingestion studies on children generally target those under 6 years. It is not expected that ingestion rates for older children (i.e., 7 to 12 years) will differ significantly from adult soil ingestion rates (i.e., 50 mg/day). However, a conservative daily ingestion rate of 100 mg/day was applied in the risk assessment, given that the children in question may spend a portion of time playing in dirt.
d – It is conservatively assumed that 100% of the trespassing child's soil ingestion is derived from the site.
e – USEPA (1997a) recommends that the skin surface area of dermal contact be 25% of the total body surface area. The total body surface area for a child is based on a high-end estimate (USEPA 1997a).
f – USEPA (1997a) presents body-part-specific soil adherence data for outdoor soccer playing. Three data sets are provided; the average of the values for the high-end data set will be used in the risk assessment.
g – Based on recommendations provided by USEPA (2001a).
h – An inhalation rate for "moderate" activity recommended by USEPA (1997a; Table 5-23) will be applied.
i – It is assumed that a child will spend 4 hours per day at the site.
j – It is assumed that trespassing children will visit the site once per week.
k – Standard USEPA (1997a) default value.
l – Average weight of child in the 7-to-12-year-old age range (USEPA 1997a).

TABLE 27
Exposure Factors for an Indoor Worker
(Post-WRF Construction – Northern and Southern Exposure Areas)

Parameter		Value
Inhalation of Vapors		
CA =	Constituent concentration in indoor air ($\mu g/m^3$)	Calculated[a]
IR =	Inhalation rate (m^3/hr)	0.55[b]
ET =	Exposure time (hrs/day)	8[c]
EF =	Exposure frequency (days/yr)	250[d]
ED =	Exposure duration (yrs)	25[d]
BW =	Body weight (kg)	70[d]
AT =	Averaging time (days) Noncarcinogenic Carcinogenic	 9,125 25,550

Notes:
a – Based on migration of vapors from soil and ground water into building (Appendix J).
b – Based on an average adult daily inhalation rate of 13.25 m^3/day (USEPA 1997a; Table 5-23)
c – It is assumed an indoor worker will be exposed 8 hours per day.
d – Standard USEPA (1997a) default value.

TABLE 28
Exposure Factors for a Maintenance Worker
(Post-WRF Construction – Northern and Southern Exposure Areas)

Parameter	Value
Media Concentration	
CS = Constituent concentration in soil (mg/kg) Northern Exposure Area Southern Exposure Area	 95% UCL or maximum[a] 95% UCL or maximum[a]
CA = Constituent concentration in air ($\mu g/m^3$)	Calculated[b]
CW = Constituent concentration in water (mg/L)	Maximum exposure area concentration
Ingestion of Soil	
IR_{SOIL} = Soil ingestion rate (mg/day)	50[c]
FI = Fraction of soil ingested from contaminated source (unitless)	1.0[d]
BA = Bioavailability of chemical in soil (unitless)	0.25 for arsenic[r] 1.0 for all other chemicals
EF_{SOIL} = Exposure frequency for soil (days/yr)	250[e]
Dermal Contact with Soil	
SA_{SOIL} = Skin surface area available for contact with soil (cm^2/event)	5,800[f]
AF = Soil-to-skin adherence factor (mg/cm^2)	0.04[g]
ABS = Absorption factor (unitless)[h]	SVOCs: 0.10 Arsenic 0.03 Cadmium: 0.001 Pesticides: 0.01 Dioxins/Furans: 0.03
EF_{SOIL} = Exposure frequency for soil (days/yr)	250[e]
Incidental Ingestion of Ground Water	
IR_{GW} = Ground water ingestion rate (L/day)	0.005[q]
EF_{GW} = Exposure frequency for ground water (days/yr)	1[k]
Dermal Contact with Ground Water	
DA_{event} = Absorbed dose per event (mg/cm^2-event)	see note "i" below
SA_{GW} = Skin surface area available for contact with ground water (cm^2/event)	2,000[j]
EF_{GW} = Event frequency for ground water (events/yr)	1[k]
Inhalation of Dust/Vapors [p]	
IR_{AIR} = Inhalation rate (m^3/hr)	1.3[l]
ET = Exposure time (hrs/day)	8[m]
EF_{AIR} = Exposure frequency for air (days/yr)	250[n]
General Factors (applicable to several exposure pathways, except ground water)	
ED = Exposure duration (yrs)	25[n]
BW = Body weight (kg)	70[n]
AT = Averaging time (days) Noncarcinogenic Carcinogenic	 9,125 25,550

TABLE 28
Exposure Factors for a Maintenance Worker
(Post-WRF Construction – Northern and Southern Exposure Areas)

Parameter	Value

Notes:

a – Two estimates of soil concentrations were developed in the risk assessment as indicated in Table 17.

b – Separate estimates for dust (from on-site soil) and vapors (from on-site ground water) were developed (Appendix J).

c – Standard USEPA (1997a) default exposure estimate.

d – This factor was conservatively estimated to be 1.0, which assumes that all soil ingested by a maintenance worker is derived from the WRF expansion site. This is likely a significant overestimate, as discussed in Section X.E.4 of this report.

e – Standard USEPA (1997a) default exposure estimate.

f – USEPA (1997a) recommends that the skin surface area of dermal contact be 25% of the total body surface area. The total body surface area for an adult is based on a high-end estimate (USEPA 1997a).

g – USEPA (1997a) presents body-part-specific soil adherence data for grounds-keeping and landscaping. Six data sets are provided; the average of the values for the high-end data set will be used in the risk assessment.

h – Based on recommendations provided by USEPA (2001a).

i – DA_{event} is a function of the concentration in ground water, the chemical-specific permeability coefficient and the event duration. The method for estimating DA_{event} differs for inorganic and organic compounds, as identified in USEPA (2001a) guidance. The USEPA-recommended methods were applied in the risk assessment. The methodology used to estimate DA_{event} is provided in Appendix H.

j – Exposure assumed to be limited to hands and lower arms (USEPA 1997a).

k –Exposure to ground water is expected to occur very infrequently. It was assumed that a maintenance worker may come into contact with ground water once per year. If more extensive excavation were required (e.g., installing utility lines) it is likely that a contractor would be used. Exposure to such an individual is discussed in the uncertainties section of this assessment. Longer-term exposure to ground water is considered as part of the construction worker scenarios.

l – Based on an hourly average for an outdoor worker (USEPA 1997a; Table 5-23)

m – An 8-hour work day is assumed.

n – Standard USEPA (1997a) default exposure estimate.

p – Inhalation of dust by a maintenance worker in the southern exposure area assumes that the northern exposure area is not developed. Exposure to wind-blown dust by a maintenance worker in the northern exposure area assumes that only a portion (50%) of this area is developed and the remainder is unpaved and unvegetated.

q – USEPA (1989; RAGS) guidance provides an incidental water ingestion rate of 0.05 L/day during swimming. It was assumed that incidental ingestion of ground water by an individual maintaining the dewatering system would be significantly less than this value; thus, a value of 0.005 L/day was applied. This assumption is discussed in the uncertainty analysis section of the risk assessment.

r – Derivation of bioavailability factor for arsenic is provided in the text (Section V.C).

TABLE 29
Exposure Factors for an Off-site Resident
(Post-WRF Construction)

Parameter		Value
Inhalation of Dust/Vapors		
CA =	Constituent concentration in air ($\mu g/m^3$)	Calculated[c]
IR =	Inhalation rate (m^3/day)	13.25[a]
EF =	Exposure frequency (days/yr)	350[b]
ED =	Exposure duration (yrs)	30[b]
BW =	Body weight (kg)	70[b]
AT =	Averaging time (days) Noncarcinogenic Carcinogenic	 10,950 25,550

Notes:
a – Average adult daily inhalation rate recommended by USEPA (1997a; Table 5-23).
b – Standard USEPA (1997a) default value.
c – Separate estimates for dust (from on-site soil) and vapors (from on-site ground water) were developed (Appendix J).

TABLE 30
Exposure Factors for an Off-site Worker
(Post-WRF Construction)

Parameter		Value
Inhalation of Dust/Vapors		
CA =	Constituent concentration in air ($\mu g/m^3$)	Calculated[d]
IR =	Inhalation rate (m^3/hr)	1.3[a]
ET =	Exposure time (hrs/day)	8[b]
EF =	Exposure frequency (days/yr)	250[c]
ED =	Exposure duration (yrs)	25[c]
BW =	Body weight (kg)	70[c]
AT =	Averaging time (days) Noncarcinogenic Carcinogenic	 9,125 25,550

Notes:
a – Based on an hourly average for an outdoor worker (USEPA 1997a; Table 5-23)
b – It is assumed an off-site worker will be exposed 8 hours per day.
c – Standard USEPA (1997a) default value.
d – Separate estimates for dust (from on-site soil) and vapors (from on-site ground water) were developed (Appendix J).

VI. TOXICITY ASSESSMENT

The primary objectives of this step of the risk assessment are to identify the types of toxic effects associated with each chemical of potential concern, characterize the conditions (e.g., route, duration) of exposure under which these effects might occur, and determine the relationship between the magnitude of human exposure and the extent of adverse health effects. This relationship is represented through the use of toxicity values relating to cancer or noncancer health endpoints.

A. Toxicity Assessment Methods

In the risk assessment, the potential for both carcinogenic and noncarcinogenic health effects is evaluated. USEPA has conducted toxicity and dose-response assessments on many of the most frequently occurring environmental chemicals and has developed toxicity values for use in risk assessment, based on these analyses. The Integrated Risk Information System (IRIS) is an on-line data base maintained by USEPA (USEPA 2002b) that provides toxicity data for many commonly detected chemicals. Other sources of toxicity values include the *Health Effects Assessment Summary Tables* (HEAST) (USEPA 1997b) and provisional toxicity values in EPA's National Center for Environmental Assessment (NCEA). The procedures used by USEPA in evaluating toxicity studies to develop toxicity values are described below.

1. Carcinogenic Effects

USEPA guidance specifies that carcinogens pose a finite risk at all exposure levels. Therefore, in evaluating cancer risks, a "no-threshold" assumption is generally applied. The "no-threshold" assumption may not be valid, however, for some classes of carcinogens that act through a mechanism that requires a threshold dose to be exceeded prior to initiation of the carcinogenic process.

In assessing carcinogenic potential, USEPA uses a two-part evaluation in which the first step involves evaluating the likelihood that the substance is a human carcinogen (i.e., a weight-of-evidence assessment), and the second step involves defining the quantitative relationship between dose and response (i.e., development of an estimate of potency referred to as a potency factor or a slope factor).

In assessing the carcinogenic potential of a chemical, USEPA classifies a chemical into one of five groups based on the weight of evidence obtained from human and animal investigations. These groups are as follows:

Group A: Human Carcinogen (sufficient evidence of carcinogenicity in humans).

Group B: Probable Human Carcinogen (B1 - limited evidence of carcinogenicity in humans; B2 - sufficient evidence of carcinogenicity in animals with inadequate or lack of evidence in humans).

Group C: Possible Human Carcinogen (limited evidence of carcinogenicity in animals and inadequate or lack of human data).

Group D: Not Classifiable as to Human Carcinogenicity (inadequate or no evidence).

Group E: Evidence of Noncarcinogenicity for Humans (no evidence of carcinogenicity in adequate human studies).

As noted above, the outcome of the second part of the evaluation is the derivation of a slope factor. The slope factor, which is expressed in units of $(mg/kg\text{-}day)^{-1}$, represents the upper 95 percent confidence limit on the linear component of the slope of the carcinogenic dose-response curve in the low-dose (low-risk) region. The slope factor for chemical carcinogens is the upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime and is derived by applying a mathematical model to extrapolate from the relatively high doses administered to experimental animals to the lower exposure levels expected for human contact in the environment.

2. Noncarcinogenic Effects

The basic approach used by USEPA in developing toxicity values for noncarcinogenic effects of chemicals is based on the belief that some minimum (threshold) exposure level must be reached before the effect will occur, i.e., that protective mechanisms exist that must be overcome before an adverse health effect can occur. The estimated level of daily human exposure below which it is unlikely that deleterious effects will result is known as the Reference Dose (RfD). RfD values are reported in milligrams of chemical per unit body weight per day (mg/kg/d). Unless adequate human data are available, USEPA develops an RfD value based on data from experimental animals. If data from several animal studies are available, USEPA first seeks to identify the animal model that is most biologically relevant to humans (e.g., similar metabolism of the chemical). In the absence of information that identifies a given animal model as clearly most relevant, USEPA assumes that humans are at least as sensitive to the chemical as the most sensitive animal species tested. Accordingly,

USEPA selects a "critical" study using the most sensitive species tested and the most sensitive endpoint measured as the critical study upon which the RfD is based (USEPA 1989).

From this critical study, the experimental exposure representing the highest dose level tested at which no adverse effects were demonstrated (the no-observed-adverse-effect level, NOAEL) is identified. In selecting the NOAEL as the basis for the RfD, the assumption is made that if the critical toxic effect is prevented from occurring, then all toxic effects are prevented. The NOAEL is to be distinguished from the no-observed-effect level (NOEL), which corresponds to the exposure level at which no effect at all is observed; whereas, the NOAEL is the level at which no effect considered to be of toxicological significance is observed. In some studies, only a lowest-observed-adverse-effect level (LOAEL) is available. The use of a LOAEL in deriving an RfD requires the use of an additional uncertainty factor, as described below (USEPA 1989).

The RfD is derived from the NOAEL or LOAEL for the critical toxic endpoint by dividing the NOAEL or LOAEL by one or more uncertainty factors. These factors generally are multiples of 10, with each factor representing a specific area of uncertainty in the extrapolation from the available study data. For example, a 100-fold uncertainty factor is typically used when the RfD is based on results from long-term animal studies. This factor of 100 incorporates an uncertainty factor of 10 to account for variation in sensitivity in the human population and another uncertainty factor of 10 to account for interspecies variability between humans and experimental animals. Additional modifying factors ranging from 1 to 10 may be applied to reflect qualitative judgments about limitations or uncertainties in the critical study or in the data base as a whole that are not explicitly addressed by the standard uncertainty factors (USEPA 1989). Thus, since the RfD is intended to be adequately protective of sensitive individuals, application of the RfD to the general population is conservative.

B. Identification of Toxicity Values

The primary resource for toxicity values used in the risk assessment is USEPA's IRIS database (USEPA 2002b). As necessary, other sources of toxicity values were used to obtain toxicity values, including HEAST and NCEA values. Potential uncertainties associated with the use of provisional or withdrawn toxicity values from these sources is discussed in the uncertainties section of the risk assessment. In addition, chemicals for which USEPA toxicity values are not available will be discussed in the uncertainty section of the risk assessment. A summary of the slope factor values and RfDs used in the risk assessment is provided in Table 31.

Slope factors and RfDs have not been developed by USEPA for dermal exposure. In developing estimates of dermal exposure, an absorbed dose is calculated; whereas, oral toxicity

TABLE 31
Summary of Toxicity Values Used in the Risk Assessment

Chemical	Oral Exposure				Dermal Exposure				Inhalation Exposure			
	Slope Factor $(mg/kg\text{-}day)^{-1}$	Ref	RfD (mg/kg-day)	Ref	GI Factor	Ref	Slope Factor $(mg/kg\text{-}day)^{-1}$	RfD (mg/kg-day)	Slope Factor $(mg/kg\text{-}day)^{-1}$	Ref	RfD (mg/kg-day)	Ref
Ground Water COPCs												
Acetone	--		0.1	I	1	D	--	0.1	--		--	
Carbon tetrachloride	0.13	I	0.0007	I	1	D	0.13	0.0007	0.053	I	--	
Chloroform	0.0061	I	0.01	I	1	D	0.0061	0.01	0.081	I	0.000086	N
Tetrachloroethene	0.052	N	0.01	I	1	D	0.052	0.01	0.002	N	0.11	N
Toluene	--		0.2	I	1	D	--	0.2	--		0.11	I
bis(2-Ethylhexyl) phthalate	0.014	I	0.02	I	1	D	0.014	0.02	--		--	
Aluminum	--		1	N	0.01	T	--	0.01	NA		NA	N
Arsenic	1.5	I	0.0003	I	1	D	1.5	0.0003	NA		NA	
Barium	--		0.07	I	0.07	D	--	0.0049	NA		NA	A
Beryllium	--		0.002	I	0.01	D	--	0.00002	NA		NA	I
Cadmium	--		0.0005	I	0.05	D	--	0.000025	NA		NA	
Chromium (hexavalent)	--		0.003	I	0.025	D	--	0.000075	NA		NA	I
Chromium (total)	--		1.5	I	0.013	D	--	0.0195	NA		NA	
Cobalt	--		0.06	N	0.3	T	--	0.018	NA		NA	
Copper	--		0.037	H	1	O	--	0.037	NA		NA	
Iron	--		0.3	N	0.15	G	--	0.045	NA		NA	
Magnesium	--		--		--		--	--	NA		NA	
Manganese	--		0.024	I	0.04	D	--	0.00096	NA		NA	I
Molybdenum	--		0.005	I	0.38	T	--	0.0019	NA		NA	
Nickel	--		0.02	I	0.04	D	--	0.0008	NA		NA	
Selenium	--		0.005	I	1	D	--	0.005	NA		NA	
Silver	--		0.005	I	0.04	D	--	0.0002	NA		NA	
Thorium	--		--		--		--	--	NA		NA	
Titanium	--		4	N	0.01	T	--	0.04	NA		NA	N
Vanadium	--		0.007	H	0.026	D	--	0.000182	NA		NA	
Zinc	--		0.3	I	1	D	--	0.3	NA		NA	
alpha-BHC	6.3	I	--		1	A	6.3	--	NA		NA	
beta-BHC	1.8	I	--		1	A	1.8	--	NA		NA	
Perchlorate	--		0.00003	E	NA		NA	NA	NA		NA	
Total Cyanide	--		0.02	I	1	D	--	0.02	NA		NA	

TABLE 31
Summary of Toxicity Values Used in the Risk Assessment

Chemical	Oral Exposure				Dermal Exposure				Inhalation Exposure			
	Slope Factor $(mg/kg\text{-}day)^{-1}$	Ref	RfD (mg/kg-day)	Ref	GI Factor	Ref	Slope Factor $(mg/kg\text{-}day)^{-1}$	RfD (mg/kg-day)	Slope Factor $(mg/kg\text{-}day)^{-1}$	Ref	RfD (mg/kg-day)	Ref
Soil COPCs												
Aluminum	--		1	N	NA		NA	NA	--		0.0014	N
Antimony	--		0.0004	I	NA		NA	NA	--		--	
Arsenic	1.5	I	0.0003	I	1	D	1.5	0.0003	15.1	I	--	
Barium	--		0.07	I	NA		NA	NA	--		0.00014	H
Beryllium			0.002	I	NA		NA	NA	8.4	I	0.0000057	I
Cadmium	--		0.0005	I	0.05	D	--	0.000025	6.3	I	--	
Chromium (total)	--		1.5	I	NA		NA	NA	--		--	
Cobalt	--		0.06	N	NA		NA	NA	--		--	
Copper	--		0.037	H	NA		NA	NA	--		--	
Iron	--		0.3	N	NA		NA	NA	--		--	
Magnesium	--		--		NA		NA	NA	--		--	
Manganese	--		0.024	I	NA		NA	NA	--		0.000014	I
Mercury	--		0.0003	I	NA		NA	NA	--		--	
Molybdenum	--		0.005	I	NA		NA	NA	--		--	
Nickel	--		0.02	I	NA		NA	NA	--		--	
Selenium	--		0.005	I	NA		NA	NA	--		--	
Silver	--		0.005	I	NA		NA	NA	--		--	
Thallium	--		0.000066	I	NA		NA	NA	--		--	
Thorium	--		--		NA		NA	NA	--		--	
Titanium	--		4	N	NA		NA	NA	--		0.0086	N
Vanadium	--		0.007	H	NA		NA	NA	--		--	
Zinc	--		0.3	I	NA		NA	NA	--		--	
Dioxins/Furans TEQ	150000	I	--		1	D	150000	--	150000	I	--	
4,4'-DDD	0.24	I	--		1	D	0.24	--	--		--	
4,4'-DDE	0.34	I	--		1	D	0.34	--	--		--	
4,4'-DDT	0.34	I	0.0005	I	1	D	0.34	0.0005	0.34	I	--	
alpha-Chlordane	0.35	*	0.0005	*	1	D	0.35	0.0005	0.35	*	0.0002	*
beta-BHC	1.8	I	--		1	A	1.8	--	1.8	I	--	
Dieldrin	16	I	0.00005	I	1	T	16	0.00005	16	I	--	
Endosulfan II	--		0.006	**	1	A	--	0.006	--		--	

TABLE 31
Summary of Toxicity Values Used in the Risk Assessment

Chemical	Oral Exposure				Dermal Exposure				Inhalation Exposure			
	Slope Factor $(mg/kg\text{-}day)^{-1}$	Ref	RfD (mg/kg-day)	Ref	GI Factor	Ref	Slope Factor $(mg/kg\text{-}day)^{-1}$	RfD (mg/kg-day)	Slope Factor $(mg/kg\text{-}day)^{-1}$	Ref	RfD (mg/kg-day)	Ref
Endosulfan sulfate	--		0.006	**	1	A	--	0.006	--		--	
Endrin	--		0.0003	I	0.02	T	--	0.000006	--		--	
Endrin aldehyde	--		0.0003	***	0.02	T	--	0.000006	--		--	
Endrin ketone	--		0.0003	***	0.02	T	--	0.000006	--		--	
gamma-Chlordane	0.35	*	0.0005	*	1	A	0.35	0.0005	0.35	*	0.0002	*
Heptachlor epoxide	9.1	I	0.000013	I	1	A	9.1	0.000013	9.1	I	--	
Methoxychlor	--		0.005	I	1	A	--	0.005	--		--	
Perchlorate	--		0.00003	E	NA		NA	NA	--		--	

References (Ref):

I - USEPA's IRIS data base

N - USEPA's NCEA office (provisional value)

E - USEPA Office of Research and Development

H - USEPA 1997b (*Health Evaluation Assessment Summary Tables*)

G - Goyer 1991

D - USEPA 1998

A - Value of 1 assumed

T- ATSDR Toxicological Profile

O - Owen 1990

* - Value for Chlordane used

** - Value for Endosulfan used

*** - Value for Endrin used

values are based on the applied dose. Therefore, USEPA (1989; 2002b) recommends that oral slope factors and RfDs that have been adjusted for an absorbed dose be used in evaluating dermal risks. For this assessment, factors that represent the absorption of COPCs through the gastrointestinal (GI) tract were applied to the oral toxicity values to develop dermal toxicity values. For slope factor values, the oral value is divided by the GI absorption factor, and for RfDs, the toxicity value is multiplied by the GI factor, as indicated below:

$$SF_{dermal} = \frac{SF_{oral}}{GI}$$

$$RfD_{dermal} = RfD_{oral} \times GI$$

For dermal contact with soil, exposure is evaluated for only two metals, arsenic and cadmium (USEPA 2001a); thus, toxicity values are presented for these two metals in soil.

The GI factors were derived from a variety of sources, including USEPA's dermal guidance for Superfund (USEPA 2001a), chemical-specific toxicological profiles, USEPA health assessment documents, and other sources in the scientific literature. USEPA (2001a) recommends that adjustments to oral toxicity values be made only when the GI absorption value is "significantly less than 100% (i.e., <50%)." Otherwise, no adjustment to the oral toxicity value is made. The chemical-specific GI factors applied in developing RfDs and slope factor values for the dermal route of exposure are summarized in Table 31. If no adjustment is warranted, because GI absorption is greater than 50 percent or if sufficient data are available, a value of 100 percent is indicated in Table 31.The specific approaches for certain chemicals are discussed below. These chemicals have been highlighted because there are specific issues associated with the toxicity of these chemicals that should be noted.

1. PCDDs/PCDFs

There are over 200 individual forms or "congeners" of chlorinated PCDDs/PCDFs (dioxins and furans). A congener is a single member of a chemical family (e.g., there are 75 congeners of chlorinated dibenzo-p-dioxins). USEPA has developed procedures for assessing the cancer risks associated with exposure to certain dioxins and furans based on the relative toxicity of these compounds to the toxicity of 2,3,7,8-TCDD, which is generally believed to be the most toxic form (USEPA 1994). Each congener that is chlorinated in the 2, 3, 7, and 8 positions of the dioxin or furan compound is assigned a value, referred to as a toxicity equivalency factor (TEF), corresponding to its toxicity relative to 2,3,7,8-TCDD (i.e., 2,3,7,8-TCDD has a TEF of 1.0 and other dioxin and furan congeners have TEFs between zero and 1.0), as summarized in Table 32. The

concentration of each congener in a given medium is multiplied by its TEF. The sum of the calculated values for the 17 congeners is referred to as the 2,3,7,8-TCDD toxicity equivalency (TEQ). In the risk assessment, exposure and risk were evaluated for TEQs. The appropriate toxicity value for 2,3,7,8-TCDD TEQ is the toxicity value for 2,3,7,8-TCDD.

It should be noted that TEQ values were developed for individual samples; thus, exposure point concentrations used in this assessment are 95% UCLs of TEQs (i.e., 95% UCL concentrations of each congener were not developed).

TABLE 32
Toxicity Equivalence Factors for Dioxin/Furan Congeners

Dioxin/Furan Congener	Toxicity Equivalence Factor (TEF)
2,3,7,8 TCDD	1
1,2,3,7,8 PeCDD	0.5
1,2,3,4,7,8 HxCDD	0.1
1,2,3,6,7,8 HxCDD	0.1
1,2,3,7,8,9 HxCDD	0.1
1,2,3,4,6,7,8 HpCDD	0.01
OCDD	0.001
2,3,7,8 TCDF	0.1
1,2,3,7,8 PeCDF	0.05
2,3,4,7,8 PeCDF	0.5
1,2,3,4,7,8 HxCDF	0.1
1,2,3,6,7,8 HxCDF	0.1
2,3,4,6,7,8 HxCDF	0.1
1,2,3,7,8,9 HxCDF	0.1
1,2,3,4,6,7,8 HpCDF	0.01
1,2,3,4,7,8,9 HpCDF	0.01
OCDF	0.001

2. Chromium

The oxidation state of chromium is a crucial issue in evaluating the toxicity of this metal and the risks associated with exposure. Hexavalent chromium (Cr^{+6}) is the most toxic valence state of chromium and has been shown to be a human carcinogen through inhalation exposure. Trivalent chromium, a commonly found less oxidized form of chromium, has not been shown to be carcinogenic in either humans or laboratory animals. As part of the site characterization program, soil and ground water samples were analyzed for both total chromium and hexavalent chromium; thus, toxicity values for total

chromium were applied to the sampling results for total chromium and the toxicity value for hexavalent chromium were applied for the analytical results of hexavalent chromium.

3. Perchlorate

The IRIS data base does not provide a toxicity value for perchlorate. However, USEPA recently released a perchlorate toxicological analysis (2002), which recommends an oral RfD of 0.00003 mg/kg-day (approximately a factor of 17 below the previous oral RfD for perchlorate). This revised RfD was applied in the calculation of risks in this assessment. Dermal exposure to perchlorate in soil and in groundwater was not evaluated in this assessment because USEPA's recent evaluation of perchlorate indicates that perchlorate does not pass readily through the skin (e.g., uptake of inorganic ions such as perchlorate is typically less than 10% and frequently less than 1% (USEPA 2002). Additionally, remedial actions for groundwater underlying the site will likely be based on chronic human ingestion of groundwater and/or ecological risk, which will result in more stringent perchlorate groundwater concentrations than those associated with incidental dermal contact with groundwater.

VII. RISK CHARACTERIZATION

In the risk characterization step, chemical toxicity values are used in conjunction with the dose estimates for each of the various exposure pathways and populations to evaluate both carcinogenic risks and the potential for noncarcinogenic health effects. The following sections present the methodology that was used in the risk assessment for estimating carcinogenic risks and the potential for noncancer health effects.

This methodology results in highly conservative estimates of risk. The risks estimated using these risk assessment methods are not actuarial (i.e., the risk estimates cannot be used to predict the actual number of individuals who might experience health consequences as a result of exposure). Given the conservative nature of the numerous assumptions employed, the actual health risks are almost certainly less than those derived using the methods of risk assessment described in this chapter. Although current risk assessment approaches generally overstate risk, USEPA and other regulatory agencies generally recognize that these methods provide a systematic approach that allows public health policy makers to establish the relative risk posed by various environmental substances and potential exposure pathways.

A. Estimation of Cancer Risks

The numerical estimate of the excess lifetime cancer risk resulting from the modeled exposure to a specific carcinogenic chemical was calculated by multiplying the lifetime average daily dose (LADD) by the risk per unit dose, or slope factor, as follows:

$$Risk_i = LADD_i \times SF_i$$

where:

$Risk_i$	=	lifetime probability of developing cancer due to exposure to site-related contaminants, unitless
$LADD_i$	=	lifetime average daily dose to chemical i, mg/kg-day
SF_i	=	carcinogenic slope factor for chemical i, $(mg/kg\text{-}day)^{-1}$

In cases of multiple chemical exposures, it was assumed that cancer risks are additive (USEPA 1986b). Accordingly, the risk estimates for each exposure pathway were developed by summing the risk estimates of the individual chemicals. The risks calculated for each exposure pathway were summed for all pathways applicable to a given population.

Interpretations of the significance of the carcinogenic risk estimates are often based on USEPA policy for acceptable levels of risk. Specifically, USEPA has adopted a risk range under which to regulate Superfund clean-ups. In the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 CFR §300.430), USEPA states that "[f]or known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an

excess upper-bound lifetime cancer risk to an individual of between 10^{-4} and 10^{-6} using information on the relationship between dose and response." Below 10^{-6} cancer risks are generally assumed to be insignificant. Specifically, USEPA (1991b), citing an Office of Solid Waste and Emergency Response (OSWER) Directive (USEPA 1991a), indicates that "action is generally warranted at a site when the cumulative carcinogenic risk is greater than 10^{-4}." For individual chemicals, USEPA (1991b) has indicated that, in evaluating the need for risk-based remediation, an appropriate point of departure is a concentration of a given chemical in a particular medium that represents a cancer risk of 10^{-6}. Moreover, NDEP has indicated that 10^{-6} represents a preliminary target level for risk management decisions. Estimated carcinogenic risks developed in this assessment, therefore, are evaluated in light of the range of risks generally regarded as acceptable by USEPA and NDEP.

B. Estimation of the Potential for Noncancer Effects

Unlike the measure of risk used for carcinogens, the measure used to describe the potential for noncarcinogenic toxicity to occur is not expressed as a probability of experiencing an adverse effect. Instead, the numerical estimate of the potential for adverse noncancer effects resulting from exposure to a chemical was derived in the following manner:

$$HQ_i = ADD_i/RfD_i$$

where:

HQ_i	=	hazard quotient for chemical i, unitless
ADD_i	=	average daily dose of chemical i, mg/kg-day
RfD_i	=	reference dose for chemical i, mg/kg-day

If the resulting HQ value is less than or equal to one, it is assumed that the exposed population would not be affected (USEPA 1991a). If the HQ value is greater than one, there may be concern for potential noncarcinogenic effects. An HQ value that is greater than one should not be interpreted to mean that adverse effects will occur, because both the uncertainty (safety) factors used in estimating the RfD and the conservative assumptions used in estimating the ADD tend to overestimate exposure. As a rule, however, the greater the value of the HQ above one, the greater the likelihood that an adverse effect will occur.

The assessment of overall potential for noncancer effects posed by simultaneous exposure to multiple chemicals was conducted using the "Hazard Index" approach developed in USEPA's "Guidelines for the Health Risk Assessment of Chemical Mixtures" (USEPA 1986b) and described in RAGS (USEPA 1989). As a first screening, the HQ values for individual chemicals associated with a given exposure pathway were summed to provide an indication of the potential for noncancer effects posed by multiple chemical exposure. This sum of the HQ values for individual chemicals is referred to as the Hazard Index (HI). The HI approach assumes that

multiple sub-threshold exposures could result in an adverse effect and that a reasonable criterion for evaluating the potential adverse effects is the sum of the hazard quotients (USEPA 1986b). As recommended by USEPA, if an HI greater than unity is calculated as a consequence of summing several HQ values less than unity, it is appropriate to segregate the chemicals by target organ effect and mechanism of toxicity and derive HI values for each group.

C. Estimates of Risk

Potential risks associated with exposure to chemicals in soil and ground water at the WRF expansion property were evaluated for several scenarios, including three populations potentially exposed during the construction of the WRF expansion (WRF construction workers, off-site residents, and off-site workers) and seven populations that could be exposed after construction of the WRF expansion is completed (trespassing children, maintenance workers in the northern and southern exposure areas, on-site indoor workers, default construction workers in the northern exposure area, off-site residents, and off-site workers). For each of these populations, excess lifetime cancer risks and the potential for adverse noncancer health effects (i.e., HI values) were estimated for the relevant exposure pathways, identified in Table 15. A summary of the cumulative cancer risks and noncancer HI values for the identified populations is provided in Tables 33 and 34, respectively. Chemical-specific cancer risks and noncancer HQ values are tabulated in Appendix M.

An overview of the quantitative results of the risk assessment is provided in the following sections for each of the exposure scenarios separately. This discussion provides an indication of the exposure pathways and chemicals that were found to be the greatest contributors to the total estimated cancer risks and cumulative noncancer HI values. A discussion of the conclusions of the risk assessment is provided in Chapter X.

1. Exposure Scenarios During WRF Construction

During construction of the WRF expansion, several populations may be exposed to chemicals related to the site, including workers associated with the WRF construction, off-site workers at the existing WRF facility, and off-site residents. The estimated cancer risks and the potential for adverse noncancer health effects are discussed in the following sections.

a. WRF Construction Worker (Southern Exposure Area)

In this assessment, it was assumed that a worker involved with various aspects of the WRF expansion construction could be exposed to chemicals in soil and ground water at the site through incidental ingestion of soil, dermal contact with soil, and inhalation of dust and vapors (from ground water). In addition, it was assumed that direct contact (incidental ingestion and dermal contact) with

TABLE 33
Summary of Estimated Chemical Cancer Risks

Time Frame	Exposure Scenario	Pathway	Estimated Cancer Risk*
During WRF Construction	WRF Construction Worker (Southern Exposure Area)	Ingestion of Soil	6×10^{-7}
		Dermal Contact with Soil	1×10^{-7}
		Inhalation of Dust	1×10^{-7}
		Ingestion of Ground Water	3×10^{-8}
		Dermal Contact with Ground Water	1×10^{-8}
		Inhalation of Vapors from Ground Water	1×10^{-7}
		Total Risk	**1×10^{-6}**
	Off-site Resident	Inhalation of Dust	1×10^{-9}
		Inhalation of Vapors from Ground Water	8×10^{-8}
		Total Risk	**8×10^{-8}**
	Off-site Worker	Inhalation of Dust	7×10^{-10}
		Inhalation of Vapors from Ground Water	5×10^{-8}
		Total Risk	**5×10^{-8}**
Future (Post WRF Construction)	Maintenance Worker (Northern Exposure Area)	Ingestion of Soil	7×10^{-7}
		Dermal Contact with Soil	3×10^{-7}
		Inhalation of Dust	2×10^{-10}
		Ingestion of Ground Water	2×10^{-8}
		Dermal Contact with Ground Water	7×10^{-9}
		Inhalation of Vapors from Ground Water	3×10^{-7}
		Total Risk	**1×10^{-6}**
	Maintenance Worker (Southern Exposure Area)	Ingestion of Soil	1×10^{-6}
		Dermal Contact with Soil	4×10^{-7}
		Inhalation of Dust	3×10^{-10}
		Ingestion of Ground Water	9×10^{-9}
		Dermal Contact with Ground Water	4×10^{-9}
		Inhalation of Vapors from Ground Water	3×10^{-7}
		Total Risk	**2×10^{-6}**
	Default Construction Worker (Northern Exposure Area)	Ingestion of Soil	2×10^{-7}
		Dermal Contact with Soil	3×10^{-8}
		Inhalation of Dust	3×10^{-8}
		Ingestion of Ground Water	3×10^{-8}
		Dermal Contact with Ground Water	1×10^{-8}
		Inhalation of Vapors from Ground Water	6×10^{-8}
		Total Risk	**3×10^{-7}**
	Trespassing Child (Northern Exposure Area)	Ingestion of Soil	5×10^{-7}
		Dermal Contact with Soil	2×10^{-8}
		Inhalation of Dust	2×10^{-11}
		Inhalation of Vapors from Ground Water	2×10^{-8}
		Total Risk	**5×10^{-7}**
	Indoor Worker (Southern Exposure Area)	Inhalation of Vapors	**6×10^{-7}**
	Indoor Worker (Northern Exposure Area)	Inhalation of Vapors	**8×10^{-7}**
	Off-site Resident	Inhalation of Dust	6×10^{-10}
		Inhalation of Vapors from Ground Water	6×10^{-7}
		Total Risk	**6×10^{-7}**
	Off-site Worker	Inhalation of Dust	3×10^{-10}
		Inhalation of Vapors from Ground Water	3×10^{-7}
		Total Risk	**3×10^{-7}**

Note:
* - Pathway-specific cancer risks may not add to the total risk due to rounding

TABLE 34
Summary of Estimated Chemical Hazard Index Values

Time Frame	Exposure Scenario	Pathway	Estimated Hazard Index*	Target-organ-specific HI Values[1]
During WRF Construction	WRF Construction Worker (Southern Exposure Area)	Ingestion of Soil	0.40	Thyroid (GW) – 1.8[2]
		Dermal Contact with Soil	0.005	Thyroid (soil) – 0.26
		Inhalation of Dust	1.1	CNS – 0.96
		Ingestion of Ground Water	1.8	Nasal – 0.45
		Dermal Contact with Ground Water	0.004	Respiratory – 0.16
		Inhalation of Vapors from Ground Water	0.45	GI Tract – 0.062
		Hazard Index	**3.8**	Reproductive – 0.054
				Skin – 0.034
				Other – <0.02
	Off-site Resident	Inhalation of Dust	0.012	
		Inhalation of Vapors from Ground Water	0.26	NA
		Hazard Index	**0.27**	
	Off-site Worker	Inhalation of Dust	0.007	
		Inhalation of Vapors from Ground Water	0.14	NA
		Hazard Index	**0.15**	
Future (Post WRF Construction)	Maintenance Worker (Northern Exposure Area)	Ingestion of Soil	0.33	
		Dermal Contact with Soil	0.002	
		Inhalation of Dust	0.0002	
		Ingestion of Ground Water	0.071	NA
		Dermal Contact with Ground Water	0.001	
		Inhalation of Vapors from Ground Water	0.13	
		Hazard Index	**0.53**	
	Maintenance Worker (Southern Exposure Area)	Ingestion of Soil	0.26	
		Dermal Contact with Soil	0.002	
		Inhalation of Dust	0.0003	
		Ingestion of Ground Water	0.071	NA
		Dermal Contact with Ground Water	0.0002	
		Inhalation of Vapors from Ground Water	0.10	
		Hazard Index	**0.44**	

TABLE 34
Summary of Estimated Chemical Hazard Index Values

Time Frame	Exposure Scenario	Pathway	Estimated Hazard Index*	Target-organ-specific HI Values[1]
	Default Construction Worker (Northern Exposure Area)	Ingestion of Soil	0.68	Thyroid (GW) – 3.5[3]
		Dermal Contact with Soil	0.005	Thyroid (soil) – 0.54
		Inhalation of Dust	0.82	CNS – 0.65
		Ingestion of Ground Water	3.5	Nasal – 0.58
		Dermal Contact with Ground Water	0.059	Respiratory – 0.20
		Inhalation of Vapors from Ground Water	0.58	GI Tract – 0.08
		Hazard Index	**5.7**	Reproductive – 0.04
				Skin – 0.04
				Other - <0.1
	Trespassing Child (Northern Exposure Area)	Ingestion of Soil	0.31	NA
		Dermal Contact with Soil	0.0005	
		Inhalation of Dust	0.00009	
		Inhalation of Vapors from Ground Water	0.027	
		Hazard Index	**0.34**	
	Indoor Worker (Southern Exposure Area)	Inhalation of Vapors	**0.24**	NA
	Indoor Worker (Northern Exposure Area)	Inhalation of Vapors	**0.33**	NA
	Off-site Resident	Inhalation of Dust	0.0006	NA
		Inhalation of Vapors from Ground Water	0.18	
		Hazard Index	**0.18**	
	Off-site Worker	Inhalation of Dust	0.0003	NA
		Inhalation of Vapors from Ground Water	0.10	
		Hazard Index	**0.10**	

Note:
* - Pathway-specific hazard index values may not add to the total risk due to rounding
NA – Not applicable
1 - Target-organ specific HI values were not calculated for scenarios with an HI value less than 1.0.
2 - Most (1.8) of the HI value associated with the thyroid is due to exposure to perchlorate in ground water, which can be eliminated through the use of PPE during dewatering pipeline maintenance activities.
3 – Most (3.5) of the HI value associated with the thyroid is due to exposure to perchlorate in ground water, which can be eliminated through the use of PPE during dewatering pipeline maintenance activities.

ground water could occur due to periodic maintenance of the dewatering system associated with the construction activities. Exposure to ground water is expected to be limited to only those individuals involved in dewatering pipeline maintenance; most WRF construction workers will not come into contact with ground water.

As indicated in Table 33, the total estimated cancer risk for all exposure pathways combined is 1×10^{-6}. The primary contributor (approximately 60 percent) to the total estimated cancer risk is ingestion of soil; although, inhalation of vapors from ground water, inhalation of dust, and dermal contact with soil each contribute between 10 percent and 15 percent of the total risk. Most of the cumulative risk estimate (6×10^{-7} of the total 1×10^{-6}) is associated with exposure to soil at the site. The estimated risk associated with exposure to ground water alone is less than 2×10^{-7}. The chemical that contributes most significantly to the total cancer risk is arsenic, which accounts for almost 80 percent of the total estimated cancer risk. The next greatest contributor to total cancer risk is chloroform in ground water, with an associated cancer risk of 1.3×10^{-7}, approximately 13 percent of the cumulative risk.

The estimated cumulative HI value for WRF construction workers is 3.8, as indicated in Table 34. This value is above the USEPA target HI value of 1.0. Ingestion of perchlorate in ground water accounts for a large fraction (47 percent; 1.8 of the total HI of 3.8) of the total HI value. Although this assessment is based on a series of highly conservative assumptions and adverse noncancer health effects are not expected, use of PPE for any individual who may have long-term contact with ground water would eliminate ingestion of ground water as a concern.

For most workers, exposure to ground water will not occur. Thus, the estimated HI value for WRF construction workers not involved in dewatering pipeline maintenance is 2.0, which is primarily associated with inhalation of dust (1.1) and inhalation of vapors (0.45). As discussed in Section B of this chapter, a target organ analysis was performed for scenarios with HI values greater than one. The individual chemicals that account for most of the noncancer HI value for WRF construction workers not involved in dewatering pipeline maintenance are manganese (HQ = 0.96), chloroform (HQ = 0.45), and perchlorate in soil (HQ = 0.26). All other chemicals combined account for only 0.33 of the total HI value. Although the cumulative HI value for workers not involved in dewatering pipeline maintenance exceeds 1.0, adverse noncancer health effects are not expected for this subgroup of the WRF construction worker population because the chemicals that contribute most significantly to the total HI value affect different target

organs. Manganese affects the central nervous system, chloroform affects the nasal passages, liver, and kidneys, and perchlorate affects the thyroid. The target organ-specific HI values are below 1.0, as indicated in Table 34. Thus, adverse noncancer health effects are not expected for WRF construction workers that wear PPE during pipeline maintenance activities. For all other construction workers, the potential for adverse noncancer health effects is not significant.

b. Off-site Resident and Off-site Worker

Cancer risks and the potential for adverse noncancer health effects were estimated for off-site workers and off-site residents, assuming that these populations would be exposed to dust and vapors emitted from the site. The total estimated cancer risk and HI value for an off-site resident are 8×10^{-8} and 0.3, respectively. For the off-site workers, the estimated cancer risk and HI value are 5×10^{-8} and 0.2, respectively. Thus, the estimated cancer risks and noncancer HI values for off-site residents and off-site workers during WRF construction are below risk thresholds identified by USEPA.

For both of these off-site populations, inhalation of vapors (almost entirely chloroform) is the greatest contributor to both the total cancer risk and the cumulative noncancer HI value.

2. Future – After Construction of the WRF

After construction of the WRF, there are several possible populations that could come into contact with chemicals related to the site, including a maintenance worker at the newly constructed WRF, a maintenance worker in a future (hypothetical) building in the northern area of the site, a default construction worker associated with development (as of yet unplanned) in the northern exposure area, a child trespasser on the northern portion of the site (prior to any development), an indoor worker (northern and southern exposure areas), off-site worker, and off-site resident. A discussion of the estimated cancer risks and the potential for adverse noncancer health effects is provided in the following sections.

a. Maintenance Worker (Northern and Southern Exposure Areas)

Two separate maintenance worker scenarios were evaluated in the risk assessment, one assuming exposure in the southern portion of the site and a second based on exposure in the northern portion of the site (if development of this area were to occur in the future). The estimated cancer risks and HI values for the two scenarios are very similar.

The estimated cancer risks to a maintenance worker are 2 x 10^{-6} in the southern exposure area and 1 x 10^{-6} in the northern exposure area. Ingestion of soil is the primary contributing exposure pathway for both scenarios (over 50 percent in both areas). Inhalation of vapors from ground water and dermal contact with soil also contribute significantly for both areas.

The chemical that contributes most to total risk is arsenic; although, exposure to chloroform emitted from ground water and dioxins in soil also contribute at least 10 percent of the total estimated cancer risk.

For the chemicals with noncarcinogenic effects, HI values of 0.4 and 0.5 were estimated for the southern and northern exposure areas, respectively. Thus, adverse noncancer health effects are not expected for maintenance workers at the proposed WRF expansion in the southern area of the site or in the northern exposure area, if this area were developed by the city. In both areas, the pathways that contribute most significantly are inhalation of vapors, ingestion of ground water, and ingestion or soil. Almost all of the cumulative HI values for the northern and southern exposure areas are associated with exposure to chloroform (due to inhalation of vapors emitted from ground water) and perchlorate (due to ingestion of both soil and ground water).

b. Default Construction Worker (Northern Exposure Area)

Although there is currently no plan to do so, the City may decide in the future, to develop the northern portion of the site. The type and extent of construction that would be conducted in the northern exposure area is not known; thus, for the purposes of this assessment, risks to a default construction worker were estimated, applying many of the same assumptions as used for the WRF construction worker scenario.

The estimated cancer risk for this scenario is 3 x 10^{-7}, as indicated in Table 33, which is significantly below the lower end of USEPA's acceptable cancer risk range. Ingestion of soil (almost entirely accounted for by arsenic) and inhalation of vapors emitted from ground water (primarily chloroform) contribute 53 percent and 18 percent of the total cancer risk, respectively. The other pathways of exposure each contribute between 5 and 10 percent of the total cancer risk.

The estimated cumulative HI value for a default construction worker in the northern exposure area is 5.7, as indicated in Table 34. This total HI value is primarily associated with exposure to perchlorate in ground water (3.5 of the total HI of 5.7), which could be eliminated through the use of PPE during dewatering pipeline maintenance, effectively reducing the estimated HI value to 2.2. This HI value is also applicable to default construction workers who are not exposed to

ground water through dewatering pipeline maintenance. As discussed in Section B of this chapter, a target organ analysis was conducted for scenarios with HI values greater than one. The individual chemicals that account for most of the noncancer HI value (for workers not exposed to ground water) include manganese (HQ = 0.65), chloroform (HQ = 0.58), perchlorate in soil (HQ = 0.54), and aluminum (HQ = 0.20). All other chemicals combined account for approximately 0.23 of the total HI value. Although the cumulative HI value for default construction workers not involved in dewatering pipeline maintenance exceeds 1.0, adverse noncancer health effects are not expected because the chemicals that contribute most significantly to the total HI value affect different target organs, as indicated in Table 34. Thus, adverse noncancer health effects are not expected for default construction workers, if PPE is worn during pipeline maintenance activities, or if no contact with ground water is expected.

c. Trespassing Child (Northern Exposure Area)

The total estimated cancer risk and HI value for a child trespassing in the northern exposure area after WRF construction is completed are 5×10^{-7} and 0.3, respectively, which are significantly below USEPA risk thresholds. The total cancer risk is due primarily (92 percent of the total) to exposure to arsenic in soil. The estimated cancer risk associated with the next greatest contributor to total risk is significantly below 10^{-7}. The other pathways of exposure for a trespasser (inhalation of dust, inhalation of vapors, and dermal contact with soil) account for less than 6 percent of the total risk.

The total estimated HI value for the trespassing child is associated with exposure to chloroform vapors emitted from ground water and arsenic, iron, manganese, and perchlorate through ingestion of soil.

d. Indoor Worker (Northern and Southern Exposure Areas)

The indoor worker scenario assumes that volatile chemicals in ground water migrate upward through the soil column and infiltrate an overlying building. This scenario was evaluated separately for an individual located in the northern and southern exposure areas. The total cancer risk and HI value associated with exposure to VOC vapors indoors by an indoor worker in the southern part of the site were estimated to be 6×10^{-7} and 0.2, respectively. Although not currently planned, if development were to occur in the northern portion of the site, the estimated cancer risk and HI value for an indoor worker in this part of the site is 8×10^{-7} and 0.3, respectively. For both the cancer risk

estimates and the HI values in the northern and southern exposure areas, exposure to chloroform accounts for almost all of the total estimated value.

As noted previously, this exposure scenario was evaluated based on a screening model for vapor transport from ground water to indoor air. Given that cancer risks are below 1 x 10^{-6} and HI values are below 1, it is not necessary to apply a more refined vapor transport model to estimate exposures by an indoor worker.

e. Off-site Resident and Off-site Worker

Cancer risks and the potential for adverse noncancer health effects were estimated for off-site workers and off-site residents after construction of the WRF expansion has been completed. The estimated cancer risks for these populations are 3 x 10^{-7} and 6 x 10^{-7}, respectively, and total estimated HI values are 0.1 and 0.2, respectively. Thus, off-site transport of dust and vapors after WRF construction is completed does not pose a significant concern.

D. Potential Exposure by Ecological Populations

The nearest ecological habitats to the site of any significance include a bird preserve, which is located north of the current WRF and west of the northern portion of the site, Las Vegas Wash, which flows from west to east approximately ½-mile north of the site, and a wetlands area approximately 1,000 feet north of the site. It is likely that ground water that passes beneath the WRF site discharges to these wetlands and Las Vegas Wash. Possible mechanisms for the transport of contaminants from the site to these locations include surface water runoff/erosion, wind-blown dust, and migration through ground water.

As discussed in the conceptual site model, there are no current surface water discharges from the site to either the wetlands/bird preserve or to Las Vegas Wash, nor are any planned for the future[16]. Thus, surface water pathways of exposure for ecological populations in these areas are not expected.

It is possible that ecological populations could be exposed to chemicals in ground water that discharges into Las Vegas Wash and the wetlands located approximately 1,000 feet north of the site. It is less likely that ground water from the site is discharging to the bird preserve west of the site based on the apparent direction of ground water flow to the north. To provide a basis for comparison, Table D-5 provides a summary of ground water concentrations in monitoring wells on-site and north of the site and AWQC for freshwater. Several metals (aluminum, iron,

[16] Ground water removed during construction of the WRF expansion may be discharged; however, such releases will be permitted and pretreated, as necessary, to meet discharge limitations. Before contaminated ground water is pumped and discharged, pretreatment methods shall be reviewed with NDEP, Bureau of Water Pollution Control and Bureau of Corrective Action.

hexavalent chromium, and selenium) exceed the corresponding freshwater AWQC, as indicated in Table D-5. Therefore, it is possible that ground water could be adversely impacting surface water quality in the wetlands and Las Vegas Wash. As discussed previously, a refined analysis of potential leaching of chemicals from the site into underlying ground water will be conducted in the future (separately from this risk assessment). As part of that analysis, an evaluation of the potential ecological effects of contaminants in ground water will be conducted.

Although it is possible that surficial soils could be blown from the site and deposit within the wetlands, bird preserve, or on Las Vegas Wash, this pathway appears to be limited. Construction activities will be conducted under a permit from the Clark County Air Pollution Control Division (Black & Veatch 2000b), which will require that fugitive dust emissions from the site be controlled using a variety of methods, including application of water or dust palliatives, paving, use of gravel, or other methods approved by the Board of Health. Construction projects are regulated specifically by several District Board of Health of Clark County Air Quality Regulations (Section 17 – Dust Control Permit for Construction Activities including Surface Grading and Trenching; Section 91 - Fugitive Dust from Unpaved Roads, Unpaved Alleys, and Unpaved Easement Roads; Section 92 – Fugitive Dusts from Unpaved Parking Lots; and Section 94 – Permitting and Dust Control for Construction Activities), the application of which will significantly limit emissions of dust from the site during construction. Furthermore, once construction activities are complete, the City will be required to continue to control dust from the undeveloped portions of the site under a separate section of the Clark County Air Regulations (Section 90 – Fugitive Dust from Open Area and Vacant Lots). Thus, it is unlikely that the construction activities or the presence of the site after construction of the site will pose a significant concern due to the transport of dust to potential ecological areas located approximately 1,000 feet north of the site.

VIII. RISK ASSESSMENT OF RADIONUCLIDES

ENVIRON applied the radiological risk assessment methodology recommended by USEPA in RAGS, Chapter 10 (USEPA 1989) and the *Soil Screening Guidance for Radionuclides: User's Guide* (USEPA 2000b). These guidance documents recommend that estimates of cancer risk associated with radionuclides be developed and reported separately from cancer risks associated with chemical exposure; thus, this risk assessment presents the results of ENVIRON's analysis of radionuclide exposure separately in this chapter.

A. Identification of Radionuclide COPCs

As noted in Chapter IV, 18 radionuclides were detected in soil and 9 were detected in ground water during the May 2001 site characterization field program. The detected radionuclides (organized by decay chain) are identified in Table 35. In addition to the detected radionuclides, the presence of several decay products of the detected radionuclides was assumed based on the detection of the parent radionuclide. The decay chains for the identified radionuclides are presented in Appendix D. Tables and figures that address the statistical characteristics and spatial distribution of radionuclides in soil at the WRF expansion site are presented in Appendix D and discussed in Chapter II. Similar information for radionuclides in the background soil samples is provided in Appendix E.

Radon appears in the decay chains as two isotopes, radon 222 (a decay product of radium 226) and radon 220 (a decay product of radium 224). Both radon isotopes are gases at the temperature and pressure conditions commonly found in soils and the human environment. Radon 222 has a half-life of 3.8 days, and radon 220 has a half-life of 56 seconds. Given the short half-life of radon 222, the concern associated with this chemical is not associated with the transport of radon to the site from off-site sources but with the generation of radon 222 on the site from its parent, radium 226, and its migration into buildings[17]. NDEP has indicated that there is some concern about slightly elevated levels of thorium and uranium isotopes because of metal ores that were brought to the BMI Complex for processing. In addition, NDEP has indicated that radium 226 was concentrated in CSD solids at the TIMET facility and disposed within certain TIMET ponds with other liquid wastes. NDEP has not provided any direct evidence that the ponds on the WRF expansion site have been impacted by the disposal of solids with elevated levels of radium 226. The half-life of radon 222 is very short relative to the 1,600-year half-life of its parent, radium 226. Because any wastes that were impacted by radium 226 were disposed of years ago, the assumption of secular equilibrium between these two radionuclides is appropriate.

[17] Because of the very short half-life of radon 220, there is very little concern associated with potential exposures to this radionuclide, and it is not evaluated further in this assessment.

TABLE 35
Radionuclides Chemicals of Potential Concern in Soil and Ground Water

Chemical	COPC in Soil	COPC in Ground Water	Parent Radionuclide
Uranium-238 Chain			
Uranium 238	X	X	
Thorium 234	X		
Protactinium 234*	X		Thorium 234
Uranium 234	X	X	
Thorium 230	X	X	
Radium 226	X	X	
Radon 222*	X		Radium 226
Polonium 218*	X	X	Radium 226
Lead 214	X		
Bismuth 214	X		
Polonium 214*	X		Bismuth 214
Lead 210	X	X	
Bismuth 210*	X	X	Lead 210
Polonium 210*	X	X	Lead 210
Thorium-232 Chain			
Thorium 232	X	X	
Radium 228	X	X	
Actinium 228	X		
Thorium 228	X	X	
Radium 224	X		
Radon 220*	X		Radium 224
Polonium 216*	X		Radium 224
Lead 212	X		
Bismuth 212	X		
Polonium 212*	X		Bismuth 212
Thallium 208	X		
Other			
Potassium 40	X		
Uranium 235	X	X	

Note:
* - These radionuclides were not analyzed for but were assumed to be present as decay products if the identified parent radionulclide was detected.

Based on the results of the background soil sampling conducted by ENVIRON in April 2002 (described in Appendix E), radium 226 levels at the site are not significantly elevated with respect to background levels. The mean radium 226 concentrations in soils at the WRF expansion site were compared to the mean concentrations in the background soil samples using statistical hypothesis tests. The tests performed using all of the data for each exposure area (northern and southern) are presented in Appendix E; additional tests for the various EPC data groups are provided in Appendix G. In each test, the null hypothesis was that the mean concentration in the WRF samples is equal to the mean background concentration. The results of these tests were evaluated at the five percent level of significance. The null hypothesis was rejected when the mean of all of the data from the northern exposure area was compared to the background mean, but this comparison indicates that the background concentrations are higher (not lower). This comparison is not important to the risk assessment because (as shown in Tables 16 and 17) none of the risk calculations are based on exposure point concentrations derived using the data collected from all depths in the northern exposure area. Comparison of the concentration data for each of the exposure point concentration groups to the background concentrations is more important to the risk assessment because the risk calculations are based on these subsets. These comparisons, which are presented in Appendix G, indicate that radium 226 is not present in soils at the WRF expansion site at levels greater than background. Tests performed using all of the radium 224 data for each exposure area (northern and southern) are presented in Appendix E. These comparisons indicate that the levels of radium 224 in soils at the WRF expansion site are no greater than background. Tests using the radium 224 data for each exposure point concentration group were not performed because (as explained in Appendix G) the risks associated with this radionuclide were less than one percent of the assumed radionuclide action level.

Because radon's parent isotopes (radium 226 and radium 224) are not present at levels above background, the radon levels at the WRF expansion site are naturally occurring. Estimation of the risks associated with exposure to radon gas at background levels is beyond the scope of this risk assessment. Furthermore, the USEPA has classified Clark County, Nevada within the lowest category of predicted indoor radon concentrations.[18] Therefore, radon was not included explicitly in the list of radionuclide COPCs and the risks associated with exposure to radon gas have not been evaluated.

[18] The USEPA category ("Zone 3") has average predicted indoor radon concentrations of less than 2 pCi/L (www.epa.gov/iaq/radon/zonemap.html).

B. Exposure Assessment

1. Identification of Potentially Exposed Populations and Pathways

Potential carcinogenic effects associated with exposure to radionuclides in soil and ground water at the site were evaluated for the scenarios identified in Table 36.

2. Estimation of Exposure Point Concentrations

The exposure point concentrations for the scenarios identified in Table 36 were developed using the approaches outlined in Section B of Chapter V and Tables 16 and 17. The estimated chemical-specific exposure point concentrations in soil, ground water, and air for the radionuclide COPCs are tabulated in Tables 37, 38, and 39, respectively.

3. Estimation of Radiological Intake

The radiological intake equations used in the risk assessment are specific to a given exposure pathway (i), as summarized below. For most pathways, a radiological intake is calculated, with the exception of the external exposure pathway, for which an external radiation factor is calculated, as indicated below.

Ingestion of Soil:

$$Rad\ Intake\ (pCi) = CS\ x\ IR\ x\ FI\ x\ EF\ x\ ED\ x\ 10^{-3}\ g/mg$$

Inhalation of Dust[19] *(non-residential)*:

$$Rad\ Intake\ (pCi) = \frac{CS}{PEF}\ x\ IR\ x\ ET\ x\ EF\ x\ ED$$

Inhalation of Dust (residential):

$$Rad\ Intake\ (pCi) = \frac{CS}{PEF}\ x\ IR\ x\ EF\ x\ ED\ x\ \left[ET_o + \left(ET_i\ x\ DF_i\right)\right]$$

Incidental Ingestion of Ground Water

$$Rad\ Intake\ (pCi) = CW\ x\ IR\ x\ EF\ x\ ED$$

External Exposure

$$External\ Radiation\ Factor\ \left(^{pCi-yr}/_{g}\right) = CS\ x\ \frac{ET}{24}\ x\ \frac{EF}{365}\ x\ ED\ x\ ACF\ x\ GSF$$

[19] In the equation, the term CS/PEF is used to calculate a concentration in air. The PEF methodology is described in Appendix J, which also provides a summary of the estimated concentrations in air.

TABLE 36
Summary of Populations and Pathways Evaluated in the Radionuclide Risk Assessment of the Proposed WRF Expansion Site

Population	Exposure Area	Exposure Pathways			
		Soil			Ground Water
		Ingestion	External Exposure	Inhalation of Dust	Incidental Ingestion
During WRF Construction					
WRF Construction Worker	South	X	X	X	X[2]
Off-site Resident	Off-site	Incomplete	Incomplete	X	Incomplete
Off-site Worker	Off-site	Incomplete	Incomplete	X	Incomplete
Future Use – After WRF Construction					
Trespasser	North	X	X	X[3]	Incomplete
Indoor Worker	South	Not significant[1]	X	Not significant[1]	Incomplete
Indoor Worker	North	Not significant[1]	X	Not significant[1]	Incomplete
Maintenance Worker	North	X	X	X[3]	X
Maintenance Worker	South	X	X	X[3]	X
Off-site Resident	Off-site	Incomplete	Incomplete	X[3]	Incomplete
Off-site Worker	Off-site	Incomplete	Incomplete	X[3]	Incomplete
Default Construction Worker	North	X	X	X[3]	X[2]

Notes:
X – Exposure by this pathway is evaluated for the indicated population. "Incomplete" indicates that the specified receptor population will not be exposed to the specified medium by this pathway.
1 – Although assumed to be on-site, indoor workers are expected to spend most or all of the time indoors.
2 – Dewatering is being required (in the construction specifications) for the WRF expansion project in the southern exposure area. The northern portion of the site, if developed, would likely be used for surface uses (e.g., parking lot, warehouse); however, if excavation were required, dewatering would be conducted there as well. For the purposes of the risk assessment, exposure to ground water by a WRF construction worker in southern exposure area and a future default construction worker in the northern exposure area are evaluated, assuming an individual who maintains the dewatering pipeline periodically contacts ground water.
3 - Exposure to airborne dust is estimated assuming that the northern area of the site is not developed immediately and that it represents a source of dust emissions for all scenarios, with one exception. For the maintenance worker in the northern exposure area, it is assumed that the northern area is eventually developed but a portion (50%) remains undeveloped/unvegetated. ENVIRON recognizes that these are somewhat conflicting assumptions, but they are applied in this risk assessment to evaluate the scenarios conservatively.

TABLE 37
Summary of Exposure Point Concentrations for Radionuclides in Soil
(Activities in Units of pCi/kg)

Chemical	NEA 0-1'	NEA 0-5'	NEA All	SEA 0-1'	SEA 0-12'	SEA All
Uranium-238 Chain						
Uranium 238	1026	1036	1038	1058	1192	1457
Thorium 234	1026	994	947	1066	1046	1258
Protactinium 234*	1026	1036	1038	1058	1192	1457
Uranium 234	1291	1263	1309	1209	1393	1624
Thorium 230	1148	1166	1194	1152	1357	1674
Radium 226	1729	1526	1409	1716	1659	1721
Radon 222	1729	1526	1409	1716	1659	1721
Polonium 218	1729	1526	1409	1716	1659	1721
Lead 214	835	832	881	918	1017	1444
Bismuth 214	918	897	940	1018	1091	1505
Polonium 214	918	897	940	1018	1091	1505
Lead 210	1067	1180	1183	1379	1352	1827
Bismuth 210	1067	1180	1183	1379	1352	1827
Polonium 210	1067	1180	1183	1379	1352	1827
Thorium-232 Chain						
Thorium 232	1549	1492	1458	1392	1409	1364
Radium 228	1800	1628	1565	1352	1311	1299
Actinium 228	1500	1441	1418	1509	1455	1373
Thorium 228	1461	1482	1470	1417	1423	1360
Radium 224	3406	3602	3483	3671	3274	3803
Radon 220	3406	3602	3483	3671	3274	3803
Polonium 216	3406	3602	3483	3671	3274	3803
Lead 212	1290	1211	1186	1252	1252	1209
Bismuth 212	1559	1312	1247	1377	1217	1204
Polonium 212	1559	1312	1247	1377	1217	1204
Thallium 208	495	456	454	455	452	440
Other						
Potassium 40	25615	24719	25016	25659	25563	25724
Uranium 235	97	97	101	55	62	78

Note:

* Uranium 238, Thorium 234, and Protactinium 234 should have approximately equal activities, assuming equilibrium. Uranium 238 and Thorium 234 were both measured. Although approximately equal, Uranium 238 is somewhat higher; thus, the activity for Uranium 238 was used to represent the activity of Protactinium 234 to be conservative.

TABLE 38
Summary of Exposure Point Concentrations for
Radionuclides in Ground Water
Activities in Units of pCi/L

Chemical	Northern Exposure Area	Southern Exposure Area
Uranium-238 Chain		
Uranium 238	18.5	6.0
Thorium 234 *	18.5	6.0
Protactinium 234	18.5	6.0
Uranium 234	25.9	8.4
Thorium 230	7.5	1.0
Radium 226	1.6	1.1
Radon 222	1.6	1.1
Polonium 218	1.6	1.1
Lead 210	115.0	260.0
Bismuth 210	115.0	260.0
Polonium 210	115.0	260.0
Thorium-232 Chain		
Thorium 232	2.1	0.2
Radium 228	4.7	0.6
Thorium 228	1.9	0.3
Other		
Uranium 235	1.1	0.4

Note:
* Thorium 234 was not detected in any of the ground water samples collected at the WRF expansion site; however, assuming secular equilibrium, the activity of Thorium 234 should be equivalent to Uranium 238.

TABLE 39
Summary of Exposure Point Concentrations for Radionuclides in Outdoor Air
Radionuclide Activities in pCi/m³

	During WRF Construction			Future (Post WRF Construction)					
	WRF Construction Worker	Off-site Resident	Off-site Worker	Default NEA Construction Worker	SEA Maintenance Worker	NEA Maintenance Worker	Trespassing Child	Off-site Resident	Off-site Worker
Uranium-238 Chain									
Uranium 238	1.87×10^{-4}	1.22×10^{-6}	1.22×10^{-6}	1.62×10^{-4}	6.72×10^{-8}	4.30×10^{-8}	8.60×10^{-8}	6.72×10^{-8}	6.72×10^{-8}
Thorium 234	1.67×10^{-4}	1.10×10^{-6}	1.10×10^{-6}	1.60×10^{-4}	6.66×10^{-8}	4.26×10^{-8}	8.52×10^{-8}	6.66×10^{-8}	6.66×10^{-8}
Protactinium 234	1.87×10^{-4}	1.22×10^{-6}	1.22×10^{-6}	1.62×10^{-4}	6.72×10^{-8}	4.30×10^{-8}	8.60×10^{-8}	6.72×10^{-8}	6.72×10^{-8}
Uranium 234	2.19×10^{-4}	1.43×10^{-6}	1.43×10^{-6}	2.02×10^{-4}	8.38×10^{-8}	5.36×10^{-8}	1.07×10^{-7}	8.38×10^{-8}	8.38×10^{-8}
Thorium 230	2.13×10^{-4}	1.39×10^{-6}	1.39×10^{-6}	1.82×10^{-4}	7.56×10^{-8}	4.84×10^{-8}	9.69×10^{-8}	7.56×10^{-8}	7.56×10^{-8}
Radium 226	2.69×10^{-4}	1.74×10^{-6}	1.74×10^{-6}	2.70×10^{-4}	1.12×10^{-7}	7.18×10^{-8}	1.44×10^{-7}	1.12×10^{-7}	1.12×10^{-7}
Radon 222	2.69×10^{-4}	1.74×10^{-6}	1.74×10^{-6}	2.70×10^{-4}	1.12×10^{-7}	7.18×10^{-8}	1.44×10^{-7}	1.12×10^{-7}	1.12×10^{-7}
Polonium 218	2.69×10^{-4}	1.74×10^{-6}	1.74×10^{-6}	2.70×10^{-4}	1.12×10^{-7}	7.18×10^{-8}	1.44×10^{-7}	1.12×10^{-7}	1.12×10^{-7}
Lead 214	1.60×10^{-4}	1.07×10^{-6}	1.07×10^{-6}	1.31×10^{-4}	5.42×10^{-8}	3.47×10^{-8}	6.94×10^{-8}	5.42×10^{-8}	5.42×10^{-8}
Bismuth 214	1.71×10^{-4}	1.14×10^{-6}	1.14×10^{-6}	1.43×10^{-4}	5.95×10^{-8}	3.81×10^{-8}	7.62×10^{-8}	5.95×10^{-8}	5.95×10^{-8}
Polonium 214	1.71×10^{-4}	1.14×10^{-6}	1.14×10^{-6}	1.43×10^{-4}	5.95×10^{-8}	3.81×10^{-8}	7.62×10^{-8}	5.95×10^{-8}	5.95×10^{-8}
Lead 210	2.17×10^{-4}	1.43×10^{-6}	1.43×10^{-6}	1.85×10^{-4}	7.66×10^{-8}	4.90×10^{-8}	9.80×10^{-8}	7.66×10^{-8}	7.66×10^{-8}
Bismuth 210	2.17×10^{-4}	1.43×10^{-6}	1.43×10^{-6}	1.85×10^{-4}	7.66×10^{-8}	4.90×10^{-8}	9.80×10^{-8}	7.66×10^{-8}	7.66×10^{-8}
Polonium 210	2.17×10^{-4}	1.43×10^{-6}	1.43×10^{-6}	1.85×10^{-4}	7.66×10^{-8}	4.90×10^{-8}	9.80×10^{-8}	7.66×10^{-8}	7.66×10^{-8}
Thorium-232 Chain									
Thorium 232	2.21×10^{-4}	1.45×10^{-6}	1.45×10^{-6}	2.42×10^{-4}	1.01×10^{-7}	6.43×10^{-8}	1.29×10^{-7}	1.01×10^{-7}	1.01×10^{-7}
Radium 228	2.12×10^{-4}	1.42×10^{-6}	1.42×10^{-6}	2.81×10^{-4}	1.17×10^{-7}	7.47×10^{-8}	1.49×10^{-7}	1.17×10^{-7}	1.17×10^{-7}
Actinium 228	2.37×10^{-4}	1.52×10^{-6}	1.52×10^{-6}	2.34×10^{-4}	9.73×10^{-8}	6.23×10^{-8}	1.25×10^{-7}	9.73×10^{-8}	9.73×10^{-8}
Thorium 228	2.23×10^{-4}	1.45×10^{-6}	1.45×10^{-6}	2.32×10^{-4}	9.62×10^{-8}	6.16×10^{-8}	1.23×10^{-7}	9.62×10^{-8}	9.62×10^{-8}
Radium 224	5.76×10^{-4}	3.73×10^{-6}	3.73×10^{-6}	5.63×10^{-4}	2.34×10^{-7}	1.50×10^{-7}	2.99×10^{-7}	2.34×10^{-7}	2.34×10^{-7}
Radon 220	5.76×10^{-4}	3.73×10^{-6}	3.73×10^{-6}	5.63×10^{-4}	2.34×10^{-7}	1.50×10^{-7}	2.99×10^{-7}	2.34×10^{-7}	2.34×10^{-7}
Polonium 216	5.76×10^{-4}	3.73×10^{-6}	3.73×10^{-6}	5.63×10^{-4}	2.34×10^{-7}	1.50×10^{-7}	2.99×10^{-7}	2.34×10^{-7}	2.34×10^{-7}
Lead 212	1.96×10^{-4}	1.27×10^{-6}	1.27×10^{-6}	2.02×10^{-4}	8.37×10^{-8}	5.36×10^{-8}	1.07×10^{-7}	8.37×10^{-8}	8.37×10^{-8}
Bismuth 212	2.16×10^{-4}	1.40×10^{-6}	1.40×10^{-6}	2.44×10^{-4}	1.01×10^{-7}	6.47×10^{-8}	1.29×10^{-7}	1.01×10^{-7}	1.01×10^{-7}
Polonium 212	2.16×10^{-4}	1.40×10^{-6}	1.40×10^{-6}	2.44×10^{-4}	1.01×10^{-7}	6.47×10^{-8}	1.29×10^{-7}	1.01×10^{-7}	1.01×10^{-7}
Thallium 208	7.14×10^{-5}	4.66×10^{-7}	4.66×10^{-7}	7.74×10^{-5}	3.21×10^{-8}	2.06×10^{-8}	4.11×10^{-8}	3.21×10^{-8}	3.21×10^{-8}
Other									
Potassium 40	4.03×10^{-3}	2.60×10^{-5}	2.60×10^{-5}	4.00×10^{-3}	1.66×10^{-6}	1.06×10^{-6}	2.13×10^{-6}	1.66×10^{-6}	1.66×10^{-6}
Uranium 235	9.81×10^{-6}	6.96×10^{-8}	6.96×10^{-8}	1.52×10^{-5}	6.32×10^{-9}	4.04×10^{-9}	8.09×10^{-9}	6.32×10^{-9}	6.32×10^{-9}

The exposure factors used in the intake equations for each of the exposure scenarios being evaluated in the risk assessment are summarized in individual tables, as follows:

During Construction of the WRF

Table 40 – WRF Construction Worker (Southern Exposure Area)
Table 41 – Off-site Resident
Table 42 – Off-site Worker

Future (Post-WRF Construction)

Table 43 – Future (Default) Construction Worker (Northern Exposure Area)
Table 44 – Trespassing Child (Northern Exposure Area)
Table 45 – Maintenance Worker (Northern and Southern Exposure Areas)
Table 46 – Off-site Resident
Table 47 – Off-site Worker
Table 48 – Indoor Worker (Northern and Southern Exposure Areas)

Where overlap exists with the chemical dose equations, the parameter values are the same, including soil ingestion rates, inhalation rates, exposure frequencies, and exposure duration. For certain parameters that are specific to the radionuclide intake equations, the values are based on USEPA guidance provided in the *Soil Screening Guidance for Radionuclides: User's Guide* (USEPA 2000b). Chemical-specific intake values are presented in Appendix N.

C. Toxicity Values

Similar to the process used for chemicals, the radiological intakes are multiplied by appropriate cancer slope factors to estimate risk. The cancer slope factors used in this assessment are values for morbidity obtained from USEPA's *Health Evaluation Assessment Summary Tables* (HEAST), which compiles pathway-specific (incidental water and soil ingestion, inhalation, and external exposure) cancer slope factors. The current HEAST tables are based on toxicity values published in Federal Guidance Report No. 13. It should be noted that for certain radionuclides, the cancer slope factors that take into consideration short-lived decay products were used in this assessment. The pathway-specific cancer slope factors used in this assessment are summarized in Table 49.

TABLE 40 Exposure Factors for a WRF Construction Worker[a] (Southern Exposure Area)[b]	
Parameter	**Value**
Media Concentration	
CS = Constituent concentration in soil (pCi/g)	95% UCL or maximum[c]
CA = Constituent concentration in air (pCi/m^3)	Calculated
CW = Constituent concentration in water (pCi/L)	Maximum exposure area concentration
Ingestion of Soil	
IR_{SOIL} = Soil ingestion rate (mg/day)	100[d]
FI = Fraction of soil ingested from contaminated source (unitless)	1.0[e]
EF_{SOIL} = Exposure frequency for soil (days/yr)	250[f]
ED_{SOIL} = Exposure duration for soil (yrs)	3[g]
Inhalation of Dust	
IR_{AIR} = Inhalation rate (m^3/hr)	1.3[h]
ET = Exposure time (hrs/day)	8[i]
EF_{AIR} = Exposure frequency for air (days/yr)	250[f]
ED_{AIR} = Exposure duration for air (yrs)	3[g]
Incidental Ingestion of Ground Water	
IR_{GW} = Ground water ingestion rate (L/day)	0.005[j]
EF_{GW} = Ground water exposure frequency (days/yr)	50[k]
ED_{GW} = Exposure duration for ground water (yrs)	1.5[l]
External Exposure	
ACF = Area correction factor, unitless	0.9[m]
GSF = Gamma shielding factor (unitless)	1.0

TABLE 40
Exposure Factors for a WRF Construction Worker[a]
(Southern Exposure Area)[b]

Parameter	Value

Notes:

a - This scenario includes hypothetical exposure to ground water through periodic maintenance of the dewatering pipeline. Most construction workers will not experience this type of exposure but it is included to be conservative.

b - Most of the activities associated with construction of the WRF will occur in the southern exposure area. Exposure that occurs in the northern exposure area during construction of the WRF will be of limited duration and significantly lower magnitude than exposures in the southern exposure area. Thus, for the purposes of this assessment, this scenario is associated with the southern exposure area.

c – Two estimates of soil concentration were developed in the risk assessment, as identified in Table 16.

d – USEPA (1997a) indicates that an adult ingestion rate of 100 mg/day may be appropriate for agricultural settings. It is assumed that construction workers would be exposed to a similar extent as agricultural workers.

e – It is conservatively assumed that 100% of the construction worker's soil ingestion is derived from the site.

f – Standard USEPA (1997a) default value.

g – Black & Veatch (2001) has indicated that the period of construction is approximately three years.

h – Based on an hourly average for an outdoor worker (USEPA 1997a; Table 5-23)

i – It is assumed that a worker were exposed 8 hours per day.

j – USEPA (1989; RAGS) guidance provides an incidental water ingestion rate of 0.05 L/day during swimming. It was assumed that incidental ingestion of ground water by an individual maintaining the dewatering system would be significantly less than this value; thus, a value of 0.005 L/day was applied. Additional discussion of this assumption is provided in the uncertainties section of this report.

k – Exposure to ground water is expected to be associated with maintenance of the dewatering system, which is estimated to occur weekly by a very limited number of individual workers.

l – According to correspondence from Black & Veatch (2001), the dewatering pipeline is expected to be operated for a period of 1.5 years for the WRF expansion construction.

m – USEPA 2000b: *Soil Screening Guidance for Radionuclides: User's Guide*

TABLE 41
Exposure Factors for an Off-site Resident During WRF Construction

Parameter	Value
Inhalation of Dust	
CA = Constituent concentration in air (pCi/m^3)	Calculated
IR = Inhalation rate (m^3/day)	13.25[a]
ET_{out} = Exposure time fraction, outdoor (unitless)	0.073[b]
ET_{in} = Exposure time fraction, indoor (unitless)	0.683[b]
DF_{in} = Dilution factor for indoor inhalation (unitless)	0.4[b]
EF = Exposure frequency (days/yr)	350[c]
ED = Exposure duration (yrs)	3[d]

Notes:
a – USEPA 1997a (Table 5-23)
b – USEPA 2000b: *Soil Screening Guidance for Radionuclides: User's Guide.*
c – Standard USEPA (1997a) default value.
d – Black & Veatch (2001) has indicated that the period of construction is approximately three years.

TABLE 42
Exposure Factors for an Off-site Worker During WRF Construction

Parameter		Value
Inhalation of Dust		
CA=	Constituent concentration in air (pCi/m^3)	Calculated
IR =	Inhalation rate (m^3/hr)	1.3[a]
ET =	Exposure time (hrs/day)	8[b]
EF =	Exposure frequency (days/yr)	250[c]
ED =	Exposure duration (yrs)	3[d]

Notes:
a – Based on an hourly average for an outdoor worker (USEPA 1997a; Table 5-23)
b – It is assumed an off-site worker will be exposed 8 hours per day.
c – Standard USEPA (1997a) default value.
d – Black & Veatch (2001) has indicated that the period of construction is approximately three years.

TABLE 43
Exposure Factors for a Future (Default) Construction Worker[a]
(Northern Exposure Area)[b]

Parameter	Value
Media Concentration	
CS = Constituent concentration in soil (pCi/g)	95% UCL or maximum[c]
CA = Constituent concentration in air (pCi/m^3)	Calculated
CW = Constituent concentration in ground water (pCi/L)	Maximum exposure area concentration
Ingestion of Soil	
IR_{SOIL} = Soil ingestion rate (mg/day)	100[d]
FI = Fraction of soil ingested from contaminated source (unitless)	1.0[e]
EF_{SOIL} = Exposure frequency for soil (days/yr)	250[f]
ED_{SOIL} = Exposure duration for soil (yrs)	1[g]
Inhalation of Dust	
IR_{AIR} = Inhalation rate (m^3/hr)	1.3[h]
ET = Exposure time (hrs/day)	8[i]
EF_{AIR} = Exposure frequency for air (days/yr)	250[f]
ED_{AIR} = Exposure duration for air (yrs)	1[g]
Incidental Ingestion of Ground Water	
IR_{GW} = Ground water ingestion rate (L/day)	0.005[j]
EF_{GW} = Exposure frequency for ground water (days/yr)	50[k]
ED_{GW} = Exposure duration for ground water (yrs)	1[l]
External Exposure	
ACF = Area correction factor (unitless)	0.9[m]
GSF = Gamma shielding factor (unitless)	1.0

TABLE 43
Exposure Factors for a Future (Default) Construction Worker[a]
(Northern Exposure Area)[b]

Notes:

a - This scenario includes hypothetical exposure to ground water through periodic maintenance of a dewatering pipeline. Most construction workers will not experience this type of exposure, but it is included to be conservative.

b – Given that most of the southern portion of the site will be developed by the WRF, this future scenario is limited to the northern exposure area.

c – Two estimates of soil concentration were developed in the risk assessment, as identified in Table 17

d – USEPA (1997a) indicates that an adult ingestion rate of 100 mg/day may be appropriate for agricultural settings. It is assumed that construction workers would be exposed to a similar extent as agricultural workers.

e – It is conservatively assumed that 100% of the future construction worker's soil ingestion is derived from the site.

f – Standard USEPA (1997a) default value.

g – The city has indicated that construction in the northern portion of the site, if any, would not be as extensive as is planned for the WRF expansion. A default estimate of 1 year for construction was applied.

h – Based on an hourly average for an outdoor worker (USEPA 1997a; Table 5-23)

i – It is assumed that a worker will be exposed 8 hours per day.

j – USEPA (1989; RAGS) guidance provides an incidental water ingestion rate of 0.05 L/day during swimming. It was assumed that incidental ingestion of ground water by an individual maintaining the dewatering system would be significantly less than this value; thus, a value of 0.005 L/day was applied. This assumption is discussed in the uncertainty analysis section of the risk assessment.

k – Exposure to ground water is expected to be associated with maintenance of the dewatering system, which is estimated to occur weekly to a very limited number of individuals.

l – Dewatering is assumed to occur over the entire default period of construction of 1 year.

m - USEPA 2000b: *Soil Screening Guidance for Radionuclides: User's Guide*

TABLE 44
Exposure Factors for a Trespassing Child
(Post-WRF Construction – Northern Exposure Area)

Parameter		Value
Media Concentration		
CS =	Constituent concentration in soil (pCi/g)	95% UCL or maximum[a]
CA =	Constituent concentration in air (pCi/m^3)	Calculated
Ingestion of Soil		
IR_{SOIL} =	Soil ingestion rate (mg/day)	100[b]
FI =	Fraction of soil ingested from contaminated source (unitless)	1.0[c]
Inhalation of Dust		
IR_{AIR} =	Inhalation rate (m^3/hr)	1.2[d]
ET =	Exposure time (hrs/day)	4[f]
External Exposure		
ACF =	Area correction factor (unitless)	0.9[e]
GSF =	Gamma shielding factor (unitless)	1.0
General Factors (applicable to several exposure pathways)		
EF =	Exposure frequency (days/yr)	50[g]
ED =	Exposure duration (yrs)	6[h]

Notes:
a – Two estimates of soil concentrations were developed in the risk assessment, as indicated in Table 17.
b – Soil ingestion studies on children generally target those under 6 years. It is not expected that ingestion rates for older children (i.e., 7 to 12 years) will differ significantly from adult soil ingestion rates (i.e., 50 mg/day). However, a conservative daily ingestion rate of 100 mg/day will be applied in the risk assessment, given that the children in question may spend a portion of time playing in dirt.
c – It is conservatively assumed that 100% of the trespassing child's soil ingestion is derived from the site.
d – An inhalation rate for "moderate" activity recommended by USEPA (1997a; Table 5-23) will be applied.
e – USEPA 2000b: *Soil Screening Guidance for Radionuclides: User's Guide*
f – It is assumed that a child will spend 4 hours per day at the site.
g – It is assumed that trespassing children will visit the site once per week.
H – Standard USEPA (1997a) default value.

TABLE 45 Exposure Factors for a Maintenance Worker (Post-WRF Construction – Northern and Southern Exposure Areas)	
Parameter	**Value**
Media Concentration	
CS = Constituent concentration in soil (pCi/g) Northern Exposure Area Southern Exposure Area	 95% UCL or maximum[a] 95% UCL or maximum[a]
CA = Constituent concentration in air (pCi/m^3)	Calculated
Ingestion of Soil	
IR_{SOIL} = Soil ingestion rate (mg/day)	50[b]
FI = Fraction of soil ingested from contaminated source (unitless)	1.0[c]
EF_{SOIL} = Exposure frequency for soil (days/yr)	250[d]
Incidental Ingestion of Ground Water	
IR_{GW} = Ground water ingestion rate (L/day)	0.005[e]
EF_{GW} = Exposure frequency for ground water (days/yr)	1[f]
Inhalation of Dust[g]	
IR_{AIR} = Inhalation rate (m^3/hr)	1.3[h]
ET = Exposure time (hrs/day)	8[i]
EF_{AIR} = Exposure frequency for air (days/yr)	250[d]
External Exposure	
ACF = Area correction factor (unitless)	0.9[j]
GSF = Gamma shielding factor (unitless)	0.2[k]
EF_{EXT} = Exposure frequency for external radiation (days/yr)	250[d]
General Factors (applicable to several exposure pathways)	
ED = Exposure duration (yrs)	25[d]

TABLE 45
Exposure Factors for a Maintenance Worker
(Post-WRF Construction – Northern and Southern Exposure Areas)

Parameter	Value

Notes:
a – Two estimates of soil concentrations were developed in the risk assessment as indicated in Table 17.
b – Standard USEPA (1997a) default exposure estimate.
c – It is conservatively assumed that 100% of the maintenance worker's soil ingestion is derived from the site.
d – Standard USEPA (1997a) default exposure estimate.
e – USEPA (1989; RAGS) guidance provides an incidental water ingestion rate of 0.05 L/day during swimming. It was assumed that incidental ingestion of ground water by an individual maintaining the dewatering system would be significantly less than this value; thus, a value of 0.005 L/day was applied. This assumption is discussed in the uncertainty analysis section of the risk assessment.
f – Exposure to ground water is expected to occur very infrequently. It was assumed that a maintenance worker may come into contact with ground water once per year. If more extensive excavation were required (e.g., installing utility lines) it is likely that a contractor would be used. It is assumed that such exposure is a subset of the future default construction worker scenario. Exposure to a utility worker is discussed in the uncertainties section of this assessment.
g – Inhalation of dust by a maintenance worker in the southern exposure area assumes that the northern exposure area is not developed. Exposure to wind-blown dust by a maintenance worker in the northern exposure area assumes that only a portion (50%) of this area is developed and the remainder is unpaved and unvegetated.
h – Based on an hourly average for an outdoor worker (USEPA 1997a; Table 5-23)
i – An 8-hour work day is assumed.
j – USEPA 2000b: *Soil Screening Guidance for Radionuclides: User's Guide*
k - USEPA (2000b) provides a GSF of 0.4 for residential exposure, which is based on exposure in a wood frame house. The *Technical Background Document* (USEPA 2000c) indicates that a value of 0.2 is appropriate for "heavily constructed block and brick homes." It is expected that almost the entire site will be paved or covered with buildings; thus, a GSF of 0.2 is appropriate due to the shielding effect of these structures and paving.

TABLE 46
Exposure Factors for an Off-site Resident
(Post-WRF Construction)

Parameter		Value
Inhalation of Dust		
CA =	Constituent concentration in air (pCi/m^3)	Calculated
IR =	Inhalation rate (m^3/day)	13.25[a]
ET_o =	Exposure time fraction, outdoor (unitless)	0.083[b]
ET_i =	Exposure time fraction, indoor (unitless)	0.683[b]
DF_i =	Dilution factor for indoor inhalation (unitless)	0.4[b]
EF =	Exposure frequency (days/yr)	350[c]
ED =	Exposure duration (yrs)	30[c]

Notes:
a – Average adult daily inhalation rate recommended by USEPA (1997a; Table 5-23).
b –The value of 0.073 presented by USEPA in the *Soil Screening Guidance for Radionuclides: User's Guide* is not consistent with the value of 0.083 (2 hours perday) recommended by USEPA (1997a) in the *Exposure Factors Handbook*. The higher value was used in this assessment.
c – Standard USEPA (1997a) default value.

TABLE 47
Exposure Factors for an Off-site Worker
(Post-WRFConstruction)

Parameter		Radiological Value
Inhalation of Dust		
CA =	Constituent concentration in air (pCi/m^3)	Calculated
IR =	Inhalation rate (m^3/day)	1.3[a]
ET =	Exposure time (hrs/day)	8[b]
EF =	Exposure frequency (days/yr)	250[c]
ED =	Exposure duration (yrs)	25[c]

Notes:
a – Based on an hourly average for an outdoor worker (USEPA 1997a; Table 5-23)
b – It is assumed an off-site worker will be exposed 8 hours per day.
c – Standard USEPA (1997a) default value.

TABLE 48
Exposure Factors for an Indoor Worker
(Post-WRF Construction – Northern and Southern Exposure Areas)

Parameter		Value
External Exposure		
CS =	Constituent concentration in soil (pCi/g) Northern Exposure Area Southern Exposure Area	 95% UCL or maximum[a] 95% UCL or maximum[a]
ACF =	Area correction factor (unitless)	0.9[b]
GSF =	Gamma shielding factor (unitless)	0.2[c]
ET =	Exposure time (hrs/day)	8[d]
EF =	Exposure frequency (days/yr)	250[e]
ED =	Exposure duration (yrs)	25[e]

Notes:
a – Two estimates of soil concentrations were developed in the risk assessment as indicated in Table 17.
b – USEPA 2000b: *Soil Screening Guidance for Radionuclides: User's Guide*
c – USEPA (2000b) provides a GSF of 0.4 for residential exposure, which is based on exposure in a wood frame house. The *Technical Background Document* (USEPA 2000c) indicates that a value of 0.2 is appropriate for "heavily constructed block and brick homes," which is more applicable to the current setting.
d – An 8-hour work day is assumed.
e – Standard USEPA (1997a) default exposure estimate.

TABLE 49
Toxicity Values for Radionuclides

Chemical	Slope Factor Soil Ingestion (risk/pCi)	Slope Factor Water Ingestion (risk/pCi)	Slope Factor Inhalation (risk/pCi)	Slope Factor External Exposure (risk/yr per pCi/g)
Ground Water COPCs				
Bismuth 210	NA	8.92E-12	NA	NA
Lead 210+D	NA	1.27E-09	NA	NA
Polonium 210	NA	3.77E-10	NA	NA
Polonium 218	NA	--	NA	NA
Protactinium 234	NA	2.56E-12	NA	NA
Radium 226+D	NA	3.86E-10	NA	NA
Radium 228+D	NA	1.04E-09	NA	NA
Radon 222+D	NA	--	NA	NA
Thorium 228+D	NA	3.00E-10	NA	NA
Thorium 230	NA	9.10E-11	NA	NA
Thorium 232	NA	1.01E-10	NA	NA
Thorium 234	NA	2.31E-11	NA	NA
Uranium 234	NA	7.07E-11	NA	NA
Uranium 235+D	NA	7.18E-11	NA	NA
Uranium 238+D	NA	8.71E-11	NA	NA
Soil COPCs				
Actinium 228	5.55E-12	NA	4.92E-11	4.53E-06
Bismuth 210	2.55E-11	NA	3.17E-10	1.01E-06
Bismuth 212	1.78E-12	NA	7.77E-11	8.87E-07
Bismuth 214	4.33E-13	NA	2.90E-11	7.48E-06
Lead 210+D	2.66E-09	NA	1.39E-08	4.21E-09
Lead 212	6.70E-11	NA	5.77E-10	5.09E-07
Lead 214	8.51E-13	NA	3.63E-11	9.82E-07
Polonium 210	7.96E-10	NA	1.08E-08	3.95E-11
Polonium 212	--	NA	--	--
Polonium 214	--	NA	--	3.86E-10
Polonium 216	--	NA	--	7.87E-11
Polonium 218	--	NA	--	4.26E-11
Potassium 40	6.18E-11	NA	1.03E-11	7.97E-07
Protactinium 234	7.03E-12	NA	1.46E-12	6.87E-08
Radium 224	4.51E-10	NA	9.99E-09	3.72E-08
Radium 226+D	7.30E-10	NA	1.16E-08	8.49E-06
Radium 228+D	2.29E-09	NA	5.23E-09	4.53E-06
Radon 220	--	NA	--	1.70E-09
Radon 222+D	--	NA	7.57E-12	--
Thallium 208	--	NA	--	1.76E-05
Thorium 228+D	8.09E-10	NA	1.43E-07	7.76E-06
Thorium 230	2.02E-10	NA	2.85E-08	8.19E-10
Thorium 232	2.31E-10	NA	4.33E-08	3.42E-10
Thorium 234	6.70E-11	NA	3.07E-11	1.63E-08
Uranium 234	1.58E-10	NA	1.14E-08	2.52E-10
Uranium 235+D	1.63E-11	NA	1.01E-08	5.43E-07
Uranium 238+D	2.10E-10	NA	9.35E-09	1.14E-07

Notes:
Values based on USEPA's *Health Effects Assessment Summary Tables (HEAST)* for radionuclides. The values in the table are for morbidity.
+D - The slope factors for the identified radionuclide includes the risk associated with internal exposure to decay products.

D. Risk Characterization

The method for calculating cancer risks associated with radionuclide exposure is similar to that used for chemical exposure:

$$Risk_i = Intake_i \times SF_i$$

where:

$Risk_i$	=	probability of developing cancer due to exposure to radionuclide i, unitless
$Intake_i$	=	average intake of radionuclide i, pCi
SF_i	=	carcinogenic slope factor for radionuclide i, risk/pCi

For external exposure the units vary somewhat. The intake is in terms of a external radiation factor in units of pCi-yr/g and the slope factor in units of risk/yr per pCi/g.

It is generally accepted that background radioactivity poses a baseline cancer risk significantly greater than that of chemical carcinogens; thus, the results of the radionuclide assessment are presented separately from the results of the chemical assessment. USEPA (1997c) guidance suggests that exposure to radionuclides, in terms of a dose, should not exceed 15 mrem/yr, which USEPA (1997c) indicates is approximately equivalent to a risk of 3×10^{-4}. The Nuclear Regulatory Commission has proposed a dose limit of 25 mrem/yr above background, but USEPA (1997c) does not believe that NRC's target level is sufficiently protective. A dose of 15 mrem/yr is generally considered equivalent to a lifetime cancer risk of 3×10^{-4}. According to USEPA (1997c), the NRC proposed dose limit would be equivalent to a risk of approximately 5×10^{-4}.

Excess lifetime cancer risks were estimated for each of the populations identified in Table 36. A summary of the cumulative cancer risks for the identified populations is provided in Table 50. Chemical-specific cancer risk estimates are summarized in Appendix O. As indicated in Table 50, the highest cancer risks were estimated for the maintenance worker scenarios in both the northern and southern exposure areas of the site. Estimated lifetime cancer risks for these populations are approximately 9×10^{-5}, which is below USEPA's radiological risk threshold. It should be noted that this estimate includes background levels of radionuclides in soil; thus, it should be considered as a conservative representation of risks associated with contamination at the site. For each of these scenarios, over 90 percent of the total estimated risk is associated with external exposure, and in each case the greatest contributor to total risk is Potassium-40 (20 to 25 percent of the total cancer risk). Four additional radionuclides (radium-226, radium-228, thallium-208, and thorium 228) each contribute between 10 percent and 20 percent to the total risk. The total estimated risks and the chemicals contributing to total risk differ only very slight based on the area of the site in which exposure is occurring, indicating that the concentration profiles in these two areas are very similar.

TABLE 50
Summary of Estimated Cancer Risks for Radionuclides

Time Frame	Exposure Scenario	Pathway		Estimated Cancer Risk*
During WRF Construction	WRF Construction Worker (Southern Exposure Area)	Ingestion of Soil		1×10^{-6}
		Inhalation of Dust		5×10^{-7}
		Ingestion of Ground Water		2×10^{-7}
		External Exposure		5×10^{-5}
			Total Risk	**5×10^{-5}**
	Off-site Resident	Inhalation of Dust		**2×10^{-9}**
	Off-site Worker	Inhalation of Dust		**3×10^{-9}**
Future (Post WRF Construction)	Maintenance Worker (Northern Exposure Area)	Ingestion of Soil		5×10^{-6}
		Inhalation of Dust		1×10^{-9}
		Ingestion of Ground Water		3×10^{-8}
		External Exposure		8×10^{-5}
			Total Risk	**9×10^{-5}**
	Maintenance Worker (Southern Exposure Area)	Ingestion of Soil		5×10^{-6}
		Inhalation of Dust		2×10^{-9}
		Ingestion of Ground Water		5×10^{-8}
		External Exposure		8×10^{-5}
			Total Risk	**9×10^{-5}**
	Default Construction Worker (Northern Exposure Area)	Ingestion of Soil		4×10^{-7}
		Inhalation of Dust		2×10^{-7}
		Ingestion of Ground Water		5×10^{-8}
		External Exposure		2×10^{-5}
			Total Risk	**2×10^{-5}**
	Trespassing Child (Northern Exposure Area)	Ingestion of Soil		5×10^{-7}
		Inhalation of Dust		5×10^{-11}
		External Exposure		1×10^{-5}
			Total Risk	**1×10^{-5}**
	Indoor Worker (Southern Exposure Area)	External Exposure		**8×10^{-5}**
	Indoor Worker (Northern Exposure Area)	External Exposure		**8×10^{-5}**
	Off-site Resident	Inhalation of Dust		**1×10^{-9}**
	Off-site Worker	Inhalation of Dust		**2×10^{-9}**

Note:
* - Pathway-specific cancer risks may not add to the total risk due to rounding

Estimated cancer risks associated with the other scenarios are somewhat lower. The estimated total cancer risk to the WRF construction worker in the southern exposure areas is 5×10^{-5} almost all of which is associated with external exposure. For a future default construction worker in the northern exposure area, the estimated cancer risk is 2×10^{-5}. The greatest radionuclide contributors to total risk are the same as those noted above for the maintenance worker. Estimated cancer risks for the trespasser are approximately 1×10^{-5}, and the risks to the off-site populations (residents and worker, before and after construction) are very low (3×10^{-9} and lower). Thus, it does not appear that the presence of radionuclides at the site poses a significant concern.

IX. ASBESTOS RISK ASSESSMENT

A. Introduction

This chapter presents an assessment of the potential risks associated with exposure to asbestos in soils at the WRF expansion site. As explained in Section II.B.3, the assessment of potential asbestos-related risks is based on analysis of soil samples that were collected in October 2002. The soil samples collected by ENVIRON during the May 2001 site characterization program were analyzed for asbestos content using a PLM method. Because the results were all non-detect, ENVIRON was not able to perform a meaningful risk assessment for exposure to asbestos in soils at the WRF expansion site using only the data obtained by PLM analysis. As a result, the NDEP requested that ENVIRON collect additional asbestos measurements. In October 2002, ENVIRON provided a plan for assessing the potential asbestos risks using the method described in *Methodology for Conducting Risk Assessments at Asbestos Superfund Sites – Part 1: Protocol* (Berman and Crump 1999). Application of this method to the WRF expansion site involved use of the analytical methods described in *Modified Elutriator Method for the Determination of Asbestos in Soils and Bulk Material* (Berman and Kolk 2000). The analytical method described by Berman and Kolk is referred to in this report as the "elutriator method." Although the sensitivity of the methods cannot be compared directly, calculations[20] suggest that the elutriator analysis is much more sensitive to the presence of asbestos than the earlier PLM analysis.

B. Estimation of Potential Asbestos Risks

The potential risks associated with exposure to asbestos in soils at the WRF expansion site are characterized by applying the method described by Berman and Crump (1999) to the elutriator data. This method involves adjustment of the risk estimates presented in Table 2-2 of Berman and Crump (1999) to correspond to the potential exposure conditions at the WRF expansion site. Table 2-2 quantifies the risks associated with exposure to asbestos in air as a function of the type of asbestos (chrysotile or amphibole) and the percentage of asbestos fibers that are greater than 10 microns long. The risk estimates are specific to each of four sub-populations (male nonsmokers, female nonsmokers, male smokers, and female smokers). Table 51 of this report is identical to Table 2-2 of Berman and Crump (1999) with one modification; although the risks of lung cancer and mesothelioma are quantified separately in Table 2-2, these risks are combined in Table 51. Berman and Crump (1999) indicate that lung cancer and mesothelioma are the most important sources of risk associated with exposure to low levels of

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[20] Under the Berman and Crump (1999) methodology, the smallest asbestos structure of concern is 5 μm long and no more than 1 μm in diameter, with a mass of approximately 1×10^{-5} μg. At the stated sensitivity of 1×10^{6} structures/g of dust, the mass of asbestos would be about 10 μg/g of dust if all of the structures were of the minimum size. This corresponds to 0.001 percent of the mass of the dust. The detection limit of the PLM analysis was reported as approximately 0.1 percent by weight. This indicates that the elutriator analysis is much more sensitive to the presence of asbestos than the earlier PLM analysis.

TABLE 51
Additional Risk per One Hundred Thousand Persons from Lifetime Continuous Exposure to 0.0005 TEM f/mL Longer than 5.0 μm and Thinner than 0.5 μm

Population Subset	Percent Fibers Greater than 10 μm in Length										
	0.5%	1%	2%	4%	6%	10%	15%	20%	30%	40%	50%
Chrysotile											
Male Nonsmoker	0.109	0.177	0.31	0.59	0.86	1.41	2	2.7	4.2	5.5	6.9
Female Nonsmoker	0.103	0.163	0.29	0.55	0.8	1.33	1.94	2.58	3.9	5.1	6.4
Male Smoker	0.518	0.832	1.51	2.81	4	6.59	9.83	13	19.4	25.9	32.4
Female Smoker	0.377	0.613	1.09	2.01	2.95	4.94	7.3	9.7	14.4	18.9	23.6
Amphiboles											
Male Nonsmoker	6.21	10.12	17.5	33.7	49	80.5	118.7	158	235	313	391
Female Nonsmoker	6.78	10.61	19.1	36	53	87.8	130.2	172.6	257	342	427
Male Smoker	8.5	13.8	24	46	67	109	162	215	320	427	532
Female Smoker	8.9	14.5	25.1	48	70	115	171	226	337	448	559

Notes:
Risks represent the sum of lung cancer risk and mesothelioma risk presented in Table 2-2 of Berman and Crump (1999)

asbestos, and that asbestosis is not expected to contribute substantially to risks associated with environmental asbestos exposure (as opposed to higher levels of exposure in workplace settings). Therefore, the total cancer risk associated with exposure to asbestos in soil is estimated by the sum of the risks for lung cancer and mesothelioma.

In order to assess the potential asbestos risks at the WRF site, the risk estimates in Table 51 must be adjusted to represent site conditions. The estimates in Table 51 quantify the risks associated with lifetime continuous exposure to a specific level of asbestos in air (0.0005 asbestos fibers per mL) where the fibers of concern are longer than 5 microns and thinner than 0.5 microns. Berman and Crump (1999) note that risk estimates presented in their Table 2-2 should be used with asbestos measurements derived using the methods described by Berman and Kolk (1997). The data obtained from the elutriator analysis of the soils from the WRF expansion site were generated using these asbestos measurement protocols, but both the duration and the intensity of the potential exposures at the WRF expansion site are much different from those specified for the lifetime exposure risk estimates in Table 51. As explained below, the risk estimates in Table 51 were adjusted to account for these differences. The adjusted values are estimates of the potential asbestos-related risks at the WRF expansion site.

1. Adjustments for Exposure Duration

The risk estimates in Table 51 were adjusted to represent the potential risks associated with nine of the eleven exposure scenarios considered in the risk assessment. Potential asbestos risks were not evaluated for the two post-construction indoor worker exposure scenarios because these workers will not have significant exposure to dust generated from site soils (as explained in Section V.A).

The exposure duration adjustments applied for the nine remaining scenarios are based on the exposure factors summarized in Tables 22 through 30. Table 52 compares the exposure factors for each of the nine scenarios to the lifetime exposure on which the risk estimates in Table 51 are based. An adjustment factor is derived for each scenario as the ratio of the number of hours of exposure for the scenario to the number of hours in a lifetime exposure scenario. The three scenarios that represent potential exposures during construction of the WRF expansion facility involve exposure over a three-year period to soils in both the northern exposure area (NEA) and the southern exposure area (SEA). The other six scenarios represent potential exposures after construction of the WRF expansion facility. The duration of exposures for these scenarios ranges from one year (for a construction worker involved in development of the NEA) to 30 years (for an off-site resident). All of the post-WRF development scenarios are based on exposure to soils in the NEA only because no significant quantities of dust will be generated from soils in the SEA after development (as explained in Section V.A.2).

TABLE 52
Dust Concentrations and Exposure Factors
for Exposed Populations During and Post WRF Construction

Population	Aggregate Controlled Dust Concentration in Air (µg/m³)			Exposure Duration Factors				
	SEA	NEA	Aggregate	Years	Days per Year	Hours per Day	Total Hours	Exposure Multiplier
Lifetime (assumed)*	NA	NA	NA	70	365	24	613200	NA
During WRF Construction								
WRF Construction Worker	156.28	0.54	156.82	3	250	8	6000	9.78E-03
Off-site Resident	0.89	0.12	1.01	3	350	24	25200	4.11E-02
Off-site Worker	0.89	0.12	1.01	3	250	8	6000	9.78E-03
Future (Post WRF Construction)								
Trespassing Child in the NEA	0	0.0826	0.0826	6	50	4	1200	1.96E-03
Maintenance Worker in the NEA	0	0.0417	0.0417	25	250	8	50000	8.15E-02
Maintenance Worker in the SEA	0	0.0649	0.0649	25	250	8	50000	8.15E-02
Off-site Resident	0	0.0649	0.0649	30	350	24	252000	4.11E-01
Off-site Worker	0	0.0649	0.0649	25	250	8	50000	8.15E-02
Default Construction Worker in the NEA	0	156.28	156.28	1	250	8	2000	3.26E-03

Notes:
* as assumed in Table 2-2 of Berman and Crump (1999)

As shown in Table 52, the adjustment factors based on exposure duration range from 0.00196 (for a trespassing child) to 0.411 (for off-site residents after WRF construction).

2. Adjustments for Exposure Intensity

To estimate the intensity of exposure to asbestos in ambient air both during and after the WRF construction, the dust concentrations derived in Appendix J are combined with the concentrations of asbestos in dust obtained from the elutriator analyses. The resulting exposure concentrations for asbestos are compared to the exposure concentration assumed in Table 51 (i.e., 0.0005 asbestos fibers per mL) and the risk estimates in Table 51 are adjusted for the differences in the exposure intensity.

a. Estimation of Dust Concentrations

The methods used to simulate the concentration of dust (i.e., PM_{10}) in air are described in detail in Appendix J and summarized briefly in this section. In Appendix J, ENVIRON used a particulate emission factor (PEF) approach as prescribed by EPA documentation (USEPA 2001c). A PEF value represents the relationship between the concentration of a contaminant in soil and the concentration of the same contaminant in airborne dust; i.e., it represents the inverse of the concentration of dust particles in air. The PEF values resulting from ENVIRON's analysis of dust sources both during and after the WRF construction are presented in Table J-2, which is presented in duplicate as Table 53. To calculate the airborne dust concentration associated with each dust emission source listed in Table 53, the PEF value is inverted, as follows:

$$C_{dust,i} = \frac{1}{PEF_i} \times 10^9 \mu g/kg$$

where:

$C_{dust, i}$ = the uncontrolled dust concentration in air from emissions source i ($\mu g/m^3$); and

PEF_i = the PEF value for emission source i as calculated in Appendix J of the risk assessment report (m^3/kg).

The "Controlled Dust Concentration in Air ($\mu g/m^3$)" column in Table 53 represents the airborne dust concentration after dust suppression measures have been implemented. The dust suppression measures[21] are assumed to be 90 percent

[21] For a discussion on dust suppression measures applicable to the WRF expansion site, see Section B.4 of Appendix J.

TABLE 53
Dust Concentrations in Air During and Post WRF Construction

Population	Emission Source	Controlled Dust Concentration in Air ($\mu g/m^3$)	Aggregate Controlled Dust Concentration in Air ($\mu g/m^3$)
During WRF Construction			
WRF Construction Worker	Unpaved Road Traffic in the SEA	155.04	156.82
	Excavation in the SEA	0.0141	
	Dozing in the SEA	0.833	
	Wind Erosion in the SEA	0.392	
	Unpaved Road Traffic in the NEA	0.230	
	Grading in the NEA	0.0218	
	Wind Erosion in the NEA	0.285	
Off-site Resident	Unpaved Road Traffic in the SEA	0.69	1.01
	Excavation in the SEA	0.0022	
	Dozing in the SEA	0.13	
	Wind Erosion in the SEA	0.062	
	Unpaved Road Traffic in the NEA	0.053	
	Grading in the NEA	0.0050	
	Wind Erosion in the NEA	0.065	
Off-site Worker	Unpaved Road Traffic in the SEA	0.69	1.01
	Excavation in the SEA	0.0022	
	Dozing in the SEA	0.13	
	Wind Erosion in the SEA	0.062	
	Unpaved Road Traffic in the NEA	0.053	
	Grading in the NEA	0.0050	
	Wind Erosion in the NEA	0.065	
Future (Post WRF Construction)			
Trespassing Child in the NEA	Wind Erosion in the NEA	0.0826	0.0826
Maintenance Worker in the NEA	Wind Erosion in the NEA	0.0417	0.0417
Maintenance Worker in the SEA	Wind Erosion in the NEA	0.0649	0.0649
Off-site Resident	Wind Erosion in the NEA	0.0649	0.0649
Off-site Worker	Wind Erosion in the NEA	0.0649	0.0649
Default Construction Worker in the NEA	Unpaved Road Traffic in the NEA	155.04	156.28
	Excavation in the NEA	0.0141	
	Dozing in the NEA	0.833	
	Wind Erosion in the NEA	0.392	

effective, so the values in the table are 10 percent of the uncontrolled values derived using the equation above. The "Aggregate Controlled Dust Concentration in Air ($\mu g/m^3$)" column represents the cumulative controlled dust concentration in air to which each population is exposed. For example, for the WRF Construction Worker during WRF construction, the aggregate controlled dust concentration in air (156.82 $\mu g/m^3$) is the sum of the following contributions: unpaved road traffic in the SEA (155.04 $\mu g/m^3$); excavation in the SEA (0.0141 $\mu g/m^3$); dozing in the SEA (0.833 $\mu g/m^3$); wind erosion in the SEA (0.392 $\mu g/m^3$); unpaved road traffic in the NEA (0.230 $\mu g/m^3$); grading in the NEA (0.0218 $\mu g/m^3$); and wind erosion in the NEA (0.285 $\mu g/m^3$).

b. Characterization of Asbestos Concentrations in Dust

The aggregate controlled dust concentrations presented in Table 52 for each exposure scenario are combined with concentrations of asbestos in dust to derive exposure concentrations for asbestos. To be consistent with the tabular method described by Berman and Crump (1999), the concentrations of asbestos in dust are characterized by the type of asbestos (chrysotile or amphibole) and the percentage of asbestos fibers that are greater than 10 microns long. The relevant characteristics of the elutriator data are presented in Table 54.

In deriving the concentrations from the elutriator data, the results obtained from all of the composite samples for each exposure area are pooled. This procedure is consistent with the elutriator results, which do not establish that there are systematic differences between the composites that represent the different land use categories (Pond, Ditch, and Other) within each exposure area. As shown in Table 54, asbestos fibers were found in only one of the SEA composite samples. The sample in which asbestos was found is one of two composites that represent Pond locations. The probability calculations for the Poisson process (discussed below) indicate that the difference between finding one fiber and finding no fibers is not statistically significant; therefore, no systematic difference is suggested. Table 54 also shows that asbestos fibers were found in all but one of the NEA composite samples. The only NEA composite in which asbestos was not found (NEA-1) represents the Other (i.e., non-Pond, non-Ditch) locations. Although this suggests that the asbestos found in the pond and ditch composites may be associated with waste disposal, the numbers of asbestos fibers detected in the NEA Pond and Ditch composites are not high enough to establish that the difference in counts is statistically significant. This conclusion is based on probability calculations for a Poisson distribution with an intensity parameter of zero. Assuming that this distribution represents the concentration of asbestos

TABLE 54
Interpretation of Elutriator Data

Sample Identification	Analytical Sensitivity (structures/ gram of dust)	Reciprocal Analytical Sensitivity (gram of dust/ structure)	Amphibole		Chrysotile	
			No. of Structures	Percent >10 µm	No. of Structures	Percent >10 µm
Northern Exposure Area						
NEA 1 (Other locations)	9.90E+05	1.01E-06	0	0	0	0
NEA 2 (Ditch locations)	9.90E+05	1.01E-06	1	0	0	0
NEA 3 (Pond locations)	9.90E+05	1.01E-06	1	0	0	0
NEA 4 (Pond locations)	9.90E+05	1.01E-06	2	50	1	0
Pooled Sensitivity	2.48E+05	4.04E-06	-	-	-	-
Total Counts	-	-	4	-	1	-
Integer Upper Bounds	-	-	9	-	5	-
Pooled Average Concentration (structures/g dust)	-	-	9.90E+05	25	2.48E+05	0
Poisson Upper Bound (structures/g dust)	-	-	2.23E+06	25	1.24E+06	0
Southern Exposure Area						
SEA 1 (Ditch locations)	9.70E+05	1.03E-06	0	0	0	0
SEA 2 (Pond locations)	9.70E+05	1.03E-06	0	0	0	0
SEA 3 (Pond locations)	9.90E+05	1.01E-06	0	0	2	50
Pooled Sensitivity	3.26E+05	3.07E-06	-	-	-	-
Total Counts	-	-	0	-	2	-
Integer Upper Bounds	-	-	3	-	6	-
Pooled Average Concentration (structures/g dust)	-	-	0	0	6.51E+05	50
Poisson Upper Bound (structures/g dust)	-	-	9.77E+05	0	1.95E+06	50

fibers in dust generated from soil in the Pond portions of the NEA that were not used for waste disposal (as represented by the Other locations), a count of three or more fibers would be expected in about five percent of the samples[22]. The number of fibers detected in the rest of the NEA composites ranges from 1 to 3; the average number for the two Pond composites is 2 fibers, and the number for the Ditch composite is 1 fiber. These results do not establish conclusively that the concentration of asbestos fibers in dust derived from the Other locations is significantly lower than the concentration in dust derived from the Pond and Ditch locations, so the results of all of the NEA composites are pooled. This procedure provides an average value that is used to represent conditions throughout the NEA.

Pooled average concentration values and percentages of fibers longer than 10 microns are provided in Table 54 for each exposure area and type of asbestos (chrysotile and amphibole). The pooled average concentrations are derived from the analytical sensitivity of the counting process for each composite. The analytical sensitivity indicates the concentration of fibers in dust that corresponds to detection of a single fiber in the TEM analysis. For example, detection of a single fiber in a composite sample for the NEA indicates an asbestos concentration of 9.9×10^5 asbestos fibers per gram of dust. This level of sensitivity is slightly better than the target level of 1.0×10^6 that was specified in the instructions to the laboratory. All of the grid openings counted for the composite samples in each exposure area are representative of the same conditions, so the pooled analytical sensitivity is calculated as the inverse of the sum of the reciprocals of the sensitivities for the composite samples. Thus, the pooled analytical sensitivity for the NEA samples is 2.48×10^5 asbestos fibers per gram of dust, and the pooled analytical sensitivity for the SEA samples is 3.26×10^5 asbestos fibers per gram of dust.

The total number of amphibole fibers detected in the four NEA composites is 4 and the total number of chrysotile fibers detected in the four NEA composites is 1. Multiplying these totals by the pooled analytical sensitivity provides the mean concentrations (9.9×10^5 fibers per gram of dust for amphibole and 2.48×10^5 fibers per gram of dust for chrysotile). The corresponding calculations for the SEA are based on zero amphibole fibers and 2 chrysotile fibers and provide mean concentrations of zero fibers per gram of dust for amphibole and 6.51×10^5 fibers per gram of dust for chrysotile.

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[22] The calculations used to estimate the Poisson probabilities are summarized in Table 55.

In addition to the average concentrations, Table 54 provides upper bound concentrations derived using the Poisson distribution. The number of composite samples analyzed for each exposure area is not sufficient to derive meaningful upper confidence limits (UCLs) by the procedures described in Section V.B.1. As an alternative, upper bounds on the mean asbestos concentrations were calculated as integer upper bounds on the mean number of fibers that might be detected in the composites from each exposure area. Each integer upper bound represents a probability statement concerning the mean count (i.e., the mean number of fibers counted if representative samples were drawn and counted repeatedly) that may be expected in light of the observed count (i.e., the number of fibers counted in the elutriator analyses of the composite samples). For example, the number of amphibole fibers counted in all of the SEA samples is zero; given this observed count, calculations based on the Poisson distribution indicate that the likelihood that the mean count is greater than 3 is five percent. Because the probability that the mean count exceeds 3 when the observed count is zero is five percent, 3 is used as a 95 percent upper confidence limit on the mean count. The integer upper bounds used as the upper confidence limits on the mean counts are provided in Table 54. These integer upper bounds were obtained by deriving the exact 95 percent UCL for each count by Poisson calculations, then rounding off to the nearest integer.

c. Calculation of Asbestos Concentrations in Air

The concentrations of asbestos in the air for each exposure scenario are calculated by multiplying the concentrations of dust in air by the concentrations of asbestos in dust. The dust concentrations are presented in Table 52 in units of $\mu g/m^3$ and the concentrations of asbestos in dust are presented in Table 54 in units of structures (or fibers) per gram of dust. The risk estimates in Table 51 are based on lifetime exposure to an asbestos concentration in air of 0.0005 fibers/mL. Thus, the exposure concentration for asbestos in air is calculated for each exposure scenario by multiplying the dust concentration in Table 52 by the asbestos in dust concentration in Table 54, then dividing by 10^{12} to provide units that are consistent with Table 51. These concentrations are an intermediate step in calculating the site-specific asbestos risk estimates and are not tabulated herein.

3. Risk Estimates for the WRF Expansion Site

The asbestos risk estimates for the WRF expansion site are calculated by adjusting the estimated risks for lifetime exposure presented in Berman and Crump

TABLE 55
Poisson Probability Calculations

Calculate the probability of x given m, where:

x is the observed count (number of fibers)

m is the intensity of the Poisson process

$$p(x \mid m) = \frac{m^x e^{-m}}{x!}$$

x	m	exp(-m)	m^x	x!	p(x|m)
0	1	0.3679	1	1	0.3679
0	2	0.1353	1	1	0.1353
0	3	0.0498	1	1	0.0498
0	4	0.0183	1	1	0.0183
0	5	0.0067	1	1	0.0067
0	6	0.0025	1	1	0.0025
0	7	0.0009	1	1	0.0009
0	8	0.0003	1	1	0.0003
0	9	0.0001	1	1	0.0001
1	1	0.3679	1	1	0.3679
1	2	0.1353	2	1	0.2707
1	3	0.0498	3	1	0.1494
1	4	0.0183	4	1	0.0733
1	5	0.0067	5	1	0.0337
1	6	0.0025	6	1	0.0149
1	7	0.0009	7	1	0.0064
1	8	0.0003	8	1	0.0027
1	9	0.0001	9	1	0.0011
2	1	0.3679	1	2	0.1839
2	2	0.1353	4	2	0.2707
2	3	0.0498	9	2	0.2240
2	4	0.0183	16	2	0.1465
2	5	0.0067	25	2	0.0842
2	6	0.0025	36	2	0.0446
2	7	0.0009	49	2	0.0223
2	8	0.0003	64	2	0.0107
2	9	0.0001	81	2	0.0050
4	1	0.3679	1	24	0.0153
4	2	0.1353	16	24	0.0902
4	3	0.0498	81	24	0.1680
4	4	0.0183	256	24	0.1954
4	5	0.0067	625	24	0.1755
4	6	0.0025	1296	24	0.1339
4	7	0.0009	2401	24	0.0912
4	8	0.0003	4096	24	0.0573
4	9	0.0001	6561	24	0.0337

(1999) for the site-specific exposure durations, concentrations of dust in air, and concentrations of asbestos in dust concentrations as discussed in the preceding sections.

Some of the lifetime risk estimates in Table 51 cannot be used directly, however, because the percentages of long fibers for which lifetime risk estimates are presented do not match all of the percentages observed in the elutriator results obtained from the WRF expansion site. As shown in Table 54, the percentages of fibers longer than 10 microns observed at the WRF site are zero, 25, and 50 percent. Therefore, in order to use the tabular risk assessment method presented by Berman and Crump (1999), ENVIRON has assumed that the risks associated with 25 percent long fibers can be obtained by linear interpolation between the risk estimates for 20 percent and 30 percent long fibers. In addition, the risk estimates for 0.5 percent long fibers are used for situations in which the observed percentage of long fibers is zero. The lifetime risk estimates that are used to calculate potential asbestos risks are presented in Table 56.

Using the Berman and Crump method, the potential asbestos-related risks are calculated separately for each of four subpopulations (e.g., male nonsmokers), two types of asbestos (amphibole and chrysotile), and two exposure areas. The post-construction exposure scenarios do not include exposure to the SEA soils, so potential risks associated with the SEA soils are calculated only for the three exposure scenarios that address conditions during construction of the WRF expansion facility. The total asbestos risk estimates for each scenario and subpopulation are calculated by summing the estimates derived for amphibole and chrysotile for the relevant exposure areas.

Risk estimates for the general population (males and females, smokers and nonsmokers) were computed as weighted averages of the risk estimates derived for the various subpopulations. The weights used in this calculation were developed from percentages of male and female smokers in the general population of the U.S. in 1998 as reported in Table 226 of *Statistical Abstract of the United States: 2000* (U.S. Census Bureau 2001). The general population risk estimates can be compared and combined directly with the risk estimates derived for exposure to chemicals and radionuclides in other sections of this report. The risk estimates based on the average asbestos concentrations are presented in Table 57, and the risk estimates based on the upper bound asbestos concentrations are presented in Table 58.

C. Discussion

The risk estimates for each exposure scenario vary somewhat from one subpopulation to another, but the range of risk estimates is generally small. The male smoker is the subpopulation with the highest risk estimate for all three of the scenarios during WRF construction; after WRF construction, the risk estimates are always highest for the female smoker subpopulation. The ratio of the highest to lowest subpopulation risk estimates is less than 2 for all of the scenarios

TABLE 56
Additional Risk per One Hundred Thousand Persons from Lifetime Continuous Exposure to 0.0005 TEM f/mL Longer than 5.0 μm and Thinner than 0.5 μm

Population Subset	Percent Fibers Greater than 10 μm in Length			
	Chrysotile		Amphibole	
	0.5%	50%	0.5%	25%*
Male Nonsmoker	0.109	6.9	6.21	196.5
Female Nonsmoker	0.103	6.4	6.78	214.8
Male Smoker	0.518	32.4	8.5	267.5
Female Smoker	0.377	23.6	8.9	281.5

Notes:
Risks represent the sum of lung cancer risk and mesothelioma risk presented in Table 2-2 of Berman and Crump (1999)
*Interpolated from Table 2-2 of Berman and Crump (1999)

TABLE 57
Carcinogenic Risk Estimates Associated with Inhalation of Asbestos at Average Asbestos Concentrations

Population		Amphibole			Chrysotile			Total Asbestos Risk Estimate
		NEA	SEA	Total	NEA	SEA	Total	
During WRF Construction								
WRF Construction Worker	Male Nonsmoker	2.04E-08	0.00E+00	**2.04E-08**	2.84E-12	1.37E-07	**1.37E-07**	**1.58E-07**
	Female Nonsmoker	2.23E-08	0.00E+00	**2.23E-08**	2.68E-12	1.27E-07	**1.27E-07**	**1.50E-07**
	Male Smoker	2.78E-08	0.00E+00	**2.78E-08**	1.35E-11	6.45E-07	**6.45E-07**	**6.73E-07**
	Female Smoker	2.93E-08	0.00E+00	**2.93E-08**	9.82E-12	4.70E-07	**4.70E-07**	**4.99E-07**
	Total asbestos risk estimate (general population)							**2.59E-07**
Off-site Resident	Male Nonsmoker	1.96E-08	0.00E+00	**1.96E-08**	2.72E-12	3.29E-09	**3.29E-09**	**2.29E-08**
	Female Nonsmoker	2.14E-08	0.00E+00	**2.14E-08**	2.57E-12	3.05E-09	**3.05E-09**	**2.45E-08**
	Male Smoker	2.67E-08	0.00E+00	**2.67E-08**	1.29E-11	1.54E-08	**1.55E-08**	**4.21E-08**
	Female Smoker	2.81E-08	0.00E+00	**2.81E-08**	9.42E-12	1.12E-08	**1.13E-08**	**3.93E-08**
	Total asbestos risk estimate (general population)							**2.78E-08**
Off-site Worker	Male Nonsmoker	4.67E-09	0.00E+00	**4.67E-09**	6.48E-13	7.83E-10	**7.84E-10**	**5.45E-09**
	Female Nonsmoker	5.10E-09	0.00E+00	**5.10E-09**	6.13E-13	7.26E-10	**7.27E-10**	**5.83E-09**
	Male Smoker	6.35E-09	0.00E+00	**6.35E-09**	3.08E-12	3.68E-09	**3.68E-09**	**1.00E-08**
	Female Smoker	6.68E-09	0.00E+00	**6.68E-09**	2.24E-12	2.68E-09	**2.68E-09**	**9.36E-09**
	Total asbestos risk estimate (general population)							**6.62E-09**
Future (Post WRF Construction)								
Trespassing Child in the NEA	Male Nonsmoker	6.29E-10	0.00E+00	**6.29E-10**	8.74E-14	0.00E+00	**8.74E-14**	**6.29E-10**
	Female Nonsmoker	6.88E-10	0.00E+00	**6.88E-10**	8.26E-14	0.00E+00	**8.26E-14**	**6.88E-10**
	Male Smoker	8.57E-10	0.00E+00	**8.57E-10**	4.16E-13	0.00E+00	**4.16E-13**	**8.57E-10**
	Female Smoker	9.01E-10	0.00E+00	**9.01E-10**	3.02E-13	0.00E+00	**3.02E-13**	**9.02E-10**
	Total asbestos risk estimate (general population)							**7.12E-10**
Maintenance Worker in the NEA	Male Nonsmoker	1.32E-08	0.00E+00	**1.32E-08**	1.84E-12	0.00E+00	**1.84E-12**	**1.32E-08**
	Female Nonsmoker	1.45E-08	0.00E+00	**1.45E-08**	1.74E-12	0.00E+00	**1.74E-12**	**1.45E-08**
	Male Smoker	1.80E-08	0.00E+00	**1.80E-08**	8.74E-12	0.00E+00	**8.74E-12**	**1.80E-08**
	Female Smoker	1.90E-08	0.00E+00	**1.90E-08**	6.36E-12	0.00E+00	**6.36E-12**	**1.90E-08**
	Total asbestos risk estimate (general population)							**1.50E-08**
Maintenance Worker in the SEA	Male Nonsmoker	2.06E-08	0.00E+00	**2.06E-08**	2.86E-12	0.00E+00	**2.86E-12**	**2.06E-08**
	Female Nonsmoker	2.25E-08	0.00E+00	**2.25E-08**	2.70E-12	0.00E+00	**2.70E-12**	**2.25E-08**
	Male Smoker	2.80E-08	0.00E+00	**2.80E-08**	1.36E-11	0.00E+00	**1.36E-11**	**2.80E-08**
	Female Smoker	2.95E-08	0.00E+00	**2.95E-08**	9.90E-12	0.00E+00	**9.90E-12**	**2.95E-08**
	Total asbestos risk estimate (general population)							**2.33E-08**
Off-site Resident	Male Nonsmoker	1.04E-07	0.00E+00	**1.04E-07**	1.44E-11	0.00E+00	**1.44E-11**	**1.04E-07**
	Female Nonsmoker	1.13E-07	0.00E+00	**1.13E-07**	1.36E-11	0.00E+00	**1.36E-11**	**1.13E-07**
	Male Smoker	1.41E-07	0.00E+00	**1.41E-07**	6.85E-11	0.00E+00	**6.85E-11**	**1.41E-07**
	Female Smoker	1.49E-07	0.00E+00	**1.49E-07**	4.99E-11	0.00E+00	**4.99E-11**	**1.49E-07**
	Total asbestos risk estimate (general population)							**1.17E-07**
Off-site Worker	Male Nonsmoker	2.06E-08	0.00E+00	**2.06E-08**	2.86E-12	0.00E+00	**2.86E-12**	**2.06E-08**
	Female Nonsmoker	2.25E-08	0.00E+00	**2.25E-08**	2.70E-12	0.00E+00	**2.70E-12**	**2.25E-08**
	Male Smoker	2.80E-08	0.00E+00	**2.80E-08**	1.36E-11	0.00E+00	**1.36E-11**	**2.80E-08**
	Female Smoker	2.95E-08	0.00E+00	**2.95E-08**	9.90E-12	0.00E+00	**9.90E-12**	**2.95E-08**
	Total asbestos risk estimate (general population)							**2.33E-08**
Default Construction Worker in the NEA	Male Nonsmoker	1.98E-06	0.00E+00	**1.98E-06**	2.76E-10	0.00E+00	**2.76E-10**	**1.98E-06**
	Female Nonsmoker	2.17E-06	0.00E+00	**2.17E-06**	2.60E-10	0.00E+00	**2.60E-10**	**2.17E-06**
	Male Smoker	2.70E-06	0.00E+00	**2.70E-06**	1.31E-09	0.00E+00	**1.31E-09**	**2.70E-06**
	Female Smoker	2.84E-06	0.00E+00	**2.84E-06**	9.53E-10	0.00E+00	**9.53E-10**	**2.84E-06**
	Total asbestos risk estimate (general population)							**2.24E-06**

Notes:
No amphibole structures were detected in the SEA samples, so there are no amphibole risks in the SEA during construction.
Dust generation from soils in the SEA samples after construction is negligible, so there are no asbestos risks in the SEA after construction.
General population risk estimates for each exposure scenario are calculated as weighted averages of risk estimates for four subpopulations.
Weights are based on 50% Male (25.9% Smokers) and 50% Female (22.1% Smokers) as reported in
Table 226 of Statistical Abstract of the United States: 2000 (U.S. Census Bureau 2001).
Calculated weights are Male Nonsmoker 0.3705; Female Nonsmoker 0.3895; Male Smoker 0.1295; Female Smoker 0.1105.

TABLE 58
Carcinogenic Risk Estimates Associated with Inhalation of Asbestos at Upper Bound Asbestos Concentrations

Population		Amphibole			Chrysotile			Total Asbestos Risk Estimate
		NEA	SEA	Total	NEA	SEA	Total	
During WRF Construction								
WRF Construction Worker	Male Nonsmoker	4.60E-08	1.86E-07	**2.32E-07**	1.42E-11	4.11E-07	**4.12E-07**	**6.43E-07**
	Female Nonsmoker	5.03E-08	2.03E-07	**2.53E-07**	1.34E-11	3.82E-07	**3.82E-07**	**6.35E-07**
	Male Smoker	6.26E-08	2.54E-07	**3.17E-07**	6.75E-11	1.93E-06	**1.93E-06**	**2.25E-06**
	Female Smoker	6.59E-08	2.66E-07	**3.32E-07**	4.91E-11	1.41E-06	**1.41E-06**	**1.74E-06**
	Total asbestos risk estimate (general population)							**9.69E-07**
Off-site Resident	Male Nonsmoker	4.41E-08	4.44E-09	**4.86E-08**	1.36E-11	9.85E-09	**9.87E-09**	**5.84E-08**
	Female Nonsmoker	4.82E-08	4.85E-09	**5.31E-08**	1.29E-11	9.14E-09	**9.15E-09**	**6.22E-08**
	Male Smoker	6.01E-08	6.08E-09	**6.62E-08**	6.47E-11	4.63E-08	**4.63E-08**	**1.12E-07**
	Female Smoker	6.32E-08	6.37E-09	**6.96E-08**	4.71E-11	3.37E-08	**3.37E-08**	**1.03E-07**
	Total asbestos risk estimate (general population)							**7.19E-08**
Off-site Worker	Male Nonsmoker	1.05E-08	1.06E-09	**1.16E-08**	3.24E-12	2.35E-09	**2.35E-09**	**1.39E-08**
	Female Nonsmoker	1.15E-08	1.15E-09	**1.26E-08**	3.06E-12	2.18E-09	**2.18E-09**	**1.48E-08**
	Male Smoker	1.43E-08	1.45E-09	**1.58E-08**	1.54E-11	1.10E-08	**1.10E-08**	**2.68E-08**
	Female Smoker	1.51E-08	1.52E-09	**1.66E-08**	1.12E-11	8.02E-09	**8.03E-09**	**2.46E-08**
	Total asbestos risk estimate (general population)							**1.71E-08**
Future (Post WRF Construction)								
Trespassing Child in the NEA	Male Nonsmoker	1.42E-09	0.00E+00	**1.42E-09**	4.37E-13	0.00E+00	**4.37E-13**	**1.42E-09**
	Female Nonsmoker	1.55E-09	0.00E+00	**1.55E-09**	4.13E-13	0.00E+00	**4.13E-13**	**1.55E-09**
	Male Smoker	1.93E-09	0.00E+00	**1.93E-09**	2.08E-12	0.00E+00	**2.08E-12**	**1.93E-09**
	Female Smoker	2.03E-09	0.00E+00	**2.03E-09**	1.51E-12	0.00E+00	**1.51E-12**	**2.03E-09**
	Total asbestos risk estimate (general population)							**1.60E-09**
Maintenance Worker in the NEA	Male Nonsmoker	2.98E-08	0.00E+00	**2.98E-08**	9.19E-12	0.00E+00	**9.19E-12**	**2.98E-08**
	Female Nonsmoker	3.26E-08	0.00E+00	**3.26E-08**	8.69E-12	0.00E+00	**8.69E-12**	**3.26E-08**
	Male Smoker	4.06E-08	0.00E+00	**4.06E-08**	4.37E-11	0.00E+00	**4.37E-11**	**4.06E-08**
	Female Smoker	4.27E-08	0.00E+00	**4.27E-08**	3.18E-11	0.00E+00	**3.18E-11**	**4.27E-08**
	Total asbestos risk estimate (general population)							**3.37E-08**
Maintenance Worker in the SEA	Male Nonsmoker	4.64E-08	0.00E+00	**4.64E-08**	1.43E-11	0.00E+00	**1.43E-11**	**4.64E-08**
	Female Nonsmoker	5.07E-08	0.00E+00	**5.07E-08**	1.35E-11	0.00E+00	**1.35E-11**	**5.07E-08**
	Male Smoker	6.31E-08	0.00E+00	**6.31E-08**	6.80E-11	0.00E+00	**6.80E-11**	**6.32E-08**
	Female Smoker	6.64E-08	0.00E+00	**6.64E-08**	4.95E-11	0.00E+00	**4.95E-11**	**6.65E-08**
	Total asbestos risk estimate (general population)							**5.25E-08**
Off-site Resident	Male Nonsmoker	2.34E-07	0.00E+00	**2.34E-07**	7.21E-11	0.00E+00	**7.21E-11**	**2.34E-07**
	Female Nonsmoker	2.56E-07	0.00E+00	**2.56E-07**	6.81E-11	0.00E+00	**6.81E-11**	**2.56E-07**
	Male Smoker	3.18E-07	0.00E+00	**3.18E-07**	3.43E-10	0.00E+00	**3.43E-10**	**3.19E-07**
	Female Smoker	3.35E-07	0.00E+00	**3.35E-07**	2.49E-10	0.00E+00	**2.49E-10**	**3.35E-07**
	Total asbestos risk estimate (general population)							**2.64E-07**
Off-site Worker	Male Nonsmoker	4.64E-08	0.00E+00	**4.64E-08**	1.43E-11	0.00E+00	**1.43E-11**	**4.64E-08**
	Female Nonsmoker	5.07E-08	0.00E+00	**5.07E-08**	1.35E-11	0.00E+00	**1.35E-11**	**5.07E-08**
	Male Smoker	6.31E-08	0.00E+00	**6.31E-08**	6.80E-11	0.00E+00	**6.80E-11**	**6.32E-08**
	Female Smoker	6.64E-08	0.00E+00	**6.64E-08**	4.95E-11	0.00E+00	**4.95E-11**	**6.65E-08**
	Total asbestos risk estimate (general population)							**5.25E-08**
Default Construction Worker in the NEA	Male Nonsmoker	4.47E-06	0.00E+00	**4.47E-06**	1.38E-09	0.00E+00	**1.38E-09**	**4.47E-06**
	Female Nonsmoker	4.88E-06	0.00E+00	**4.88E-06**	1.30E-09	0.00E+00	**1.30E-09**	**4.88E-06**
	Male Smoker	6.08E-06	0.00E+00	**6.08E-06**	6.55E-09	0.00E+00	**6.55E-09**	**6.09E-06**
	Female Smoker	6.40E-06	0.00E+00	**6.40E-06**	4.77E-09	0.00E+00	**4.77E-09**	**6.40E-06**
	Total asbestos risk estimate (general population)							**5.05E-06**

Notes:
The upper bound amphibole risk estimate in the SEA during construction is not zero because it is based on the integer upper bound (3).
Dust generation from soils in the SEA samples after construction is negligible, so there are no asbestos risks in the SEA after construction.
General population risk estimates for each exposure scenario are calculated as weighted averages of risk estimates for four subpopulations.
Weights are based on 50% Male (25.9% Smokers) and 50% Female (22.1% Smokers) as reported in
Table 226 of Statistical Abstract of the United States: 2000 (U.S. Census Bureau 2001).
Calculated weights are Male Nonsmoker 0.3705; Female Nonsmoker 0.3895; Male Smoker 0.1295; Female Smoker 0.1105.

except the WRF construction worker. This ratio is consistent at about 1.43 for all six of the post-construction scenarios, which involve exposure to soils in the NEA only. This ratio (1.43) is determined by the ratio of the risk estimates for the female smoker and male nonsmoker subpopulations presented in Table 51 and Table 56 for exposure to amphibole asbestos because chrysotile asbestos does not contribute significantly to the risk estimates for the NEA soils. The ratios for the off-site populations (both residents and workers) during WRF construction are about 1.83 for the average asbestos concentrations (Table 57) and about 1.93 for the upper bound asbestos concentrations (Table 58). Thus, the variation from one subpopulation to another is minor for all scenarios except the WRF construction worker. The ratios of the highest subpopulation risk estimate for each scenario in Table 58 (based on upper bound asbestos concentrations) to the highest subpopulation risk estimate for the same scenario in Table 57 (based on average asbestos concentrations) are also consistent. These ratios, which are determined by the integer upper bounds calculated for the Poisson distribution, are about 2.25 for all six of the post-WRF construction scenarios, about 2.67 for the off-site populations (both workers and residents) during WRF construction, and about 3.34 for the WRF construction worker scenario.

The general population risk estimates presented in tables 57 and 58 are calculated as weighted averages of the subpopulation risk estimates. Because the range of variation of the subpopulation estimates for each scenario is relatively small, the general population estimates are quite similar to the subpopulation risks from which they are calculated. The subpopulation risk estimates range from about 64 to 123 percent of the corresponding general population risk estimates, except for the WRF construction worker scenario where the range is slightly greater (43 to 173 percent). These ratios indicate that use of the general population risk estimates for asbestos will not result in significant underestimation of the risks to any of the four identified subpopulations.

All of the asbestos risk estimates are within the range that the NDEP has identified as acceptable during construction of the WRF expansion project. NDEP's October 18, 2002 letter to Allan DeLorme indicates that if a 10^{-6} risk level for asbestos cannot be attained, the NDEP will accept an asbestos risk level of 10^{-5} during construction of the WRF expansion project. The highest risk estimates for any of the scenarios during construction of the WRF expansion facility in the SEA are for the male smoker subpopulation and the WRF construction worker scenario. The upper-bound estimate for this combination is 2.3×10^{-6} and the corresponding estimate based on average asbestos concentrations is 6.7×10^{-7}. In both cases, more than 95 percent of the potential risk is associated with soils in the SEA. The highest potential risks associated with exposure to asbestos in the SEA soils are about 6×10^{-7} (for average concentrations) or 2×10^{-6} (for upper bound concentrations). The highest potential risks are due primarily (at least 86 percent) to exposure to chrysotile asbestos.

For the NEA soils, the highest asbestos risk estimates are about 3×10^{-6} (for average concentrations) or 6×10^{-6} (for upper bound concentrations). These risk estimates are calculated for the default construction worker scenario in the NEA. As explained in Section V.A.2, this hypothetical scenario was included to address the possibility of future development of the NEA. None of the other risk estimates associated with asbestos in the NEA soils are greater than 1×10^{-6}. Exposure to amphibole accounts for nearly 100 percent of the potential asbestos risks associated with the NEA soils.

X. UNCERTAINTIES AND LIMITATIONS

Risk assessment provides a systematic means for organizing, analyzing, and presenting information on the nature and magnitude of risks posed by chemical exposures. Nevertheless, uncertainties and limitations are present in all risk assessments because of the quality of available data and the need to make assumptions and develop inferences based on incomplete information about existing conditions and future circumstances. These uncertainties and limitations should be recognized and considered when evaluating quantitative risk estimates. Recognizing the limitations and uncertainties of risk assessments, government agencies have adopted risk assessment to provide a quantitative and consistent framework for systematically evaluating human health risks. A discussion of some of the major sources of uncertainty in the risk assessment of the WRF expansion site is provided in the following sections of this chapter.

A. Uncertainties Associated with Estimation of Environmental Media Concentrations

Exposure to chemicals of potential concern, during both construction of the WRF and after its completion, may occur due to direct contact with soil or ground water or due to inhalation of airborne chemicals in dust and vapors. To estimate the magnitude of exposure, it is necessary to characterize the concentrations of chemicals in soil and ground water, model the transport of these chemicals in the environment, and predict airborne concentrations. The sections below discuss the uncertainties associated with characterizing soil and ground water concentrations and modeling the transport of chemicals to the atmosphere.

1. Soil Concentrations

The May 2001 soil sampling was conducted to provide a comprehensive characterization of chemical concentrations in soil both horizontally across the site and vertically throughout the soil column. In total, 74 soil samples (including field duplicates) were collected as part of this sampling effort. A review of the data does not indicate extreme variations in chemical concentrations across the site or with depth. The WRF expansion site, however, is almost 100 acres in size and, thus, it is possible that localized hot spots could exist that were not sampled during the May 2001 field program. If such hot spots exist, exposure point concentrations in soil could be higher than estimated; although the extent of underestimation, if any, is not likely significant given the number of samples collected (i.e., the statistical averaging would tend limit extreme variations in the calculated exposure point concentration) and the analysis of data adequacy in Appendix G. In addition, historical soil sampling data that has been collected within the boundaries of the WRF expansion site (discussed in Section II.D of this report) are at least superficially similar to the soil data that were collected as part of the May 2001 field program at the site. The quality of this historical data could not be

rigorously determined; laboratory reports were not available, and the data may or may not be comparable to the data produced by ENVIRON's site characterization work. Therefore, the historical data were not incorporated into the data set used in the risk assessment. If the historical data were included, it is possible that the exposure point concentrations (i.e., the 95 percent upper confidence limits) for soil would be lower due to the larger sample size.

Most of the chemical cancer risks are associated with a single chemical (arsenic), and most of the noncancer risks represented by the HI values are associated with perchlorate and several metals. Estimated cancer risks and HQ values for most of the other chemicals are insignificant. The analysis in Appendix G identifies only 14 chemicals for which the risk contribution may realistically exceed one percent of the assumed action levels. The uncertainty in the cumulative risk estimates that results from uncertainty in estimating the exposure point concentrations for the remaining chemicals is negligible; the exposure point concentrations for these chemicals would have to increase by orders of magnitude to affect the cumulative risk estimates significantly.

The degree of uncertainty associated with the exposure point concentrations calculated for the 14 more significant chemicals is assessed in Appendix G. The lateral and vertical variation of concentration exhibited by each of these chemicals is examined, and differences between depths and areas defined by previous use (ponds, ditches, and other) are identified. The results of this analysis indicate that the probability that the mean concentration of any individual chemical is high enough to cause unacceptable risks is small (about five percent). Therefore, although the cumulative risk estimates are subject to some degree of uncertainty associated with the soil sampling program, this uncertainty is not likely to affect the conclusions of the risk assessment.

2. Ground Water Concentrations

Estimates of exposure to chemicals in ground water were developed in this assessment for direct contact with ground water by a construction worker and a maintenance worker, and for inhalation of vapors emitted from ground water that migrate upward through the soil column and are released from the ground surface. The exposure point concentrations for the exposure scenarios are based on the maximum detected concentration in ground water wells located on or near the site in May 2001. As discussed in Section D of Chapter II, the data collected in May 2001 are generally consistent with the historical data obtained from wells on and immediately upgradient of the WRF expansion site.

Samples from two wells were used to characterize ground water concentrations in the southern exposure area, and samples from three wells (two from the site and one from a location 350 north of the northern boundary of the site) were used to represent ground

water concentrations in the northern exposure area. Ground water concentrations are expected to vary across the site but the current data are insufficient to characterize this variation; thus, the actual ground water concentration to which an individual may be exposed is uncertain. It could be higher or lower than the exposure point concentrations used in this assessment. As described below, however, it is unlikely that the risks associated with exposure to ground water by the populations evaluated in this report are underestimated, given the conservatism of the risk assessment assumptions.

The scenarios that include direct exposure to ground water (i.e., WRF and future default construction workers and maintenance workers) that are evaluated in this assessment were developed to be conservative; both include consumption of and dermal contact with ground water to an extent much greater than will likely occur over the course of employment at the site. The estimated HI values for these scenarios are due in a large part to the presence of perchlorate in ground water. Although the site may be contributing to perchlorate concentrations in ground water, as indicated by the preliminary leaching analysis presented in Chapter II, upgradient sources of perchlorate (e.g., the BMI Complex) also exist. As previously discussed, a separate analysis of leaching at the site and its potential effects on ground water beneath and down gradient of the site will be conducted in the future.

Based on the results of this assessment, one of the greatest potential contributors to total risk at the site is exposure to chloroform in ground water, primarily due to inhalation of vapors that are emitted from the ground water and migrate upward to the atmosphere.[23] The highest such risks are for a future indoor worker in the northern exposure area, for which a risk of 8×10^{-7} was estimated. Most of this estimated risk (95 percent) is associated with exposure to chloroform vapor emitted from ground water into an overlying building. Exposure to chloroform in outdoor air by other populations also contributes significantly to the total risk for these scenarios. It should be noted, however, that the estimates of exposure for chloroform are based on conservative, screening-level vapor transport and dispersion models. Thus, the exposure estimates used to develop risk associated with chloroform represent significant overestimations of actual exposure to individuals on and around the site. ENVIRON believes that, given the level of conservatism inherent in the risk calculations for chloroform, the likelihood that actual risks associated with chloroform exceed 1×10^{-6} are very low.

[23] Arsenic and carbon tetrachloride also contribute more than one percent of the total risk for certain scenarios, but the risks associated with these two chemicals are significantly less than for chloroform.

3. Air Concentrations

The estimation of exposure point concentrations in air is a multi-step process that includes, for outdoor air, the estimation of source concentrations (i.e., soil for the estimation of airborne dust and ground water for airborne vapors), emissions modeling, and dispersion in the atmosphere. The estimation of indoor air concentrations requires the development of source concentrations and the modeling of vapor transport through the soil column and into a hypothetical building. The estimation of source concentrations is discussed above; emissions models and atmospheric dispersion are discussed below.

a. Emissions Models

Transport modeling was performed using models developed or recommended by USEPA for emissions associated with grading, excavation, dozing, wind erosion, truck traffic on unpaved roads, and vapor transport from ground water. These dust emission models are generally considered screening models and, thus, are expected to provide overestimations of actual emissions. The vapor models used in this assessment are also considered to provide high-end estimates of emissions. Although there are uncertainties associated with the use of these models, these uncertainties will not result in an underestimation of risks due to the inherent conservatism.

One possible source of uncertainty that is not incorporated in the model, however, is the possible change in local ground water levels that could affect vapor migration in the subsurface. Although the area immediately surrounding the WRF expansion site is not highly developed currently, it is likely that in the future development will increase, including possible new residences, commercial establishments, light-industrial facilities, and recreational sites (e.g., golf courses). This type of development could result in an increased recharge to ground water in the area and a corresponding increase in the ground water level elevation. The emissions models used to predict the upward migration of vapors from ground water to the atmosphere and into an overlying building each take into consideration the depth to ground water. Thus, an increase in the ground water elevation could have an effect on predicted indoor and outdoor air concentrations of vapors. To evaluate this possibility, ENVIRON conducted a sensitivity analysis on the depth-to-groundwater term in the models used to estimate vapor concentrations in outdoor and indoor air. The average depth to ground water used in this risk assessment was 19 feet in the southern exposure area and 14 feet in the northern exposure area, based on an approximate average of measured ground water levels in each area (for the northern exposure area, depth to ground water in the off-site wells was included in the estimation of the average). For each area,

the effect on estimated risks was evaluated, assuming that the ground water elevation rose to 5 feet below ground surface in both areas.

For outdoor air, the estimated emission rates associated with vapor migration from ground water under the northern exposure area increased by a factor of approximately 1.8, when a depth to ground water of 5 feet was used instead of the current 14 feet. For the southern area, an increase by a factor of approximately 2.8 was associated with a corresponding rise in ground water level from 19 feet to 5 feet below ground surface.

For indoor air, the increases were significantly less. In the northern exposure area, an increase in ground water levels from 14 feet to 5 feet below ground surface resulted in an increase in vapor emissions into overlying buildings of approximately 20 percent. The increase for the southern exposure area would be approximately 30 percent, if ground water were to rise to within 5 feet of the ground surface.

Given the highly conservative nature of the approach used to estimate risks associated with exposure to chemicals in air, the observed increases in emission rates in cases of increased ground water level do not pose a significant concern.

b. Dispersion Modeling

The long-term dispersion of emissions on and from the site was simulated using simplified equations recommended by USEPA, developed for the purposes of deriving soil screening levels. These simplified dispersion equations are based on the results of dispersion modeling runs performed by the USEPA using the ISCST3 model. This model has been subjected to a peer review process to incorporate the most recent developments and is one of the primary USEPA-recommended air dispersion models. This model is generally recognized as being suitable for this type of application. The dispersion equations, which were developed by USEPA for the soil screening guidance (USEPA 2001c), simplify the ISCST3 model and are expected to provide worst-case estimates of air concentrations for the following reasons: 1) worst-case meteorology is used to derive one-hour average air concentrations for the construction worker scenario. The one-hour average air concentrations are then converted to the appropriate averaging period using a single conversion factor; 2) estimates of on-site air concentrations are predicted for a worst-case location, which assumes that an individual on the site (e.g., construction worker, trespassing child, maintenance worker) will be located at a single location during the entire exposure duration (i.e., up to 25 years); 3) off-site air concentration are predicted assuming exposure

at the fence line. Although the estimation of fence line concentrations is not uncommon for regulatory purposes, it provides an estimate of exposure that does not represent reasonable conditions (i.e., an individual is located continuously at a single point along the property boundary: off-site residents for 24 hours/day, 350 days/year for 30 years and off-site workers for 8 hours/day, 250 days/year for 25 years).

As indicated in Chapter VII, these highly conservative estimates of exposure contribute significantly to total risks for several exposure scenarios, resulting in an overestimation of total risk for these scenarios. Although the highly conservative air concentrations do not result in unacceptable risks, the results of the exposure scenarios for which air concentrations contribute significantly should be viewed in terms of this uncertainty.

B. Use of Background Data in the Risk Assessment

As explained in Chapter II and documented in Appendix E of this report, ENVIRON conducted a background soil sampling effort in April 2002. A detailed comparison of the WRF data used in the risk assessment to the background data is provided in Appendix G for the 14 chemicals that contribute most significantly to the total risk estimates. This comparison indicates that background concentrations in soil contribute significantly to the total cancer risks and noncancer HI values estimated in this assessment, and that the radionuclide concentrations in the WRF site soils are no greater than background.

When the mean concentrations are expressed as percentages of the background mean, the percentages are consistent across the EPC groups for many of the chemicals that are significant in the risk assessment. This consistency suggests that the concentration is relatively uniform throughout the area and depth zones of interest. Iron is present at about 150 percent of background in all of the EPC groups, and all of the differences are statistically significant. Aluminum is present at about 120 percent of background in all groups, and the only group for which the difference is not significant is SEA 0-1. The mean concentrations for six other chemicals (barium and five of the seven radionuclides) in soil samples collected at the WRF expansion site are lower than the mean concentrations in the background soil samples, and the hypothesis tests described in Appendix G indicate that many of these differences are statistically significant. Although the percentages for manganese are less consistent than those for these other chemicals, the mean concentrations for manganese and radium 226 are consistent with background for all five EPC groups.

The highest percentages are all for perchlorate, which is elevated relative to background for all of the EPC groups. The perchlorate concentrations in the surface samples at the WRF expansion site are nearly 140 times higher than background, but the mean concentrations in the EPC groups that include sub-surface samples are as low as 73 times background.

When expressed as a percentage of the mean concentration in the background samples, the mean levels of arsenic in the EPC groups range from 147 to 216 percent. When evaluated with the Wilcoxon Rank Sum test, the only EPC group means that are significant greater than the background mean are for the SEA groups that include subsurface samples. The maximum depth of the background soil samples was four feet and the middle and deep samples collected in both exposure areas were at depths greater than four feet. The concentrations of arsenic increase significantly with depth, so the EPC groups that include the deeper samples are expected to have higher mean concentrations. These facts suggest that if the characterization of background had included deeper samples, the comparisons may have indicated that none of the mean concentrations of arsenic are significantly greater than background.

The percentages for dioxin range from 75 percent in the NEA surface samples to 448 percent in the SEA surface samples. The dioxin concentrations appear to increase with depth in the NEA and decrease with depth in the SEA. Although the two highest percentages are for SEA 0-1 (448 percent) and SEA 0-12 (266 percent), neither of these differences is significant. This indicates that the dioxin concentrations within these EPC groups are quite variable.

These observations suggest that a large fraction of the total risk associated with exposure to chemicals in soils at the WRF expansion site is attributable to background conditions. Because a characterization of background concentrations of chemicals in soil and ground water was not performed as part of the May 2001 site characterization field program[24], a systematic approach to eliminating chemicals from the list of COPCs evaluated in the risk assessment based on comparisons with background data was not applied. Risks associated with exposure to radon gas in the breathing zone is an exception; these risks were not evaluated because the parent isotopes were not present at levels above background and the USEPA has assigned Clark County to the lowest category of predicted indoor radon concentrations.[25] Because the risks estimates presented in this assessment have not been adjusted for background levels of the COPCs, the background data summarized in Appendix E should be considered when these risk estimates are evaluated.

C. Limitations Identified in the Data Usability Analysis

Appendix F provides a discussion of the data usability analysis that was performed on the data collected during the May 2001 site characterization program. Several uncertainty issues related to data usability were identified, including the lack of calibration curves, inconsistencies between sample containers and chain-of-custody forms, the effects of holding time exceedances and elevated cooler temperatures, exceedances of laboratory QA/QC limits, and chemicals

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[24] Background conditions in soils were investigated using samples collected in April 2002, long after the site characterization sampling was completed.

[25] The USEPA category ("Zone 3") has average predicted indoor radon concentrations of less than 2 pCi/L (www.epa.gov/iaq/radon/zonemap.html).

detected in blank samples. ENVIRON attempted to include all data in the risk assessment, when possible, through the application of the comprehensive data usability process. Based on the results of the data usability analysis, very little data was determined to be unusable. The greatest source of data elimination was detection of chemicals in blanks. This elimination of chemicals, however, was limited to known laboratory contaminants (methylene chloride and acetone) that were not expected to be significant contributors to risk at the site. Thus, it is unlikely that the elimination of these chemicals, if unwarranted, represents a significant concern.

D. Uncertainties in the Dose-Response Assessment

In the majority of risk assessments, as in this risk assessment, available scientific information is insufficient to provide a thorough understanding of all the toxic properties of chemicals to which humans are potentially exposed. It is generally necessary, therefore, to infer these properties by extrapolating them from data obtained under other conditions of exposure, generally in laboratory animals.

Experimental animal data have been relied upon for many years by regulatory agencies and other expert groups for assessing the hazards and safety of human exposure to chemicals. This reliance has been supported in general by empirical observations. There may be differences in chemical absorption, metabolism, excretion, and toxic response, however, between humans and the species for which experimental toxicity data are generally available. Uncertainties in using animal data to predict potential effects in humans are introduced when routes of exposure in animal studies differ from human exposure routes, when the exposures in animal studies are short-term or subchronic, and when effects seen at relatively high exposure levels in animal studies are used to predict effects at the much lower exposure levels found in the environment. The methods for dealing with these uncertainties in the toxicological assessments for noncarcinogens and carcinogens are discussed below.

1. Uncertainties in the Characterization of the Toxicity of Noncarcinogens

To adjust for uncertainties such as those discussed above, USEPA and other regulatory agencies typically base the RfD (or other expression of the acceptable daily intake) for noncarcinogenic effects on the most sensitive animal species, i.e., the species that experiences adverse effects at the lowest dose. This dose is then adjusted by the use of safety factors or uncertainty factors to compensate for the lack of knowledge regarding interspecies extrapolation and to guard against the possibility that humans may be more sensitive than the most sensitive experimental animal species tested. The resulting toxicity factor incorporates a substantial margin of safety, although the actual size of this safety margin cannot be quantified with any certainty.

2. Uncertainties in the Characterization of the Toxicity of Carcinogens

For many substances that are carcinogenic in animals there is uncertainty as to whether they are also carcinogenic in humans. While many substances are carcinogenic in one or more animal species, only a few substances are known to be human carcinogens. The fact that some chemicals are carcinogenic in some animals but not in others raises the possibility that not all animal carcinogens are human carcinogens as well as the possibility that not all human carcinogens are animal carcinogens. The finding that relatively few substances are known human carcinogens may be due in part to the difficulty in conducting adequately designed epidemiological investigations in exposed human populations. Regulatory agencies generally assume that humans are as sensitive to carcinogens as the most sensitive animal species. In addition, there are several mathematical models available to derive low-dose unit risks from high exposure levels used in experiments. The model used by USEPA is the linearized multistage model, which generally provides the most conservative estimate of risk at low doses (i.e., highest risk/dose). The lack of knowledge regarding the validity and accuracy of this model, however, contributes to uncertainties in cancer risk estimates.

For suspected carcinogens, the normal procedure used by USEPA is to use the 95 percent upper confidence limit estimated by the linearized multistage model. Use of the 95 percent upper confidence limit value, rather than the unit risk that represents the maximum likelihood estimate, provides an estimate of the upper boundary on risk according to USEPA (1989).

3. Chemicals Without Toxicity Values

For a very limited number of chemicals, no toxicity values were available to allow the estimation of risk based on predicted exposure levels. The chemicals for which toxicity values are not available include magnesium, thorium, alpha and gamma-chlordan, endosulfan II, endosulfan sulfate, endrin aldehyde and endrin ketone. For the pesticides without toxicity values, surrogate toxicity values for similar pesticides were used in the risk assessment. Specifically, the toxicity values for chlordane were used as a surrogate for alpha and gamma-chlordane, the toxicity values for endrin were applied for endrin aldehyde and endrin ketone, and the toxicity values for endosulfan were used for endosulfan sulfate and endosulfan II. The use of surrogate toxicity values introduces some uncertainty regarding the actual risk associated with these compounds. The direction of bias (over- or underestimation of risks) is not known, however.

Magnesium and thorium were eliminated altogether from the quantitative assessment of risks. Although this may reduce the total estimate of risks, it is unlikely that these metals pose a significant concern to human health. For example, the Recommended Daily Allowance (RDA) for magnesium is 6 mg/kg bw-day. The most

sensitive population of those evaluated in this assessment would be the trespassing child (due to body weight), for which the magnesium RDA is equivalent to 186 mg/day (i.e., 6 mg/kg bw-day x 31 kg bw). Even if such an individual were to be exposed to the maximum detected magnesium concentration in soil at the site (79,500 mg/kg), the resulting exposure (approximately 8 mg/day) would be more than 20 times below the RDA. Thus, exposure to magnesium in soil at the site does not pose a concern. Very limited information on the toxicity of thorium exists; however, given that this chemical is evaluated in this assessment amongst the radionuclides, it is unlikely that risks posed by thorium, if any, are being overlooked.

In addition, several of the toxicity values used in the risk assessment are considered "provisional," because USEPA is in the process of reviewing the scientific data on these chemicals. Currently, the provisional toxicity values represent the best estimate of toxicity for these compounds. It cannot be determined, however, whether the use of these provisional values represents an under- or over-estimation of risks.

4. Uncertainties in the Assessment of Chemical Mixtures

The Hazard Index (HI) approach for the noncarcinogenic effects of chemicals assumes that multiple sub-threshold exposure could result in an adverse effect and that a reasonable criterion for evaluating the potential for adverse effects is the sum of the hazard quotients for individual chemicals. This methodology, however, is most appropriately applied to substances that induce the same effect on the same organ. Therefore, to the extent that toxic effects of the chemicals of potential concern are not additive, the HI approach is likely to result in an overestimate of potential risk. As noted in the risk characterization section, the potential for adverse noncancer effects is associated almost entirely with one chemical (perchlorate in ground water). Thus, the uncertainty associated with this issue does not represent a significant concern for this assessment.

Cancer risks for multiple chemical exposures are assumed to be additive. As noted by USEPA (1989), there are several limitations to this assumption of additivity. One of these limitations arises from the fact that risks are based on unit cancer risks that are derived as upper 95th percentiles of the probability distributions of cancer potency. Because upper 95th percentiles of probability distributions are not strictly additive, the total cancer risk estimate can become artificially more conservative as risks from a number of carcinogens are added. Secondly, the approach routinely applied in cancer risk assessment treats all carcinogens equally, regardless of the weight-of-evidence class to which a carcinogen is assigned. Each class is given equal weight; known carcinogens (Class A) are considered equal to probable and possible carcinogens (Classes B and C) in the summation of risks. Finally, the mechanism of action of any two carcinogens may

not be the same and, in fact, might be independent. The cumulative risk estimates provided in this assessment are based on the assumption that mechanisms of action are similar. This assumption may not be entirely valid and may overestimate risks.

It is also assumed that mixtures of chemicals do not act antagonistically or synergistically. The combined risk of antagonistic chemicals is expected to be less than the sum of the individual risks; whereas, the total risk from synergistic chemicals would be greater than the sum of the individual risks. Data to assess quantitatively these types of interactions, however, are not available. To this end, cancer risks may be over- or underestimated by the approach applied here.

E. Uncertainties and Variabilities in the Exposure Assessment

In any risk assessment, a large number of assumptions must be made to assess the magnitude of human exposure. In conducting an exposure assessment, it is necessary to develop assumptions about general characteristics and potential behavior patterns for exposed populations. In this risk assessment, reasonable maximum exposure doses were estimated in order to provide a reasonable upper-bound estimate of possible exposure and risk. The reasonable maximum dose represents an estimate of exposure for the upper end of the distribution, but not above the maximum possible value. This methodology is generally consistent with USEPA guidance and is not expected to underestimate actual risks within the exposed population.

For certain exposure assumptions there is little or no guidance; therefore, ENVIRON estimated values that are believed to be reasonable. For example, exposure to ground water by a maintenance worker, who periodically excavates to below ground water level, and a construction worker, who maintains the dewatering pipeline is based on an incidental ingestion rate of 5 mL per event. USEPA does not provide any guidance for estimating exposure such as this; however, USEPA (1989) provides an estimate that an individual who is swimming will ingest approximately 50 mL per event. It would seem reasonable to assume that swimming would result in significantly greater ingestion of water than an activities such excavation and maintaining a dewatering pipeline. In addition, the exposure frequency for a maintenance worker exposed to ground water is highly uncertain. The risk assessment assumes an exposure frequency of 1 day per year over an exposure duration of 25 years for dermal contact with and incidental ingestion of ground water. Although in any one year, this exposure frequency could be exceeded, ENVIRON believes that over the period of 25 years and given the current depth to ground water, such an assumption is reasonable (i.e., 25 incidents of contact with and ingestion of ground water over the period of employment). Furthermore, this exposure scenario does not take into consideration the rotation of workers, which is likely to occur (as discussed in Section 4, below). Excavation activities, if conducted, would be performed while an individual is on the "maintenance" rotation, which occurs for six months out of every three years. If the worker

rotation is considered, an individual could be exposed six days per year during the 4.16 years spent in the maintenance rotation (of the total 25 years) and still receive equivalent exposure as assumed in this assessment.

Data are available to estimate the variability of several exposure factors, such as inhalation rate, soil ingestion rate, and body weight, for example. USEPA-suggested values representing the upper bound values have been used in this assessment; therefore, these factors are sufficiently conservative. Limited data are available, however, to characterize the variability associated with such factors as exposure time and frequency (e.g., the number of times and duration a child will trespass on-site), surface area of skin exposed, and the exposure duration (e.g., length of time residents live near the site). Therefore, there is significant uncertainty associated with the use of these values in the exposure assessment. It is expected, however, that by incorporating values for several factors that are believed to be toward the upper bound of possible values, a reasonable maximum estimate will result. Estimates of reasonable maximum exposure and risk, therefore, are expected to be conservative.

1. Additional Exposure Scenarios

Although it is possible that individuals not included within the exposure scenarios evaluated in this risk assessment could be exposed to chemicals at or from the site, it is believed that the most significant pathways of exposures are evaluated in this assessment. The possible exception to this is an individual, such as a utility worker, who could be exposed to soil and ground water at the site during a brief period of contract work. Such contract work would likely result in exposure to soil and ground water to a greater extent than a maintenance worker but to a lesser extent than construction workers. Thus, for the purposes of this assessment the "utility" worker is treated as a subset of the construction worker scenario (with lower exposure and risk) and is not evaluated separately.

2. Uncertainties Associated with Additive Exposure Scenarios

The exposure scenarios in this assessment were evaluated as individual scenarios. It was not assumed that a member of one group could also be a member of another group. This assumption is reasonable for many of the exposure scenarios evaluated in this assessment; however, for certain combinations, it is possible that an individual could be exposed by two different scenarios. The most likely combination of exposure is an off-site resident who also works as a construction worker, maintenance worker, or indoor worker at the site. As indicated by the risks estimated for these scenarios, however, the contribution of off-site exposure to an on-site worker exposure scenario is almost negligible, assuming an individual worked at the site and lived nearby. The possible exception to this is the combination of an individual who is a construction worker in the southern exposure area at the site and is subsequently a worker at the site (maintenance or

indoor worker) or is involved in the future construction in the northern exposure area. Certain combinations of activities could result in lifetime cancer risk of greater than 1 x 10^{-6}. For example, a WRF construction worker in the southern exposure area who is subsequently a maintenance worker at the site (for 25 years, without rotating to other positions) would have an estimated excess lifetime cancer risk of up to 2.9 x 10^{-6}. As indicated previously, however, these estimates of risk are based on numerous conservative assumptions and include the risks associated with background concentrations. Combining such estimates of risk would increase the conservatism of the combined estimate. Thus, actual risks to individuals who may be members of more than one exposure group are still believed to be acceptable.

3. Uncertainties Associated with Dermal Absorption of Metals

The evaluation of potential exposure and risk associated with dermal contact to metals in soil is limited in this assessment to arsenic and cadmium, based on USEPA (2001a) guidance that indicates that insufficient data are available to estimate dermal absorption factors for metals other than arsenic and cadmium. It is possible, however, dermal contact with some or all of these excluded metals could result in exposure and risk through this pathway. Thus, the risks associated with dermal contact with soil could be underestimated. To evaluate this possible underestimation, ENVIRON compared the noncancer HQ values for the soil ingestion and dermal contact pathways for arsenic and cadmium for the WRF construction worker in the southern exposure area (most of the metals excluded from the dermal contact with soil pathway are noncarcinogens; thus, this comparison is most relevant). For arsenic, the HQ value for soil ingestion is approximately six times higher than the HQ value for dermal contact with soil, and for cadmium the ingestion HQ value is more than 8 times higher than the HQ value for dermal contact. The sum of the HQ values for the soil ingestion pathway for the metals not evaluated by the dermal contact pathway is approximately 0.1. Assuming that the same ratio derived for arsenic applies to these metals, the sum of the HQ values for the dermal contact with soil pathway would be less than 0.02 for the excluded metals. Such an increase in risk would have an insignificant effect on the total estimated HI value for this scenario. These same conclusions should apply to all of the exposure scenarios for which dermal contact with soil was evaluated.

4. Uncertainties Associated with Exposure to Soil by a Maintenance Worker

The magnitude of exposure to soil at the WRF expansion site by a maintenance worker in the northern and southern exposure areas is highly dependent on a variety of site-specific factors, including the fraction of soil ingested that is derived from the site (the "FI factor"), the amount of pavement that is present, and the bioavailability (BA) of

the chemicals present in soil. For the purposes of this assessment, the FI factor for the maintenance worker scenarios was assumed to be 1.0. It is likely, however, that the actual fraction of soil ingested by a maintenance worker that is from the WRF expansion site is less than 100 percent (i.e., the actual FI value is likely to be less than 1.0) due to the extensive presence of pavement at the site and the significant amount of time that workers at the site are required to spend indoors and off-site. The effect of pavement is difficult to evaluate given the significant uncertainties regarding the construction and maintenance worker activities. However, significant information is available to estimate a representative FI factor. Specifically, the City of Henderson Utilities Services Department (USD), which operates the current WRF and will operate the proposed WRF expansion, rotates its maintenance workers on a six-month basis through six different activities[26], some of which are not located on the WRF expansion site. The six activities that are conducted by workers within the USD and the fraction of time outdoors at the WRF site associated with each activity are summarized in Table 59. Based on USD policy, an individual spends six months conducting one activity before being rotated to a new activity. Over the course of a career, an individual will spend approximately equal time in each of the six activities. Based on the estimates provided in Table 59, approximately 27% of an individual's time will be spent outdoors at the WRF expansion site (i.e., the average of the six values cited in Table 59).

TABLE 59
Maintenance Worker Activity Rotation Information Used to Estimate the FI Value

Maintenance Activity	% of Time Spent Outdoors at the WRF Expansion Site	Comment
WRF Process Control	88%	USD personnel estimate that this activity requires 7 of 8 hours per day of outdoor work at the WRF site
Solids control	25%	This activity is primarily indoors, but may require 2 hours per day of outdoor work at the WRF site
Sampling	25%	This activity is conducted at several locations operated by USD. USD personnel estimate that 25% of the sampling will be conducted at the WRF expansion. The remainder of the activity will be conducted off-site.
Lift station/pumping station maintenance	0%	This activity is not associated with the WRF expansion site.
Maintenance (throughout Utilities Services Dept.)	25%	This activity is conducted at several locations operated by USD. USD personnel estimate that 25% of the activities will be conducted at the WRF expansion. The remainder of the time will be spent at other USD facilities.
Satellite WRF	0%	This activity is performed at a separate WRF facility.

[26] The USD does not maintain a written policy but has provided ENVIRON with a summary of the policy in a letter (Appendix K). This policy has been in effect for at least 8 years.

An analysis was conducted to evaluate the effect of varying the FI factor and bioavailability on the estimated risks to the maintenance worker in the southern exposure area, as indicated in Table 60. The FI factor was varied between 1.0 (as applied in the risk assessment) and 0.27 (as discussed above). The value of BA for arsenic was varied between 1.0 and 0.25 (as applied in the risk assessment). Even under the worst-case assumption (FI = 1 and BA = 1) the total chemical cancer risk to the maintenance worker is 3.7×10^{-6}. Alternatively, if the FI and BA are set at reasonable values of 0.27 and 0.25, respectively, the total risk to the maintenance worker is 9.8×10^{-7}.

TABLE 60
Variation of Cancer Risk Estimates for an SEA Maintenance Worker Based on Fraction of Soil Ingested (FI) and Arsenic Bioavailability (BA)

Risk Estimate	Values of FI and BA Factors			
	FI = 1 BA = 1	**FI = 1 BA = 0.25**	**FI = 0.27 BA = 1**	**FI = 0.27 BA = 0.25**
Soil Ingestion Risk	3.1×10^{-6}	1.1×10^{-6}	8.3×10^{-7}	3.1×10^{-7}
Total Risk	3.7×10^{-6}	1.8×10^{-6}	1.5×10^{-6}	9.8×10^{-7}

Notes:
FI – fraction of soil ingested from WRF
BA – bioavailability of arsenic in soil

F. Uncertainties Associated with Exposure to Radionuclides

Many of the sources of uncertainty that affect the estimation of risks associated with radionuclide exposure are the same as those that affect the assessment of chemical risks, including uncertainties associated with the estimation of environmental media concentrations, fate and transport modeling, and exposure assessment. These sources of uncertainty were discussed previously and are not repeated here. Several other sources of uncertainty, however, differ significantly between chemicals and radionuclides. For example, many of the toxicological uncertainties associated with chemicals do not apply to radionuclides. The toxicology of radionuclides is better understood than the toxicology of chemicals and the toxicity values are based on more reliable data (i.e., human exposure for radionuclides vs. animal studies for most chemicals). Thus, the uncertainties associated with the toxicology of radionuclides is unlikely to affect the results of this assessment significantly.

The greatest source of uncertainty, which likely outweighs all other sources in this risk assessment, is the contribution of background levels of radionuclides in soil and ground water. Based on the background soil sampling data collected by ENVIRON in April 2002, it appears that the concentrations of radionuclides in soil at the site generally represent background levels, with a few exceptions. Nonetheless, the estimated risks developed in this assessment for

radionuclides include the risk associated with naturally occurring radionuclides and from anthropogenic sources; therefore, the risk estimates are conservative.

G. Tentatively Identified Compounds

The laboratory analysis of samples collected at the WRF expansion site included the identification of tentatively identified compounds (TICs). TICs are compounds that are not included on the analytical target compound list typically analyzed by a laboratory. The possible presence of these additional compounds is indicated on the output of the analytical equipment used by the laboratory, generally in the form of peaks on a chromatogram. The laboratory uses a computerized search to match the peaks to known peaks from an electronic library to determine the most likely compound associated with the peaks. However, the actual identity, and to a greater degree, the concentration of the identified compound is highly uncertain. In fact, USEPA (1989) indicates that such estimates of concentrations may be "orders of magnitude" higher or lower than the actual concentration.

Table 61 provides a list of the TICs that were identified by Severn Trent Laboratory as part of the site characterization program conducted by ENVIRON in May 2001. Although there are numerous compounds identified, only a limited number were detected in more than a limited number of samples. The more frequently identified TICs, as indicated in Table 61, include 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 2,4-dimethylheptane; 4-hydroxy-4-methyl-2-pentanone; and cis-1,3-dimethylcyclohexane. The 1,1,2,2-tetrachloroethane and 1,1,2-trichloroethane are likely misidentifications because these compounds are included on the target analyte list for the method and were not detected in any of the samples from the site. There are no toxicity values for the other three compounds. In addition, USEPA (1989) recommends that where no site-specific information is available to indicate the TICs are site-related and only few TICs are present, it is not necessary to include the TICs in the risk assessment. Thus, no quantitative estimate of potential risks associated with TICs was developed.

H. Uncertainties Associated with the Asbestos Risk Assessment

The asbestos risk estimates may be subject to a number of uncertainties and limitations. Many of the potential sources of uncertainty discussed in this chapter of the risk assessment report are applicable to the asbestos risk estimates. For instance, the asbestos risk estimates are based on elutriator analysis of seven composite samples, which were formed from grab samples of surface soil collected at 26 locations. It is possible that the data obtained from these samples do not provide an accurate estimate of the mean concentration of asbestos in dust that may be generated from soils at the WRF expansion site. This possibility has been addressed by developing upper bound estimates of the asbestos concentrations. Another relevant source of uncertainty is the use of mathematical models to simulate the emission and dispersion of dust during and after the WRF construction period. As explained in Section A.3 of this chapter, the

TABLE 61 Summary of Tentatively Identified Compounds in Soil and Ground Water Concentrations in Units of mg/kg				
	# of Detections	Minimum Detect	Maximum Detect	Average of Detects
Tentatively Identified Compounds in Soil				
(e)-4-Methyl-2-pentene	6	0.16	0.63	0.40
(z)-4-Methyl-2-hexene	1	0.27	0.27	0.27
(z)-9-Octadecenamide	5	0.3	1.1	0.63
1,1,2,2-tetrachloroethane	60	0.14	0.61	0.25
1,1,2,2-tetramethylcyclopropane	2	0.71	0.81	0.76
1,1,2-trichloroethane	49	0.15	0.48	0.31
1,15-Hexadecadiene	1	1.8	1.8	1.80
1,2,3,5-Tetramethyl benzene	1	0.25	0.25	0.25
1,4-Dichlorobenene-d4	1	0.24	0.24	0.24
1,4-Pentadien-3-ol	1	0.8	0.8	0.80
1-Decene	1	0.16	0.16	0.16
1H-Imidazol-2-amine	1	0.82	0.82	0.82
2,3,3-trimethyl-1-butene	1	0.58	0.58	0.58
2,3,4,5-Tetrahydro-pyridine	1	0.9	0.9	0.90
2,3,5-Trimethyl hexane	2	0.19	0.22	0.21
2,3-Dimethyl-1-butene	4	0.16	1.9	0.74
2,3-Dimethyl-2-butene	1	0.19	0.19	0.19
2,4-Dimethyl heptane	62	0.14	0.31	0.20
2,4-Dimethyl hexene-1	1	0.29	0.29	0.29
2,5-Dimethyl-2-hexene	3	0.38	0.62	0.54
2-Acetyl-4,8-decadienoic acid	1	0.16	0.16	0.16
2-Fluoro-1,1'-biphenyl	1	0.18	0.18	0.18
2-Fluorophenol	1	1.3	1.3	1.30
2-Methyl-2-heptene	2	0.15	0.15	0.15
2-Methyl-2-pentene	1	0.21	0.21	0.21
2-Methyl-3-butyn-2-ol	2	2.1	2.3	2.20
2-Methyl-e-2-propenoic acid	1	0.43	0.43	0.43
3,3-Dimethyl-1-butene	5	0.3	1.8	1.14
3,3-Dimethyl-1-pentene	3	0.18	0.26	0.21
3,4-dimethyl-1-pentyn-3-ol	2	0.16	0.63	0.40
4-Hexen-3-one	1	0.3	0.3	0.30
4-hydroxy-4methyl-2-pentanone	78	0.2	8.9	5.33
4-Methyl pentanamide	1	0.19	0.19	0.19
4-Methyl-2-pentene	4	0.18	0.66	0.42
4-Methyl-2-pentene, (z)-	3	0.25	0.36	0.31
4-Methyl-3-heptanone	1	0.17	0.17	0.17
4-Trifluoroacetoxyoctane	1	0.54	0.54	0.54
9,12-Octadecadienoic acid (z,z)	1	1.4	1.4	1.40

TABLE 61 Summary of Tentatively Identified Compounds in Soil and Ground Water Concentrations in Units of mg/kg				
	# of Detections	Minimum Detect	Maximum Detect	Average of Detects
Acenaphthene-d10	1	0.14	0.14	0.14
Benzene, 1,1'-sulfonylbis (4-chlorobenzene)	3	0.49	2.4	1.60
Benzene-d5-, nitro	1	0.17	0.17	0.17
Cholesterol	1	0.48	0.48	0.48
Cis 1,3-dimethyl cyclohexane	32	0.14	0.25	0.19
Cis 1,4-dimethylcyclohexane	2	0.2	0.21	0.21
Dicyclohexyl propanedinitrile	3	0.61	0.97	0.80
Dodecanamide	1	0.83	0.83	0.83
Glycocyanidine	1	0.3	0.3	0.30
Heneicosane	1	0.33	0.33	0.33
Hexadecanamide	2	0.15	0.26	0.21
Hexanoic acid	1	0.71	0.71	0.71
Homomenthyl salicylate	2	0.14	0.3	0.22
Methyldipropyl borane	1	0.41	0.41	0.41
N-hexadecanoic acid	1	0.62	0.62	0.62
Naphthalene-d8	1	0.38	0.38	0.38
Octadecanoic acid	1	0.26	0.26	0.26
Tetratriacontane	2	0.18	0.32	0.25
Tricyclo[4.2.2.2(2,5)]dodecan-	1	0.35	0.35	0.35
Trimethylproply silane	1	0.69	0.69	0.69
Trimethylpropyl silane	2	0.47	0.53	0.50
Tritetracontane	1	0.15	0.15	0.15
Unknown	1	0.0069	0.0069	0.01
Valproic acid	1	0.51	0.51	0.51
Unknown	2	0.0061	0.0071	0.01
Tentatively Identified Compounds in Ground Water				
Unknown	2	0.061	0.062	0.06

models used in this study are considered to be highly conservative. Additional sources of uncertainty that may be relevant to the asbestos risk estimates include uncertainties in the dose-response assessment and in the exposure parameters. As explained in Sections D and E of this chapter, these uncertainties are addressed by using conservative procedures and parameter values.

The asbestos data have been used to estimate risks without regard to the possibility that some or all of the asbestos fibers observed by the laboratory are present due to background conditions. Furthermore, the risk estimates are based on the assumption that the tremolite fibers are asbestiform although the laboratory indicates otherwise. The actual number of fibers observed is only seven (four tremolite and three chrysotile). The laboratory report indicates that the morphology of the tremolite fibers was consistent with cleavage fragments rather than asbestiform material. Tremolite is the only form of amphibole found in the elutriator analysis, and the highest asbestos risk estimates are due almost entirely to amphiboles. A recent publication by the Agency for Toxic Substances and Disease Registry (ATSDR 2001) indicates that nonasbestiform amphibole materials are not addressed by U. S. health regulations because there is insufficient evidence that they produce adverse health effects of the same type and severity produced by chronic exposure to asbestos. This suggests that inclusion of risk estimates based on the presence of tremolite cleavage fragments may result in significant overestimation of the actual asbestos risks at the WRF site. On the other hand, the toxicological properties of cleavage fragments that qualify as protocol structures for the risk assessment method described by Berman and Crump (1999) on the basis of their geometry may not differ significantly from those of asbestiform structures of the same size and mineralogy (Berman, personal communication). Another point to be considered is that the scientific literature (e.g., Smith 1982, 1986) indicates that amphibole is present in some of the rocks found in the River Mountains to the east of the site. The native soils at the site are derived from alluvial fan deposits that originate in these mountains, so amphiboles (which may or may not include tremolite and asbestiform material) may be present naturally.

In light of these uncertainties, it seems likely that the actual risks associated with exposure to asbestos at the WRF expansion site are considerably lower than the estimates provided in this report. The degree to which these risks have been overestimated cannot be determined with the information that is currently available.

XI. CONCLUSIONS

This risk assessment presents a thorough characterization of the risks to human health associated with the planned expansion of the WRF. Other exposure and risk related issues are also addressed. The information in this report is presented as a basis for making risk management decisions. The principal question addressed by this study is whether the risks associated with exposure to chemicals at the site are low enough to allow construction and subsequent operation of the WRF expansion to proceed as planned. This risk management decision will be made by the NDEP.

This Conclusions chapter summarizes the risk estimates developed in this report and discusses their significance to assist the NDEP in making its decision. The adequacy of the site characterization as a basis for decision-making is addressed in this context. Other issues that are relevant to the decision-making process are also discussed.

A. Human Health Risks

1. Chemical and Radionuclide Risks

The potential risks associated with exposure to chemicals and radionuclides in soil and ground water at the WRF expansion site were evaluated for eleven scenarios, including three populations potentially exposed during the construction of the WRF expansion (construction workers, off-site residents, and off-site workers) and eight populations that could be exposed after construction of the WRF expansion is completed (trespassing children, maintenance workers in the northern and southern exposure areas, on-site indoor workers in the northern and southern exposure areas, construction workers in the northern exposure area, off-site residents, and off-site workers). A summary of the cumulative cancer and noncancer risks for the identified populations is provided in Table 62.[27] Several conclusions can be drawn from a review of Table 62:

- The highest chemical cancer risk is estimated for a future maintenance worker in the southern exposure area. The estimated cancer risk for this population is 2×10^{-6}. Estimated cancer risks for the WRF construction worker in the southern exposure area and the maintenance worker in the northern exposure area are 1×10^{-6}. The risks for these scenarios are based on a series of highly conservative assumptions. Actual risks are likely to be significantly below 1×10^{-6}.

[27] Cumulative cancer risks for chemicals and asbestos combined are provided in Table 63.

TABLE 62
Summary of Estimated Cancer Risks and Noncancer HI Values

Time Frame	Exposure Scenario	Chemical		Asbestos		Radionuclides
		Estimated Cancer Risk	Estimated Hazard Index	Upper-bound Cancer Risk	Average Cancer Risk	Estimated Cancer Risk
During WRF Construction	WRF Construction Worker (Southern Exposure Area)	1×10^{-6}	3.8	1×10^{-6}	3×10^{-7}	5×10^{-5}
	Off-site Resident	8×10^{-8}	0.3	7×10^{-8}	3×10^{-8}	2×10^{-9}
	Off-site Worker	5×10^{-8}	0.2	2×10^{-8}	7×10^{-9}	3×10^{-9}
Future (Post WRF Construction)	Maintenance Worker (Northern Exposure Area)	1×10^{-6}	0.5	3×10^{-8}	2×10^{-8}	9×10^{-5}
	Maintenance Worker (Southern Exposure Area)	2×10^{-6}	0.4	5×10^{-8}	2×10^{-8}	9×10^{-5}
	Default Construction Worker (Northern Exposure Area)	3×10^{-7}	5.7	5×10^{-6}	2×10^{-6}	2×10^{-5}
	Trespassing Child (Northern Exposure Area)	5×10^{-7}	0.3	2×10^{-9}	7×10^{-10}	1×10^{-5}
	Indoor Worker (Southern Exposure Area)	6×10^{-7}	0.2	NA	NA	8×10^{-5}
	Indoor Worker (Northern Exposure Area)	8×10^{-7}	0.3	NA	NA	8×10^{-5}
	Off-site Resident	6×10^{-7}	0.2	3×10^{-7}	1×10^{-7}	1×10^{-9}
	Off-site Worker	3×10^{-7}	0.1	5×10^{-8}	2×10^{-8}	2×10^{-9}

- Estimated chemical noncancer HI values exceed one (the risk threshold assumed in this report) for two exposure scenarios: a WRF construction worker and a future (default) construction worker in the northern exposure area. Most of the risk represented by the cumulative HI values for these populations is due to exposure to perchlorate in ground water. With the exception of an individual who maintains a dewatering pipeline, a construction worker at the site is not likely to come into contact with ground water on a routine basis. Therefore, the exposure pattern considered in this scenario is extremely conservative for the great majority of the construction workers. Exposure to ground water during pipeline maintenance activities can be eliminated through the use of appropriate PPE.

- The estimated chemical HI values for the WRF construction worker and the future (default) construction worker who are not involved in dewatering pipeline maintenance also exceed one. However, an analysis of target organ effects indicates that all of the target-organ-specific HI values for these populations are less than one, as shown in Table 34 (Summary of Estimated Chemical Hazard Index Values). Thus, adverse noncancer health effects are not expected.

- The estimated cancer risks associated with exposure to radionuclides in soil and ground water at the WRF expansion site are well below the USEPA acceptable radionuclide cancer risk level of 3×10^{-4}. Furthermore, the estimated risks appear to be almost entirely associated with background. The primary contributor to total radionuclide cancer risks (Potassium 40) is not present above background levels, based on a statistical comparison of activities in site soils to background levels. Thus, there is no concern associated with the presence of radionuclides in soil and ground water at the site.

The risk estimates presented in this report were derived using reasonable maximum exposure (RME) assumptions. With the exception of the HI values for the SEA and NEA construction workers (which can be mitigated by the use of appropriate PPE) and total cancer risk levels (chemicals and asbestos combined) for future maintenance workers at the SEA and future default construction workers in the NEA, these reasonable worst-case risk estimates are below the assumed action levels. In this sense, this risk assessment supports a decision to allow construction of the WRF expansion to proceed as planned. Such a decision would be erroneous if the actual risks exceed the levels at which the NDEP believes alternative action is necessary. This could occur if the average concentrations of the chemicals of concern at the site are significantly higher than indicated by the available data.

The adequacy of the data set to support a decision to allow construction to proceed is characterized by the probability of decision error. In this context, the probability of decision error is the likelihood that the actual mean concentrations exceed the concentrations that correspond to the cumulative action levels. The data adequacy analysis presented in this report identified a worst-case situation in which the probability of exceeding a cumulative action level for a specific chemical is about five percent. This exceedence probability is calculated for arsenic in the surface soils at the southern exposure area; the mean arsenic concentration in this group is not significantly greater than background. Because the exceedence probabilities calculated in this analysis are based on RME exposure patterns, the actual decision error probabilities are expected to be considerably lower. The worst-case (five percent) probability relates to a carcinogenic risk action level of 1×10^{-6}, which is the lower end of the range of acceptable risk established in the National Contingency Plan. If the NDEP decides that no further action is required before proceeding with construction of the WRF expansion project, the probability that construction workers will be exposed to chemicals in soils at levels that generate unacceptable risks is very small.

2. Asbestos Risks

All of the soil samples collected during the May 2001 site characterization program were analyzed for asbestos content by conventional PLM analyses. Because the results of the PLM analyses were all non-detect, ENVIRON was not able to perform a meaningful risk assessment for exposure to asbestos in soils at the WRF expansion site. As a result, NDEP requested that ENVIRON collect additional asbestos data and perform a more refined analysis of the asbestos content in dusts generated from site soils. ENVIRON, therefore, collected additional soil samples from the WRF expansion site on October 18, 2002.

As directed by the NDEP, the asbestos-related risks are assessed using a method described by Berman and Crump (1999). The data required by this method were generated by analyzing soil samples using the methods described by Berman and Kolk (2000). The soil samples were collected, composited, and analyzed using procedures that were discussed with and agreed to by representatives of the NDEP.

All of the asbestos-related risk estimates for exposure scenarios during the WRF construction period are much lower than the 10^{-5} risk level identified as acceptable by the NDEP in October 2002, as indicated in Table 62. The maximum risk estimate is for the WRF construction worker; the upper-bound risk estimate for this scenario is about 1×10^{-6}. This potential asbestos risk is due primarily to exposure to chrysotile asbestos in soils in the southern exposure area.

With one exception, the asbestos-related risk estimates for the post-WRF construction scenarios are less than 1×10^{-6} (i.e., below the lower end of the range of cancer risks that are considered acceptable under the National Contingency Plan). The exception is for the default NEA construction worker scenario, which is hypothetical; at present, the City of Henderson has no plans for development of the northern exposure area. The upper-bound risk estimate for this scenario is about 5×10^{-6}. Almost 100 percent of the potential asbestos-related risk for the NEA soils is associated with amphibole asbestos. As noted in the discussion of uncertainties, the laboratory report indicates that the only amphibole fibers observed during the elutriator analysis were tremolite cleavage fragments. These nonasbestiform amphibole materials are not addressed by U. S. health regulations because there is insufficient evidence that they produce adverse health effects of the same type and severity produced by chronic exposure to asbestos. Risk estimates based on the presence of nonasbestiform tremolite cleavage fragments may be significantly higher than the actual asbestos risks at the WRF site. The actual asbestos-related for the default NEA construction worker scenario may be considerably lower than the 10^{-6} threshold.

In summary, ENVIRON believes that the assessment of potential asbestos-related risks should be sufficient to allow construction of the WRF expansion facility to proceed.

3. Cumulative Risks

The asbestos risk estimates may be added to the cumulative chemical carcinogenic risk estimates derived in Chapter VII to obtain estimates of the total carcinogenic risks at the WRF expansion site. The cumulative chemical (non-radionuclide, non-asbestos) carcinogenic risk estimates are summarized in Table 62; the relevant portions of this table also appear in Table 63. Table 63 summarizes the cumulative chemical carcinogenic risk estimates, the asbestos risk estimates for the general population, and the total carcinogenic risk values obtained by adding these estimates for each scenario. When the upper bound asbestos risk estimates are used, the maximum total carcinogenic risk estimate during WRF construction is about 2×10^{-6} (for the WRF construction worker). Similarly, the maximum total carcinogenic risk estimate after WRF construction is about 5×10^{-6} (for the default NEA construction worker). Asbestos accounts for about 50 percent and 94 percent of these maximum risk estimates, respectively. If the asbestos risks are represented by the estimates for the average concentrations and the worst-case subpopulations, the maximum total risk estimates are about 1×10^{-6} and 3×10^{-6}, respectively. In this case, asbestos accounts for about 20 percent of the maximum total carcinogenic risk estimate during WRF construction and about 85 percent of the maximum total carcinogenic risk estimate after WRF construction.

TABLE 63
Total Carcinogenic Risk Estimates for the WRF Expansion Project

	Cumulative Chemical Carcinogenic Risk	Asbestos Risk* for Upper-bound Concentrations	Total Carcinogenic Risk with Upper-Bound Asbestos Risk	Asbestos Risk* for Average Concentrations	Total Carcinogenic Risk with Average Asbestos Risk
During WRF Construction					
WRF Construction Worker	9.91E-07	9.69E-07	2.0E-06	2.59E-07	1.3E-06
Off-site Resident	8.07E-08	7.19E-08	1.5E-07	2.78E-08	1.1E-07
Off-site Worker	4.54E-08	1.71E-08	6.3E-08	6.62E-09	5.2E-08
Future (Post WRF Construction)					
Trespassing Child in the NEA	5.13E-07	1.60E-09	5.1E-07	7.12E-10	5.1E-07
Maintenance Worker in the NEA	1.31E-06	3.37E-08	1.3E-06	1.50E-08	1.3E-06
Maintenance Worker in the SEA	1.85E-06	5.25E-08	1.9E-06	2.33E-08	1.9E-06
Off-site Resident	5.58E-07	2.64E-07	8.2E-07	1.17E-07	6.8E-07
Off-site Worker	2.61E-07	5.25E-08	3.1E-07	2.33E-08	2.8E-07
Default Construction Worker in the NEA	3.40E-07	5.05E-06	5.4E-06	2.24E-06	2.6E-06

Note:
* - asbestos risks for the general population developed as weighted averages of estimates for subpopulations defined by male/female and smoker/nonsmoker

In each of these calculations, the maximum total carcinogenic risk estimates during WRF construction are less than the level of 10^{-5} identified as acceptable in the NDEP's October 18 letter. Amphibole asbestos accounts for more than 90 percent of the total carcinogenic risk estimate for the default NEA construction worker, but (as noted in the preceding section) the only amphibole fibers found in the WRF samples were identified by the laboratory as nonasbestiform tremolite cleavage fragments. The toxicological properties of these cleavage fragments have not been established. This suggests that inclusion of risk estimates based on the presence of tremolite cleavage fragments may result in significant overestimation of the actual asbestos risks at the WRF site. On the other hand, the toxicological properties of cleavage fragments that qualify as protocol structures for the risk assessment method described by Berman and Crump (1999) on the basis of their geometry may not differ significantly from those of asbestiform structures of the same size and mineralogy (Berman, personal communication). If the risks associated with amphibole are not included in the asbestos risk estimates, all of the total carcinogenic risks for the post-WRF construction scenarios are less than 1×10^{-6}.

B. Other Issues

In addition to potential human health risks associated with chemicals and radionuclides in soil and ground water at the site, there are a number of other issues that need to be considered in determining whether the City may proceed with its plans to construct the WRF expansion on the site, as discussed in the following sections.

1. Potential for Impacts to Ground Water from On-site Soils

ENVIRON conducted a screening-level analysis to provide an initial indication of whether the chemicals present in soils at the WRF expansion site could also contribute to ground water degradation. This highly conservative analysis indicates that several chemicals are present in site soils at concentrations that exceed the most conservative USEPA generic soil screening levels for migration to ground water. Thus, it is possible that soils at the WRF expansion site could be adversely affecting ground water beneath the site. A more refined analysis of the possible impact of the WRF site on ground water quality will be conducted in the future. However, a complete evaluation of the potential impacts of migration of chemicals from the soil on human health and the environment should be addressed within a framework that accounts for regional ground water quality and the NDEP's associated regulatory strategy. Moreover, development of the WRF expansion site will not interfere with future investigation or remediation efforts to address existing or potential impacts to ground water, because the range of reasonable possible remediation scenarios do not include significant excavation. Thus, the potential for the

site soils to impact ground water should not affect the NDEP's decision regarding the suitability of the site for construction and operation of the WRF expansion.

2. Potential Ecological Effects

Several notable ecological habitats exist in the area around the site, including a bird preserve, Las Vegas Wash, and a wetlands area. There are several possible mechanisms for the transport of contaminants from the site to these locations, including surface water runoff/erosion, wind-blown dust, and migration through ground water. The following factors should be considered in evaluating the potential for impacts from the site on ecological populations in these habitats:

- There are no current surface water discharges from the site to the off-site habitats and none are planned for the future.

- Although chemical contamination is present in ground water, it is not clear that the site is contributing significantly to the contamination. Several metals (aluminum, iron, hexavalent chromium, and selenium) are present in ground water at levels that exceed freshwater AWQC for surface water. Therefore, it is possible that ground water flowing under the site could be adversely impacting surface water quality in the wetlands and Las Vegas Wash. As discussed previously, a refined analysis of potential leaching of chemicals from the site into underlying ground water will be conducted in the future. As part of that analysis, an evaluation of the potential ecological effects of contaminants in ground water will be conducted.

- Local dust control permitting requirements applicable to the WRF site will significantly restrict dust emissions from potential sources at the site, including construction activities, traffic on unpaved roads, and wind erosion from undeveloped areas. In fact, NDEP is requiring dust emission controls of at least 90 percent in the "Restrictions Agreement" for the site. The dust concentrations used in the risk assessment process are based on the presence of these controls. Although dust emissions will not be entirely eliminated, controls are expected to minimize the likelihood of significant impacts to off-site ecological populations.

Given these factors, the potential for adverse effects from the site on ecological populations is associated primarily with the discharge of contaminated ground water to Las Vegas Wash. These potential adverse effects are to be evaluated in the future. In the

long term, construction of the WRF expansion will reduce the likelihood of future off-site environmental impacts by reducing undeveloped acreage that acts as a source of wind-blown dust. Furthermore, the presence of the WRF will not interfere with future investigations relating to ecological populations in the off-site areas.

3. Exposure to Radon

Risks associated with exposure to radon in soils were accounted for in the radiological risk assessment by using toxicity factors for radium 226 that include the effects of short-lived decay products. Radon is a radioactive gas; the primary toxicological concern is with radon 222, which is generated by the decay of radium 226. The only exposure to radon that was not included in the risk assessment is to radon gas in the breathing zone of the potentially exposed populations. Inclusion of exposures to radon gas in the risk assessment would require the use of mathematical models to simulate the diffusion and migration of this gas from the soils in which it is generated to the breathing zones of the potentially exposed populations. The USEPA has not established standard methods for performing these analyses.

Because radium 226 is not present at levels above background in the soils at the WRF expansion site, the levels of radon that may be present are naturally occurring. The USEPA has assigned Clark County, Nevada to the lowest category of predicted indoor radon concentrations. Thus, the radon risks associated with the WRF expansion project are naturally occurring, are expected to be quite low, and should not present an obstacle to construction of the WRF expansion.

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