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RISK ASSESSMENT
HINKLEY SITE

H127093

Environmental Health Associates, Inc.

PGE0021115

Return to:
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RISK ASSESSMENT
HINKLEY SITE

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LIST OF ABBREVIATIONS

AAL	Applied Action Limit
ABS	Dermal Absorbance Rate
ACGIH	American Conference of Governmental Industrial Hygienists
ADI	Acceptable Daily Intake
AIC	Allowable Intake Chronic
BAF	Bioaccumulation Factor
BLM	U.S. Bureau of Land Management
CARB	California Air Resources Board
CNDDB	California Natural Diversity Data Base
DHS	California Department of Health Services
E&E	Ecology & Environment
EEC	Environmental Exposure Concentration
EHA	Environmental Health Associates
EPA	United States Environmental Protection Agency (USEPA)
FR	Federal Register
g/g	Gram per gram
HI	Hazard Index
HLA	Harding Lawson Associates
IARC	International Agency for Research on Cancer
ICRP	International Commission on Radiological Protection
ISCST	Industrial Source Complex Short Term Model
LADD	Lifetime Average Daily Dose
LC	Lethal Concentration
LD	Lethal Dose
LOAEL	Lowest Observed Adverse Effect Level
LOEL	Lowest Observed Effect Level

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LRWQCB	Lahontan Regional Water Quality Control Board
MCL	Maximum Contaminant Level
mg/kg	Milligram per kilogram
mg/m^3	Milligrams (thousandths of a gram) per cubic meter of air
MTD	Maximum Tolerated Dose
N_2	Nitrogen
NAAQS	National Ambient Air Quality Standard
NAS	National Academy of Science
NCI	National Cancer Institute
ng/dncm	Nanograms per dry normal cubic meter
ng/m^3	Nanograms (billionths of a gram) per cubic meter of air
NOAEL	No Observed Adverse Effect Level
NOEL	No Observed Effect Level
NIOSH	National Institute of Occupational Safety and Health
NTP	National Toxicology Program
O_2	Oxygen
OSHA	United States Occupational Safety and Health Administration
PEL	OSHA worker Permissible Exposure Limit
pg/m^3	Picograms (thousandths of a billionth of a gram) per cubic meter of air
PM_{10}	Inhalable particulate
ppb	Parts per billion
ppm	Parts per million
ppt	Parts per trillion
Rfc	Reference Concentration
Rfd	Reference Dose
TLV	Threshold Limit Value

UNAMAP	User's Network for Applied Modeling of Air Pollutants
WHR	Wildlife Habitat Relationship
WHRP	Wildlife Habitat Relationship Program

GLOSSARY OF TERMS*

Absorbed dose - The amount of a chemical that enters the body of an exposed organism.

Absorption - The uptake of water or dissolved chemicals by a cell or an organism.

Absorption factor - The fraction of a chemical making contact with an organism that is absorbed by the organism.

Acute - Occurring over a short period of time; used to describe brief exposures and effects which appear promptly after exposure

Adsorption - The process by which chemicals are held on the surface of a mineral or soil particle. Compare with absorption.

Ambient - Environmental or surrounding conditions.

Animal studies - Investigations using animals as surrogates for humans, on the expectation that results in animals are pertinent to humans.

Background level - Normal ambient environmental concentration of a chemical.

Bioaccumulation - The retention and concentration of a substance by an organism. Bioaccumulation refers to a process which includes both bioconcentration and uptake of substances from dietary sources.

Bioaccumulation Factor (BAF) - A measure of the degree to which a substance will accumulate in fish tissue as a result of contact with water, ingestion of food containing the substance, and contact with sediments containing the substances.

Bioassay - Test which is used to evaluate the effect of a chemical on a living organism.

Bioconcentration Factor (BCF) - The ratio of the amount of a chemical that will concentrate in fish tissue solely as the result of the fish swimming in and ingesting water.

Biodegradation - Decomposition of a substance into more elementary compounds by the action of microorganisms such as bacteria.

Cancer - A disease characterized by the uncontrolled growth of aberrant cells into malignant tumors.

<u>Carcinogen</u> - A chemical which causes or induces cancer.

<u>Carcinogenic potency</u> - The estimated risk of cancer per unit of administered dose.

<u>Chronic</u> - Occurring over a long period of time, either continuously or intermittently; used to describe ongoing exposures and effects that develop only after a long exposure.

<u>Chronic exposure</u> - Long-term, low-level exposure to a toxic chemical.

<u>Degradation</u> - Chemical or biological breakdown of a complex compound into simpler compounds.

<u>Demography</u> - The study of the characteristics of human populations such as size, growth, density, distribution, and vital statistics.

<u>Dermal</u> - Of the skin; through or by the skin.

<u>Dermal exposure</u> - Contact between a chemical and the skin.

<u>Dose</u> - See <u>absorbed dose.</u>

<u>Dose-response</u> - A quantitative relationship between the dose of a chemical and an effect caused by the chemical.

<u>Dose-response curve</u> - A graphical presentation of the relationship between degree of exposure to a chemical (dose) and observed biological effect or response.

<u>Environmental fate</u> - The destiny of a chemical after release to the environment; involves considerations such as transport through air, soil and water, bioconcentration, degradation, etc.

<u>Epidemiological studies</u> - Investigation of elements contributing to disease or toxic effects in human populations.

<u>Exposure</u> - Contact with a chemical or physical agent.

<u>Exposure assessment</u> - The determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, route, and extent (number of people) of exposure to a substance.

<u>Exposure level</u> - The amount (concentration) of a substance at the absorptive surfaces of an organism.

<u>Exposure scenario</u> - A set of conditions or assumptions about sources, exposure pathways, concentrations of toxic

chemicals and populations (numbers, characteristics, and habits) which aid the investigator in evaluating and quantifying exposure in a given situation.

Extrapolation - Estimation of unknown values by extending or projecting from known values.

Half-life - The length of time required for the mass, concentration, or activity of a chemical or physical agent to be reduced by one-half.

Ingestion - To take in through the mouth.

Intake - Amount of material inhaled, ingested, or absorbed dermally during a specific period of time.

In vitro studies - Studies of chemical effects conducted in tissues, cells, or subcellular extracts from an organism (i.e., not in the living organism.)

LADD - Lifetime Average Daily Dose; the amount of chemical administered to a body per unit of body weight per day averaged over an entire lifetime.

LOAEL - Lowest-Observed-Adverse-Effect Level; the lowest dose in an experiment which produced an observable adverse effect.

Metabolism - The sum of chemical reactions occurring within a cell or a whole organism; includes the energy-releasing breakdown of molecules and the synthesis of new molecules.

Metabolite - Any product of metabolism, especially a transformed chemical.

Modeling - Use of mathematical equations to simulate and predict real events and processes.

Monitoring - Measuring concentrations of substances in environmental media or in human or other biological tissues.

Mutagen - An agent that causes a permanent genetic change in a cell other than that which occurs during normal genetic recombination.

Mutagenicity - The capacity of a chemical or physical agent to cause permanent alteration of the genetic material within living cells.

NOAEL - No-Observed-Adverse-Effect-Level; the highest dose in an experiment which did not produce an observable adverse effect.

Oral - Of the mouth; through or by the mouth.

Order of Magnitude - An estimate of size or magnitude expressed as a multiple of ten. For example, two orders of magnitude (10 x 10) is 100.

Pharmacokinetics - The dynamic behavior of chemicals inside biological systems; it includes the processes of uptake, distribution, metabolism, and excretion.

Population at risk - A population subgroup that is more likely to be exposed to a substance, or is more sensitive to a substance, than the general population.

Potency - See Carcinogenic potency or unit cancer risk.

Qualitative - Descriptive of kind, type, or direction, as opposed to size, magnitude, or degree.

Quantitative - Descriptive of size, magnitude, or degree.

Receptor - In exposure assessment, an organism that receives, may receive, or has received environmental exposure to a chemical.

Retrospective study - An epidemiological study which compares diseased persons with non-diseased persons and works back in time to determine exposures.

Reversible effect - An effect which is not permanent, especially adverse effects which diminish when exposure to a toxic chemical is ceased.

Risk - The potential for realization of unwanted negative consequences or events.

Risk assessment - A qualitative or quantitative evaluation of the environmental and/or health risk resulting from exposure to a chemical or physical agent (pollutant); combines exposure assessment results with toxicity assessment results to estimate risk.

Risk estimate - A description of the probability that organisms exposed to a specified dose of chemical will develop an adverse response (e.g., cancer).

Risk factor - Characteristic (e.g., race, sex, age, obesity) or variable (e.g., smoking, occupational exposure level) associated with increased probability of an adverse effect.

Route of exposure - The avenue by which a chemical gains access to the body (e.g., inhalation, ingestion, dermal contact).

Scenario - See exposure scenario.

Subchronic - Of intermediate duration, usually used to describe studies or levels of exposure between five and 90 days.

Teratogenicity - The capacity of a physical or chemical agent to cause non-hereditary birth defects in offspring.

Threshold - The lowest dose of a chemical at which a specified measurable effect is observed and below which it is not observed.

Tissue - A group of similar cells.

Toxicity - The quality or degree of being poisonous or harmful to plant, animal, or human life.

Toxicity Assessment - Characterization of the toxicological properties and effects of a chemical, including all aspects of its absorption, metabolism, excretion, and mechanism of action, with special emphasis on establishment of dose-response characteristics.

Uncertainty Factor - A number (equal to or greater than one) used to divide into NOAEL or LOAEL values derived from measurements in animals or small groups of humans, in order to estimate a NOAEL value for the whole human population.

Unit Cancer Risk (UCR) - The estimated increased lifetime risk of cancer per unit of administered dose.

Vapor - The gaseous state of a substance that is a liquid or a solid under ordinary conditions.

Wind Rose - A circular diagram showing the relative frequency of wind directions and speeds as an annual average.

*Many of these definitions were taken from: Life Systems, Inc., 1985, Toxicology Handbook, prepared for the Office of Waste Programs Enforcement, Environmental Protection Agency.

MATHEMATICAL UNITS

The mathematical units are based on a decimal system, that is, one in which all derived units are multiples of ten. The prefixes listed below, in combination with the basic unit names, provide multiples or fractions in this system. For example, the unit "gram" with the prefix "milli-" produces milligram, meaning "one-thousandth of a gram." Values increase by orders of magnitude with increasing positive powers of ten. That is, 10^3 (or 1,000) is greater than 10^2 (or 100). However, values decrease by orders of magnitude with increasing negative powers of 10. Thus, 10^{-3} is 0.001; 10^{-2} is 0.01. The following table summarizes the principal prefixes, symbols, multiples of ten and decimal notations (values) commonly used in this report.

Mathematical units commonly used in this Report

Prefix	Symbol	Multiple	Decimal Notation
kilo	k	10^3	1000
milli	m	10^{-3}	0.001
micro	u	10^{-6}	0.000001
nano	n	10^{-9}	0.000000001
pico	p	10^{-12}	0.000000000001
femto	f	10^{-15}	0.000000000000001

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1.0 EXECUTIVE SUMMARY

1.1 INTRODUCTION

The Pacific Gas and Electric Company (PG&E), in response to Cleanup and Abatement Order No. 6-87-160 issued by the Lahontan Regional Water Quality Control Board (LRWQCB) on December 29, 1987, has retained Environmental Health Associates, Inc. and Ecology and Environment, Inc. to prepare this human health and ecological risk assessment for the Hinkley Gas Compressor Station. The risk assessment is one of four interrelated studies performed concurrently addressing various aspects of the site; in addition to this risk assessment, a site characterization, a feasibility study, and a groundwater modeling study were completed. The purpose of conducting the risk assessment is to obtain and evaluate site-specific information related to potential human health and ecological risks resulting from chromium contamination discovered in groundwater and soils near the Hinkley site. The principal goal of this assessment is to evaluate potential risks associated with three alternatives being considered for remediation of groundwater contamination identified at the site. These alternatives are described below:

- Alternative 1 - Current Irrigation Practice. This alternative involves ongoing agricultural irrigation with contaminated groundwater, combined with supply of bottled water to local residents for drinking and cooking purposes.

- Alternative 2 - Accelerated Agricultural Treatment. Additional wells would be added within the plume to accelerate chromium removal, and to manage withdrawal and application of contaminated groundwater. Bottled drinking and cooking water would also be supplied as part of this alternative.

- Alternative 3 - Domestic Water Replacement. This alternative is an extension of Alternative 1, with the addition of new residential water supplies for each of the dwellings within the plume boundary. This alternative would remove all domestic use of water including showering, dish washing and garden irrigation, which are not addressed by bottled water supply alone.

Additional ground water remediation alternatives are addressed in the feasibility study. The three alternatives evaluated in this risk assessment were selected based on the desire to evaluate the current situation as well as incremental modifications to the current situation. Other alternatives not addressed in this report involve more extensive modifications.

The risk assessment approach employed to evaluate these groundwater remediation alternatives is health-conservative, and is believed to over-estimate the true risk significantly. The analysis evaluates possibly significant environmental pathways from the groundwater to human and ecological receptors through water, air, soil and the foodchain; it addresses inhalation, oral ingestion and dermal absorption exposure routes for all potential receptors.

1.2 GROUNDWATER PROTECTION

Investigation of the original source of hexavalent chromium groundwater contamination leads to the conclusion that chromium is no longer entering the groundwater. Based upon the results of physical and chemical tests, hexavalent chromium is no longer of concern in soils, and trivalent chromium which is present will not be transported to groundwater. In the near term, proposed extraction of groundwater with subsequent irrigation treatment will reduce the groundwater concentrations of hexavalent (and total) chromium to zero, or to concentrations below the state/federal drinking water standard. Groundwater in the vicinity of the Hinkley Compressor Station is therefore no longer being contaminated, and will be restored to acceptable conditions under the contemplated remedial alternatives.

1.3 HEALTH RISKS

Health risks which might result from domestic and other use of local groundwater during remediation have been estimated for the three groundwater remedial alternatives introduced above. Both cancer and noncancer effects have been evaluated. Noncancer health effects are extremely unlikely under all three groundwater remediation alternatives. Zero cancer effects are theoretically impossible because the analytic approach employs the assumption that cancer risks exist for all levels of exposure greater than zero (the health-conservative "no threshold" approach). The estimated cancer risks for the three remedial alternatives are shown in Table 1-1. The table shows cancer risks corresponding to two different hexavalent chromium cancer potencies: 42 $(mg/kg\text{-}day)^{-1}$ and 91 $(mg/kg\text{-}day)^{-1}$. The lower potency is that employed by the U.S. Environmental Protection Agency in its regulatory decision making regarding remedial actions. The higher potency value of 91 $(mg/kg\text{-}day)^{-1}$ is a health-conservative estimate, based upon all the known uncertainty factors in the epidemiological data from which these chromium potencies have been derived. It is the 95% upper confidence limit for a value lying in the potency range promulgated by the California Department of Health Services.

Risk management decisions and designs of remedial strategy historically have been made by regulatory agencies based upon three criteria:

- the additional risk to the maximally exposed individual;
- the expected additional cancer burden in the exposed population; and
- the cost of increased remediation.

Federal regulatory agencies have required remedial action only when cancer risk to the maximally exposed individual exceeds 10- to 100-in-a-million and when the expected number of additional cancers in the exposed population exceeds one. California regulatory agencies require remedial action when the individual risk exceeds 1- to 10-in-a-million or the expected number of cancers in the exposed population exceeds one.

Remedial Alternative	Cancer Risk To Maximally Exposed Individual (per million)		Expected Cancers in Exposed Population		Cancer Risk to Other Individuals Near Plume (per million)	
	q_1^* (mg/kg-day)$^{-1}$		q_1^* (mg/kg-day)$^{-1}$		q_1^* (mg/kg-day)$^{-1}$	
	42	91	42	91	42	91
1) Current Irrigation Practice	6	13	0	0	2-5	5-11
2) Accelerated Agricultural Treatment	1	2	0	0	0.5-0.8	1-2
3) Domestic Water Replacement (Extension of Alternative 1)	2	5	0	0	0.05-2	0.1-4

Table 1-1
ESTIMATED ADDED LIFETIME CANCER RISK FOR GROUNDWATER REMEDIAL ALTERNATIVES

For all three groundwater remediation alternatives evaluated here, no additional cancers are expected in the exposed population. Maximum individual risk for all alternatives was estimated to fall below the federal regulatory agency guidelines for both cancer potencies. Only Alternative 1 fell above the range of guidelines practiced in California, for the larger cancer potency.

1.3.1 Alternative 1 - Current Irrigation Practice

In Alternative 1, the analysis estimates that the lifetime cancer risk to the maximally exposed individual is 6 to 13-in-a-million, depending upon the cancer potency used. This is below the federal regulatory agency remedial action level and under these guidelines further remedial action would not be required. It is within the California regulatory agency range of action levels for the lower potency factor. Also shown in Table 1-1 are lifetime cancer risks to other exposed individuals living or working near the center of the groundwater plume. These risks are seen to vary to significantly lower values than those for the maximally exposed individual.

1.3.2 Alternative 2 - Accelerated Agricultural Treatment

In Alternative 2, maximum individual risk is estimated to be 1 to 2-in-a-million, again below the federal regulatory agency guidelines and within the California range of guidelines. Additional remedial action is therefore not indicated. Again estimated risks for other exposed individuals can be significantly less under this alternative.

1.3.3 Alternative 3 - Domestic Water Replacement

Individual cancer risk for the third remedial option is estimated to be 2 to 5-in-a-million, depending upon the cancer potency factor employed. This alternative also meets both federal and state regulatory agency remedial action levels. Risks estimated for other exposed individuals can be significantly less than those for the maximally exposed individual under this alternative.

1.4 ECOLOGICAL RISKS

Ecological risks have been evaluated for soil (microflora and infauna), flora and fauna. Risks to soil are not expected to be significant under any alternative except for microflora at one limited on-site area (area C), where soil remediation is being evaluated in the feasibility study. Risks to fauna are likewise expected to be insignificant (evaluated for the Mojave ground squirrel, California vole, desert tortoise, desert cottontail rabbit, badger and cow).

The assessment of risk to flora indicates that impacts upon some crops grown in agricultural soils are possible, but that crops such as alfalfa should not be affected. Field observations confirm that alfalfa grown in the study area is not adversely affected by current irrigation practices. The assessment also indicates that impacts upon individual plants in family garden plots, while not presently occurring, are possible under remediation Alternatives 1 and 2 (which provide bottled drinking and cooking water only), but not under Alternative 3.

1.5 CONCLUSIONS

The risk assessment reported here is believed to overestimate risks significantly. Based upon this conservative assessment the following conclusions may be drawn.

1. Groundwater quality critical to the protection of local human and ecological health will be achieved and maintained under all of the remedial alternatives considered.
2. Estimated health risks possibly resulting from the hexavalent groundwater plume near the Hinkley Compressor Station are not significant for any of the evaluated remedial Alternatives under federal regulatory agency practices. Only for Alternative 1 might they not meet California regulatory agency guidelines.

3. Ecological risks to soil are possible under all three alternatives only in a limited on-site area; soil remediation is anticipated for this area. Some agricultural species other than alfalfa may be at risk under all three alternatives. Individual family garden plants may be at risk under Alternatives 1 and 2, but not under Alternative 3. Because of the conservatism of the risk assessment, these possible ecological risks may not exist.

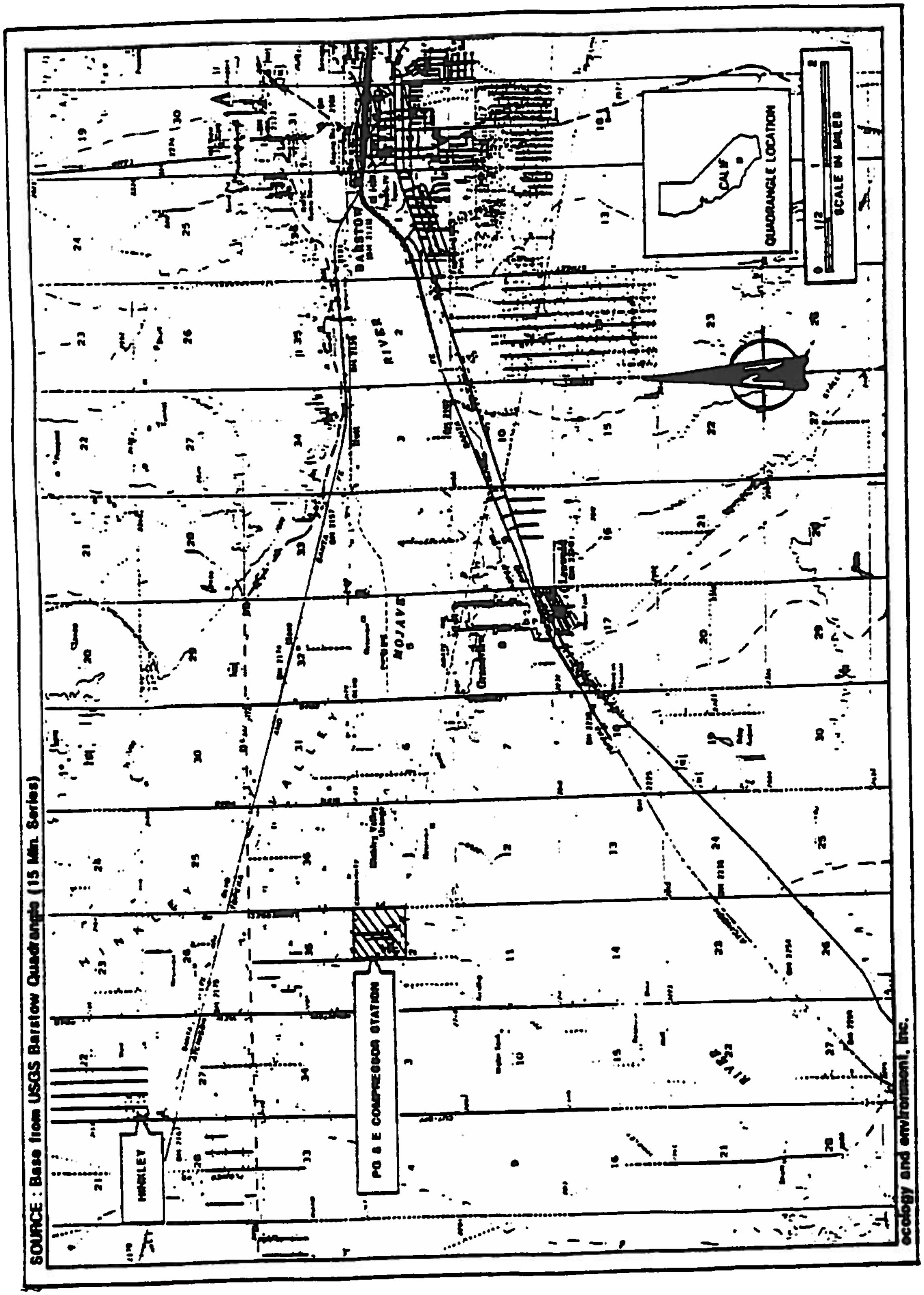
2.0 INTRODUCTION

The Pacific Gas and Electric Company (PG&E), in response to a Cleanup and Abatement Order No. 6-87-160 issued by the Lahontan Regional Water Quality Control Board (LRWQCB) on December 29, 1987, has retained Environmental Health Associates, Inc. (EHA) and Ecology and Environment, Inc. (E & E) to prepare this risk assessment for the Hinkley Gas Compressor Station. The assessment is one of four interrelated studies performed concurrently addressing various aspects of the site; in addition to this risk assessment, a site characterization, a feasibility study, and a groundwater modeling study were completed. This report evaluates potential risks associated with three alternatives being considered for remediation of contamination identified at the site. The first alternative is aquifer mitigation via current irrigation practices. Alternative 2 is agricultural treatment. In both these first two alternatives, bottled water is provided to local residents for drinking and cooking purposes. The third alternative is a variation of Alternative 1 in which water is provided to local residents for all domestic purposes.

2.1. SITE DESCRIPTION

2.1.1. LOCATION, FUNCTION, AND SETTING

The Hinkley Compressor Station is a natural gas pumping facility that is part of PG&E's Line 300 gas transmission system, extending from Needles to Milpitas, California. This system provides up to 40% of the total natural gas used by northern California. The site is located about seven miles west of Barstow and three miles southeast of Hinkley, in San Bernardino County, California (See Figure 2-1). Situated in the southern Mojave Desert about 1.5 miles north of the Mojave River, the station occupies approximately 20 acres of a larger PG&E parcel. The station, which has been in operation since 1952, consists of offices, a warehouse, and equipment and materials for compressing natural gas in order to move it through the pipeline system.



SOURCE : Base from USGS Barstow Quadrangle (15 Min. Series)

ecology and environment, inc.

Figure 2-1 LOCATION OF PG & E GAS COMPRESSOR STATION

2.1.2. SITE HISTORY

In connection with PG&E's ongoing environmental assessment program and various permitting activities, PG&E personnel collected a groundwater sample on November 13, 1987 from an inactive on-site well (Well #7). Test results received on November 29, 1987 showed a hexavalent chromium (Cr(VI)) concentration of 0.57 mg/l. This concentration exceeded the Environmental Protection Agency (EPA) standard of 0.05 mg/l for total chromium (Cr(T)) in drinking water (USEPA, 1985).

The principal operation at the station which contributed to the groundwater contamination was associated with a cooling process at the facility. Gas compression generates heat, requiring the gas and compressors to be cooled with water. The water, in turn, is cooled by passage through induced draft cooling towers. To inhibit corrosion of the cooling tower structure and associated heat exchangers, certain chemicals are normally added to the water. A chromium-based inhibitor was used for this purpose at the Hinkley Gas Compressor Station from 1952 until 1966 and has been identified as the probable source of Cr(VI) in groundwater samples collected downgradient from the site. Since 1966, a phosphate-based corrosion inhibitor has been used at the facility. Since 1972, the blowdown, or wastewater, has been discharged to double-lined evaporation ponds; the earlier ponds have since been abandoned and covered.

In early December 1987, PG&E retained the consulting firms of Harding Lawson Associates (HLA) and EHA to assist in a preliminary assessment of chromium contamination in groundwater near the site and to address any identified public health risks to local groundwater consumers. In cooperation with the LRWQCB, and the San Bernardino County Department of Environmental Health Services, PG&E and HLA sampled approximately 90 wells within a nine-square mile area. The wells sampled included active and inactive public and private supply wells for domestic, agricultural, and industrial uses. In addition to analyzing samples collected for chromium and various inorganic constituents, groundwater levels were approximated based upon mapped surface elevations for each well.

Results of the initial testing program were summarized in the Preliminary Site Appraisal Hinkley Compressor Station

(Harding Lawson Associates, 1988), which was submitted to the LRWQCB on January 27, 1988. In that report, a plume of groundwater containing chromium exceeding the current drinking water standard of 0.05 mg/l was delineated. The approximate areal extent of the plume was defined at that time, and has been refined based on further field studies by E & E (see Section 2.1.3).

Subsequent to the preliminary site appraisal, PG&E initiated a comprehensive review of historical files and other information relating to the use of chromium as a corrosion inhibitor at the Hinkley Gas Compressor Station. The purpose of this research was to ensure a full understanding of past chromium treatment and disposal practices which may affect the design of the site characterization and remediation. All information relevant to these historical activities is reflected in the current site characterization report and the feasibility study and is being used in this risk assessment.

2.1.3. EXTENT OF ENVIRONMENTAL CHROMIUM (HEXAVALENT AND TOTAL)

Groundwater

Based on samples collected by E & E and analyzed in May 1988 in conjunction with the site characterization study, concentrations of total chromium in groundwater beneath the site range from below the analytical detection limit of 0.01 mg/l to a maximum level of 4.2 mg/l. Contamination appears to be limited to the unconfined groundwater zones above an impermeable "blue clay" layer, which is found under the plume at a depth of between 120 and 150 feet. Groundwater occurs at depths ranging from approximately 75 to 105 feet. The plume delineating chromium concentrations of 0.05 mg/l or above extends about 1-1/2 miles north-northwest of the compressor plant, and reaches a maximum width of about 1/2 mile (Figure 2-2). The areal extent of the plume is approximately 0.45 square miles. The data show essentially all of the chromium in the groundwater is in the hexavalent state. Due to the greater possibility of analytical interferences at low concentrations of Cr(VI), and in order to assure consistency throughout this report, Cr(T) values will be referred to for all discussions pertaining to groundwater contamination in the Hinkley study area. The reliability of all data generated is discussed in detail in the Site Characterization Report.

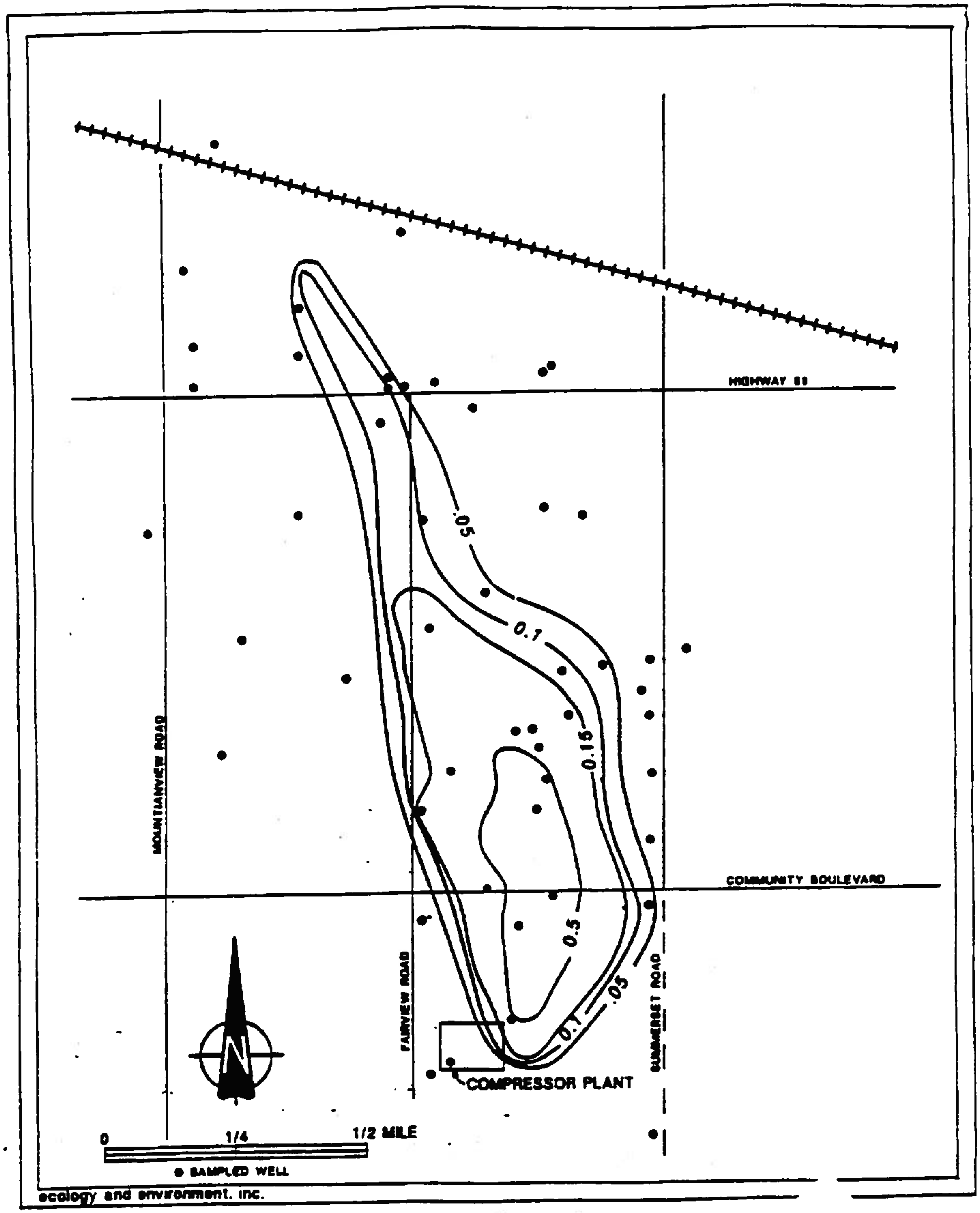


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Figure 2-2 PG & E HINKLEY, MAY 1988
TOTAL CHROMIUM GROUNDWATER
PLUME CONCENTRATIONS IN mg/l

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Soil

E & E also collected approximately 360 soil samples from three on-site areas and analyzed them for both Cr(VI) and Cr(T). Samples were collected from the surface and subsurface (down to 80 feet), from trenches, monitoring well boreholes, and soil borings. Only 19 of the samples collected contained Cr(VI) or Cr(T) at levels of concern. The highest level of Cr(VI) detected was 10.2 mg/kg, taken from visibly stained soil near the bottom of the former drainage ditch. Cr(T) levels ranged up to 3,940 mg/kg. Waste extraction tests (WETs) performed on six soil samples show that neither Cr(VI) nor Cr(T) bound to the soil are very soluble.

2.2. OBJECTIVES OF THE RISK ASSESSMENT

The principal objective of this assessment is to provide an estimate of the human health and environmental risks which could reasonably be expected under several alternatives for remediation of the Cr(VI) contamination in groundwater at Hinkley. The effects of three different mitigation options on groundwater, human, soil, plant, and non-human animal receptors are addressed.

The assessment is, by design, protective of human and environmental health. Accordingly, health-conservative interpretations of data, models, projections and estimations are used throughout. The EPA/DHS approaches to risk assessment have been followed (USEPA, 1987; California Department of Health Services, 1985).

2.3. ORGANIZATION OF THIS REPORT

This report is divided into the following sections: Executive Summary, Introduction, Source Characterization, Description of Exposed Populations, Remedial Alternatives, Environmental Pathways, Human Health Risk Assessment, Ecological Risk Assessment, and Summary and Conclusions. The Executive Summary presents the objectives, approach, results, and conclusions of the risk assessment. The Introduction provides an overview of the process followed. The Description of Exposed Populations addresses the receptors (potentially exposed organisms) present at the site, whose risks must be considered. The Remediation

Alternatives chapter outlines the proposed remediation actions which affect the environmental conditions affecting potential exposures at the site. The Environmental Pathways section describes the environmental fate and transport of the toxicants through time, estimating concentrations in various environmental media to which the receptors might be exposed. It also addresses health impacts possibly occurring during the remediation of on-site chromium concentrations. The Human Health Risk Assessment utilizes information from the previous sections to estimate the risks (probability of harm) to potentially exposed human receptors. The Ecological Risk Assessment estimates similar risks to soils, plants and non-human animals which may be exposed. The Summary and Conclusions describes the risks or lack thereof, to human and non-human receptors, and discusses those findings in the context of regulatory requirements.

Figure 2-3 shows how the various components of this risk assessment are related. Report locations for the components of the analysis are identified within the boxes.

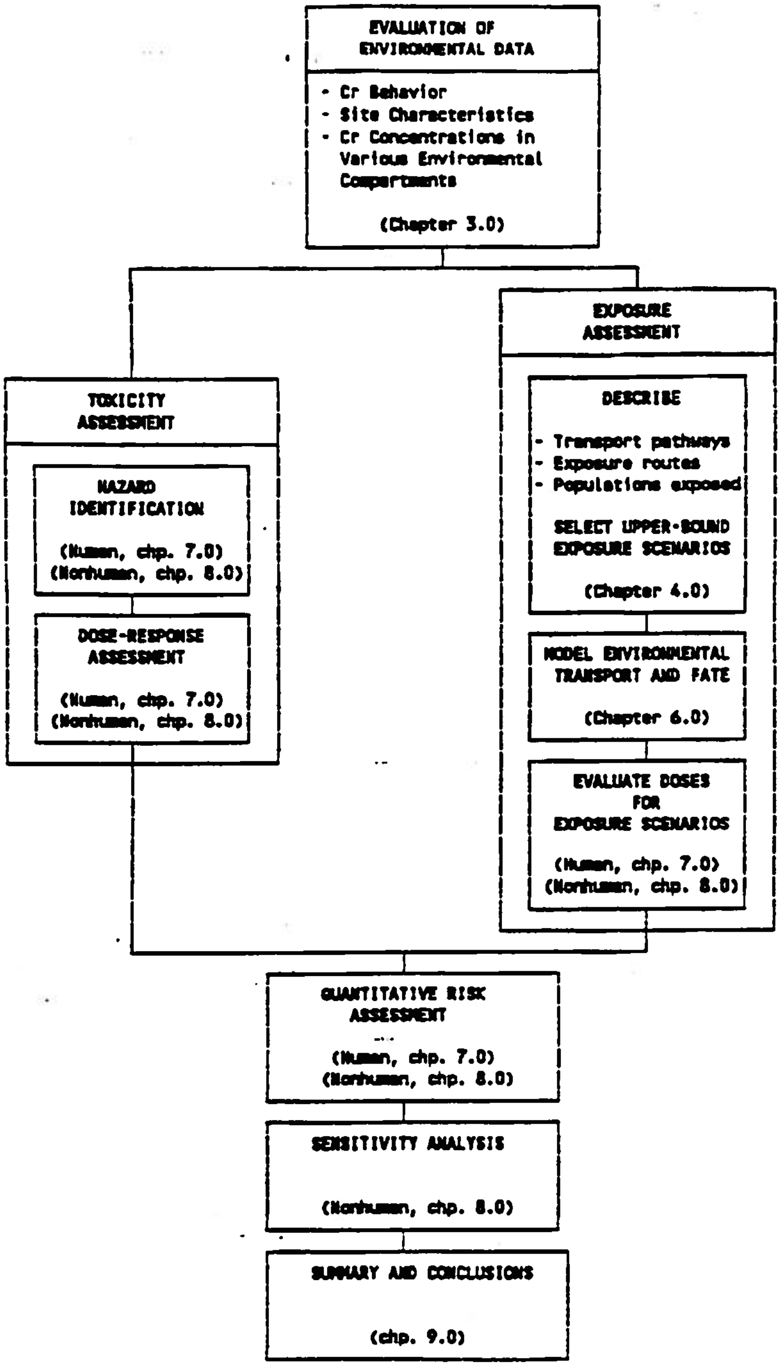

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Figure 2-3: Risk Assessment Flow Chart

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USEPA. National Primary Drinking Water Regulations; Chromium (Proposed Rule) 40 CFR Part 141, 1985 (Federal Register V. 50, November 13, p.46936).

USEPA. 1987. The Risk Assessment Guidelines of 1986, EPA/600/8-87/045.

H127123

3.0 SOURCE CHARACTERIZATION

The purpose of this chapter is to summarize significant background information used in developing the risk assessment. General chemical and physical properties and behavior of chromium species are described, followed by a summary of regional and site-specific geologic, hydrologic, and atmospheric factors potentially influencing chromium transport. The report concludes with site-specific discussions of the distribution of chromium in soil, groundwater, air, flora, and fauna, as determined by recent sampling events. This portion of the report incorporates sampling methods, locations, and results, and provides the foundation upon which risk assessment determinations are based.

3.1. PROPERTIES AND OCCURRENCE OF CHROMIUM

3.1.1. GENERAL PROPERTIES

Chromium, a member of Group VI-B of the periodic table, has an atomic number of 24, an atomic weight of 51.996, a specific gravity of 7.18 at 20°C, a melting point of 1,903°C, and four stable isotopes, of which ^{52}Cr is the most abundant at 83.76%. It is a steel-gray, lustrous, hard, brittle metal that takes a high polish. Theoretically, chromium can occur in any oxidation state from II to VI, but is commonly found only in states O, III, and VI, with III being the most stable (Mertz, 1969). Within the ranges of pH and oxidation-reduction potential (Eh) found in soils, it can exist in four states, namely, two trivalent forms, Cr^{3+} cation and the CrO^{2-} anion, and two hexavalent anion forms, $Cr_2O_7^{2-}$ (dichromate) and CrO_4^{2-} (chromate). Chromium compounds with oxidation states below III are reducing, and those with greater than III are oxidizing. Of the forms found in nature, the trivalent is relatively benign while the hexavalent is toxic.

Chemically, the trivalent state is the most stable. Trivalent chromium exists primarily as stable 6-coordinated octahedral complexes with both organic and inorganic ligands. Chromic ion does not exist in solution as such; it forms complexes with water and other anions in acidic solutions (pKa = 4.9). At higher pH, the hydroxo ion condenses to hydroxo-bridged polynuclear species which slowly precipitate out of solution.

This property contributes to the most significant removal mechanism for Cr(III) from the aquatic environment (USEPA, 1984). In neutral and basic solutions Cr(III) can form stable complexes with biological molecules such as proteins and peptides through hydroxy-(OH) or oxo-(O) bridges.

All hexavalent chromium compounds except chromium hexafloride, CrF_6, exist as oxo-species such as chromium oxide, CrO_3, chromyl chloride, CrO_2Cl_2, chromate, CrO_4^{-2}, and dichromate, $Cr_2O_7^{-2}$ which are strong oxidizing agents (USEPA, 1984). In solution, hexavalent chromium exists as part of complex anions rather than as cations and does not readily precipitate at alkaline pH (USEPA, 1985). Hexavalent chromium species are generally unstable (except in water, see below) due to their high reactivity and kinetic reactivity. They rarely occur naturally in the environment except as a consequence of contamination from industrial sources because they are readily reduced to the trivalent form in the presence of organic matter. Hexavalent chromium compounds are considerably more soluble in water than trivalent compounds, but the solubility of each of the valence states depends on the particular salt and the pH. Once introduced into water with low concentrations of organic material, hexavalent chromium frequently remains unchanged. (USEPA, 1984). Under physiological conditions ($pH = 7.4$) the oxidation-reduction potential of the chromate and dichromate half-reactions indicate that Cr(VI) should be a fairly good oxidizing agent (Hamilton, Wetterhahn & Seiler, 1988).

3.1.2. NATURAL OCCURRENCE

Chromium is an element that occurs naturally in the earth's crust and is typically found in the atmosphere, soil, and water. The primary sources of naturally occurring chromium are continental dust, volcanic dust, and gases. Chromite ore, $(Mg, Fe)(Cr, Al, Fe)_2O_4$, is the major mineral form of chromium. The occurrence of chromium in air, water, and soil is discussed below.

Air

Chromium concentrations in air vary with location (USEPA, 1978). In urban areas, concentrations of Cr(T) in the atmosphere vary on both a seasonal and a day-to-day basis, and typically range from below the detection limit to 0.1 ug/m^3. Air in rural areas does not contain measurable amounts of Cr(T) (<0.01 ug/m^3). Based on the available literature, it was estimated that a median ambient air concentration of chromium is 0.06, 0.025, and from 0.02 to 0.07 ug/m^3 for the U.S., Europe and Japan respectively (Bowen, 1979). Background levels of Cr(T) in air are difficult to determine due to urban and industrial input, but background levels of $\leq$0.001 ug/m^3 are reported. Atmospheric Cr(T) concentrations at the South Pole range from 0.0025 to 0.01 ug/m^3. These concentrations have been attributed to the weathering of South Pole crustal material and may represent a realistic background concentration for Cr(T) in air.

Water

Trace quantities of Cr(T) are found in groundwater and surface waters as Cr(III) and in certain cases Cr(VI). Concentrations of Cr(T) in various fresh water sources were measured and reported in a 1978 study of the environmental effects of chromium by Oak Ridge National Laboratories for EPA (USEPA, 1978). River waters were found to contain Cr(T) levels ranging from undetectable to 0.0078 mg/l; lake waters from 0.0003 to 0.0028 mg/l; and groundwaters and well waters from undetectable levels to 0.0011 mg/l. Substantially higher concentrations were measured in industrial areas.

Soil

Most soils contain small, but varying amounts of Cr(T). The concentration of Cr(T) in soil is determined by geographic region, age of soil, and composition of the parent rock material. Concentrations in surface soils located throughout the world are summarized in Table 3-1. These data indicate that concentrations in non-serpentine soils are extremely varied, ranging from nondetectable to 5,000 mg/kg. However, most soils contain 5 to 300 mg/kg. Serpentine and other ultramafic soils are rich in

Table 3-1

CHROMIUM CONCENTRATIONS IN SURFACE SOILS

Soil	Concentration (mg/kg) Average	Range
Worldwide	50	--
Serpentine Soils[1]	18,360	634 - 125,000
Serpentine Soils[2]	--	2,500 - 4,000
Asian Paddy	136	49 - 467
Canadian	44	20 - 125
Ontario	40	10 - 150
United States	--	5 - 1,000
United States	--	25 - 85
United States	--	1 - 5,000
United States (western)	56	3 - 2,000
Various[3]	70	5 - 1,500

[1] Based on 10 locations worldwide.

[2] British and Swedish locations.

[3] Data from 13 sources.

Source: Adriano 1987; Shacklette and Boerngen 1984.

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heavymetals and contain significantly higher concentrations ranging from 500 to 125,000 mg/kg. Cr(T) concentrations in some California basin sediments are reported to range from 90 to 140 mg/kg (USEPA, 1978). In general, the fine grained, clay fraction of soils contains the highest concentrations of chromium.

3.1.3. GENERAL ENVIRONMENTAL BEHAVIOR

Air

Low concentrations of chromium enter the atmosphere primarily as the result of soil-derived dust, industrial and commercial activities such as metal smelting and cement-producing, and the combustion of fossil fuels. Upon introduction to the atmosphere, chromium quickly becomes sorbed or complexed to entrained particulate matter. Speciation in the atmosphere has not been clearly defined but is considered to be predominantly Cr(III). Under usual conditions, trivalent chromium in the air should not undergo any reaction since this species is relatively, chemically inert (USEPA, 1984). However, if present as a salt other than Cr_2O_3, Cr(III) may be oxidized to Cr (VI) in the presence of MnO_2 greater than 1%. This reaction is unlikely under normal atmospheric conditions (USEPA, 1978).

Entrained Cr(VI), upon binding to particulate matter, undergoes reduction to the trivalent state at a rapid rate (as cited USEPA, 1978). Reversion to the hexavalent state, while thermodynamically possible, is unlikely because of slow reaction rates.

Both hexavalent and trivalent chromium are removed from the air by atmospheric fallout and precipitation. Wet precipitation accounts for more than half of all deposition (USEPA, 1984). The precipitated chromium enters the surface water or soil.

The half-life of chromium in the atmosphere depends on the particle size and density, thus small diameter particles (<10 um) remain airborne for a longer period than large diameter particles (USEPA, 1984). Typically, particulate matter bearing chromium remains airborne for less than 10 days (USEPA, 1978, 1984).

However, particles of less than 20 um in diameter may remain airborne longer and be transported substantial distances (ATSDR, 1987).

Water

Chromium enters surface or ground water as the result of surface runoff, deposition from air, and release of municipal or industrial wastewaters. Chromium is present in water in five possible forms: 1) in solution as organic complexes, 2) adsorbed onto particles, 3) precipitated or co-precipitated, 4) in organic solids, or 5) in sediments. Chromium occurs primarily in particulate form. Some soluble forms of chromium do occur, including certain Cr(III) complexes, but the majority of soluble forms are Cr(VI) compounds. The Cr(VI) compounds, while stable, will in time be reduced to the III state by reactions with organic matter, Fe(II) or sulfides present in water (Schroeder and Lee, 1975; EPA, 1978, 1984; Electric Power Research Institute (EPRI), 1988). Oxidation of Cr(III) to Cr(VI) may occur, but only at a slow rate. MnO_2 can cause oxidation of trivalent chromium, but this reaction is inhibited by substances in natural waters. It was reported that chromium was not released from sediments into sea water in significant quantities under either oxidizing or reducing conditions (Lu and Chen, 1976). Cr(VI) residence time in groundwater is unreported; residence time in surface waters may range from 4 to 18 years (ATSDR, 1987).

Soil

In soil, chromium behavior is influenced by oxidation state, pH, oxidation-reduction potential, clay minerals, competing ions, complexing agents, and other factors. Most of the chromium found in soil is in mineral, adsorbed, or precipitated form as insoluble Cr(III) oxide. Hexavalent chromium in soil is readily reduced to the trivalent form and subsequently precipitates (EPA, 1984). Cr(VI) may remain in soil if its influx equals or exceeds both the adsorbing and the reducing capacities of the soil (Bartlett and Kimble, 1976). Ross et al. (1981) added 100 ppm Cr(VI) to soils and measured Cr(VI) extractable at three and thirteen days. After three days, 25% was extractable, and none was extractable at thirteen days. Experiments by Cary, Allaway and Olson (1977) involving Cr uptake by plants growing on Cr-treated soils indicated that the reversion of soluble Cr(VI) to Cr(III) is complete within one growing season after application of Cr(VI) to the soil. In acid soils, conversion of Cr(VI) to Cr(III) proceeds at a more rapid rate (Bartlett and Kimble, 1976). However on field-moist, aerobic, nonacid soils containing manganese, some oxidation of Cr(III) may take place and in this case Cr(VI) can be extracted from these soil samples at least a year after the Cr(III) was introduced (Bartlett and James, 1979).

The primary processes by which chromium is lost from soil are physical (USEPA, 1984). There is no known chemical process that causes a loss of chromium from soil. Chromium in soil can enter the atmosphere by way of dispersion of dust. Chromium is also transported from the soil through runoff and leaching of water with final deposition in another water body or land area. The half-life of chromium in soils may be from several years to many years (USEPA, 1984; ATSDR, 1987). Concentration of chromium in soil varies over a wide range, from trace levels to 3000 ug/g dry weight. A mean soil concentration of 50-100 ug/g dry weight has been estimated (Thorne et al., 1986). A similar variability in chromium concentration is observed in sediments. It was estimated that a mean value of 75 ug/g dry weight can be assigned for all sediments (Coughtrey, 1983 by Thorne, 1986).

Mechanistic studies that allow accurate prediction of attenuation and leaching potential of the metal are used to determine the behavior of a specific soil. Such an approach has been developed by Battelle for EPRI (EPRI, 1986, 1988). The present case demonstrates that, under certain conditions, Cr(VI) moves through soils readily and can impact groundwater. This transport is accelerated in alkaline soils (Cary, Allaway and Olson, 1977) and is dependent on a hydraulic gradient. It should be remembered that CR(VI) compounds are highly water soluble. However, in high-clay soils sorption increases with pH, becoming constant above pH 8.5 (Griffin, Au and Frost, 1977). Cr(VI) behavior is principally controlled by absorption/desorption reactions (EPRI, 1986). Bartlett (1976) and Gebhardt and Coleman (1974) demonstrated that Cr(VI) is typically tightly bound;

however, this species can be out-competed for binding sites by orthophosphates. Therefore, a soil low in clay content, alkaline, and containing a high concentration of phosphate would have a greater potential for downward migration of Cr(VI), particularly with a continued hydraulic gradient.

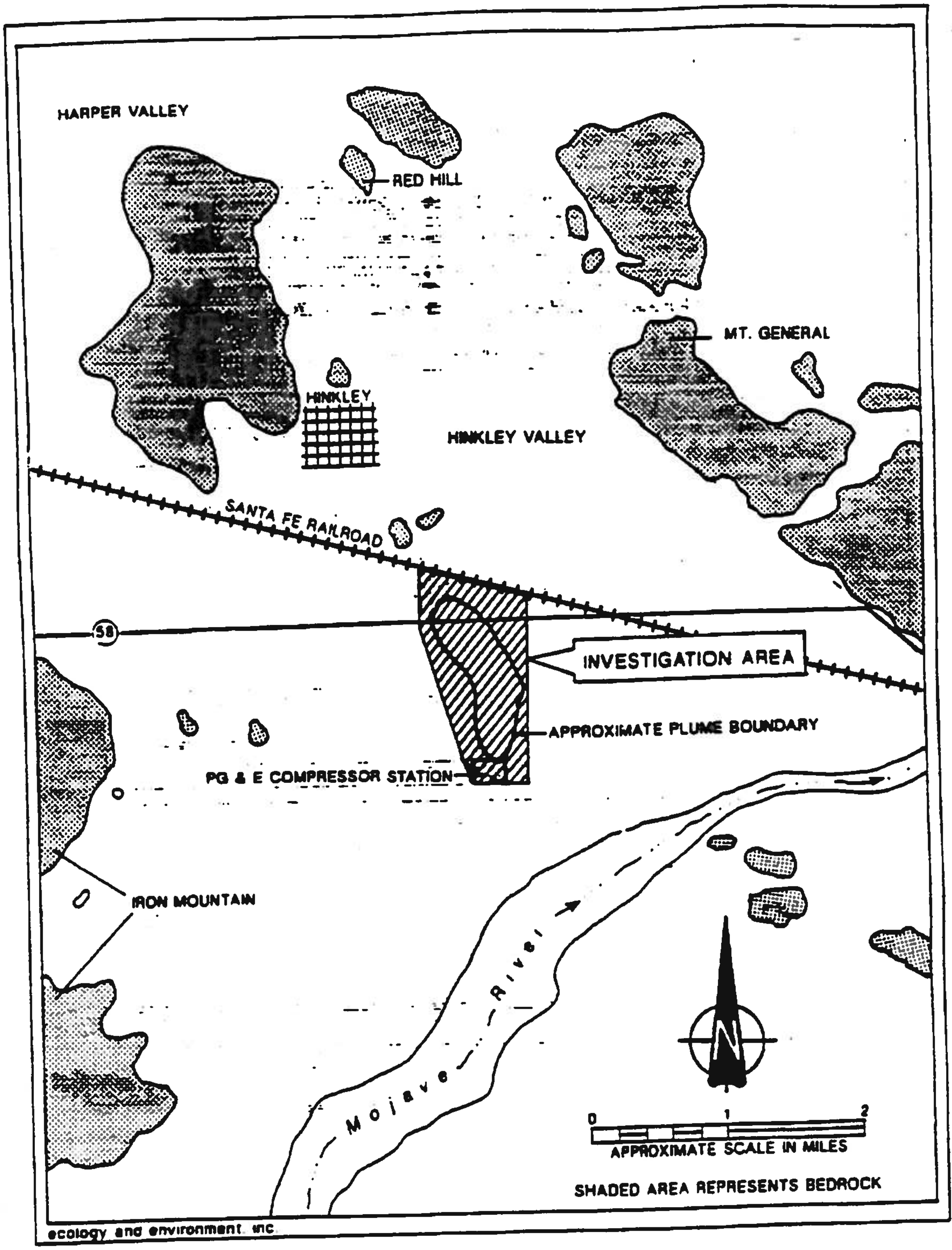
Apparently, Cr(III) is principally controlled by precipitation/dissolution reactions resulting in a variety of complexes with various anions and organic matter (EPRI, 1986; Bartlett and Kimble, 1976). Adsorption increases with pH (Griffin, Au and Frost, 1977), while solubility decreases (Bartlett and Kimble, 1976). Therefore, alkaline soils with high organic content and anion concentration would be capable of holding large concentrations of Cr(III). Further, a hydraulic gradient would have no effect on migration since Cr(III) compounds are highly insoluble.

Speciation of chromium depends upon pH, oxidation-reduction potential, organic matter, and Fe(II) and MnO_2 concentrations (the latter of which are more or less mutually exclusive). Oxidation (favoring Cr(VI) species) occurs readily under soil conditions of low pH, low organic matter, low Fe(II) concentrations, and high MnO_2 concentrations. Cr(III) species would be favored in alkaline soils with a reducing (high negative) potential, high organic carbon content, high Fe(II), and low MnO_2 concentrations. The following references discuss these trends (Bartlett and James, 1979; Bartlett and Kimble, 1976; Long, 1983; EPRI, 1986, 1988; and Korte, Skapp and Fuller, 1976).

3.2. DESCRIPTION OF STUDY AREA

3.2.1. REGIONAL SETTING

The regional setting of the study area is illustrated in Figure 3-1 and described in detail in the Site Characterization Report, which includes discussions of regional geology, hydrology, and climate. The demography of Hinkley and vicinity is detailed in Appendix A4 of this report.



H127132 Figure 3-1 GEOGRAPHIC SETTING OF THE INVESTIGATION AREA

Several factors related to the location of the study area in a sparsely populated desert environment relate directly to the development of this risk assessment, as discussed below:

Climate/Hydrology

The Hinkley Valley is located in the central Mojave Desert, and is situated at an elevation of approximately 2,200 feet above sea level. The area lies in a basin bounded by mountains, including the San Bernardino range. As a result of its elevation, latitude, and the influence of the surrounding mountains, the study area is hot, dry, and often windy. Annual rainfall is low (about 5 inches per year) and evaporation rates are extremely high. Table 3-2 summarizes precipitation and temperature data for the area.

These climatological considerations are important as they relate to high water demands and the limited capacity for recharge of the aquifer underlying the study area. Evaporation rates greatly exceed rainfall rates, and the current use of sprinklers (as opposed to flood irrigation) to irrigate local fields further limits potential recharge from agricultural applications. The Mojave River is the major source of recharge for the basin. Surface water flows only during periods of heavy rainfall, as the highly permeable river alluvium readily loses water to the underlying sediments.

High winds are common to the Mojave Desert. These winds become particularly noticeable when they are strong enough to pick up sand and dust. Localized, powerful dust storms called "dust devils" occur often during the summer months. Dust devils may reach heights of several hundred feet as they travel at high speeds across the desert floor. Although spring and winter winds generally are stronger than summer winds, occasional summer thunderstorms are capable of generating strong, gusty winds that can cause severe local dust storms. The average wind velocity for the Barstow area is 12 mph, whereas the maximum gust recorded for the Barstow area thus far in 1988 was 62 mph. A wind rose for Daggett, CA, just to the east of Barstow, presented in Figure 3-2, represents the most accurate and relevant recorded wind data.

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Table 3-2

SUMMARY OF MONTHLY PRECIPITATION AND TEMPERATURE DATA FOR BARSTOW, CA

Month	Mean Precipitation (inches)	Average Daily Temperature (F)
January	0.54	45.7
February	0.37	50.5
March	0.36	54.8
April	0.21	58.7
May	0.08	69.4
June	0.11	78.3
July	0.32	85.0
August	0.26	82.8
September	0.34	76.5
October	0.20	65.2
November	0.48	53.1
December	0.53	45.6

Source: Soil Conservation Service, 1988
Apple Valley, CA

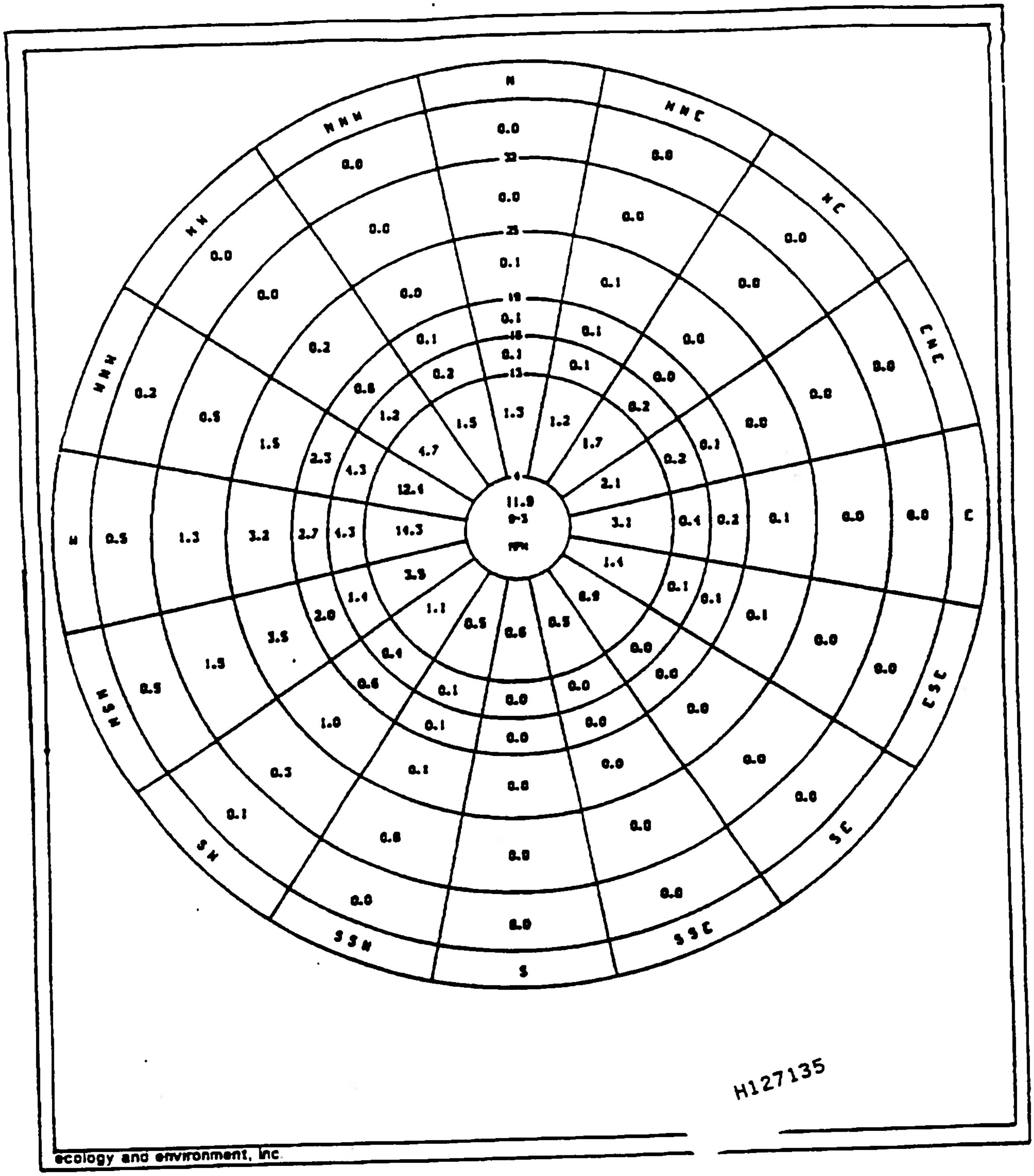

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Figure 3-2 WIND ROSE FOR DAGGETT, CALIFORNIA AIRPORT

The wind rose presents the percentage of time (annual average) that the wind blows from a particular direction within a specific speed range. For example, winds of 0-3 mph occur 11.9% of the time, and winds from the west between 4 and 13 mph prevail 14.3% of the time. The prevalence of strong winds in the study area is considered in evaluating the inhalation of dust or windborne aerosols as potential exposure routes.

Demography/Land Use

As a result of the arid environment and high summer temperatures, historical development of the study area has been limited by the availability of water. The area is sparsely populated, with alfalfa production and dairies using the vast majority of groundwater produced. Groundwater has been mined historically, and current withdrawal continues to exceed recharge. An important objective addressed in the feasibility study involves minimizing additional withdrawal from the aquifer. Further demographic and land-use data are presented in Appendix A4.

3.2.2. SITE-SPECIFIC SETTING

The chromium-contaminated groundwater plume that has been identified extends north-northwest about 1.5 miles from the compressor plant, which itself is about 1.5 miles north of the Mojave River (see Figure 3-1). The boundary of the plume is defined by groundwater with a measured or projected concentration of 0.05 mg/l chromium, the EPA drinking water standard (USEPA, 1985). The investigation area has a land surface slope of about 40 feet per mile toward the north, and an average elevation of 2,190 feet. The town of Hinkley proper is three miles northwest of the compressor station. In addition to the gas compressor station, land use in the area consists of grazing, alfalfa fields, small dairies, unimproved land, and rural residential areas.

A detailed discussion of the geology, hydrology, and groundwater quality of the study area is presented in the Site

Characterization Report. Hydrogeologic and water quality conditions relevant to the risk assessment are summarized below:

Hydrogeology

Groundwater beneath the study area occurs in two water-bearing zones that are separated by a really widespread and thick "blue clay." Groundwater above the blue clay, referred to as the shallow aquifer, occurs in permeable alluvial strata and is unconfined or semi-confined. Deeper, confined groundwater also occurs in and/or below the blue clay.

The majority of groundwater pumped from the basin is derived from the shallow aquifer. Subsurface lithologic data and the results of aquifer tests indicate that permeable strata within and/or below the blue clay are not thick or laterally extensive and generally cannot supply moderate quantities of water to wells. The shallow aquifer, however, can supply large quantities of water to wells and locally (generally near the Mojave River) can be pumped at rates up to 300 gallons per minute (gpm). A typical average sustainable pumping rate appears to be approximately 150 gpm.

The shallow aquifer above the blue clay in the study area appears to consist of two contrasting water-bearing zones. Immediately above the blue clay, there is a layer of silty fine to medium sand, which is overlain by coarser sands. The majority of water pumped from the shallow aquifer probably comes from this shallower, coarser-grained zone.

Water Quality

Regional well sampling of shallow groundwater has revealed that a plume of chromium with concentrations exceeding 0.05 mg/l extends north of the compressor plant for approximately 1-1/2 miles and covers an area of approximately 0.45 square miles. In domestic and irrigation supply wells, the highest concentration (as Cr(T)) detected in December 1987 was 1.00 mg/l. This value represents a mixture of groundwater from separate water-bearing zones and as such the chromium level represents a composite concentration.

3.3. EXTENT OF CHROMIUM DISTRIBUTION AND RELATED ANALYTICAL DATA

3.3.1. GROUNDWATER

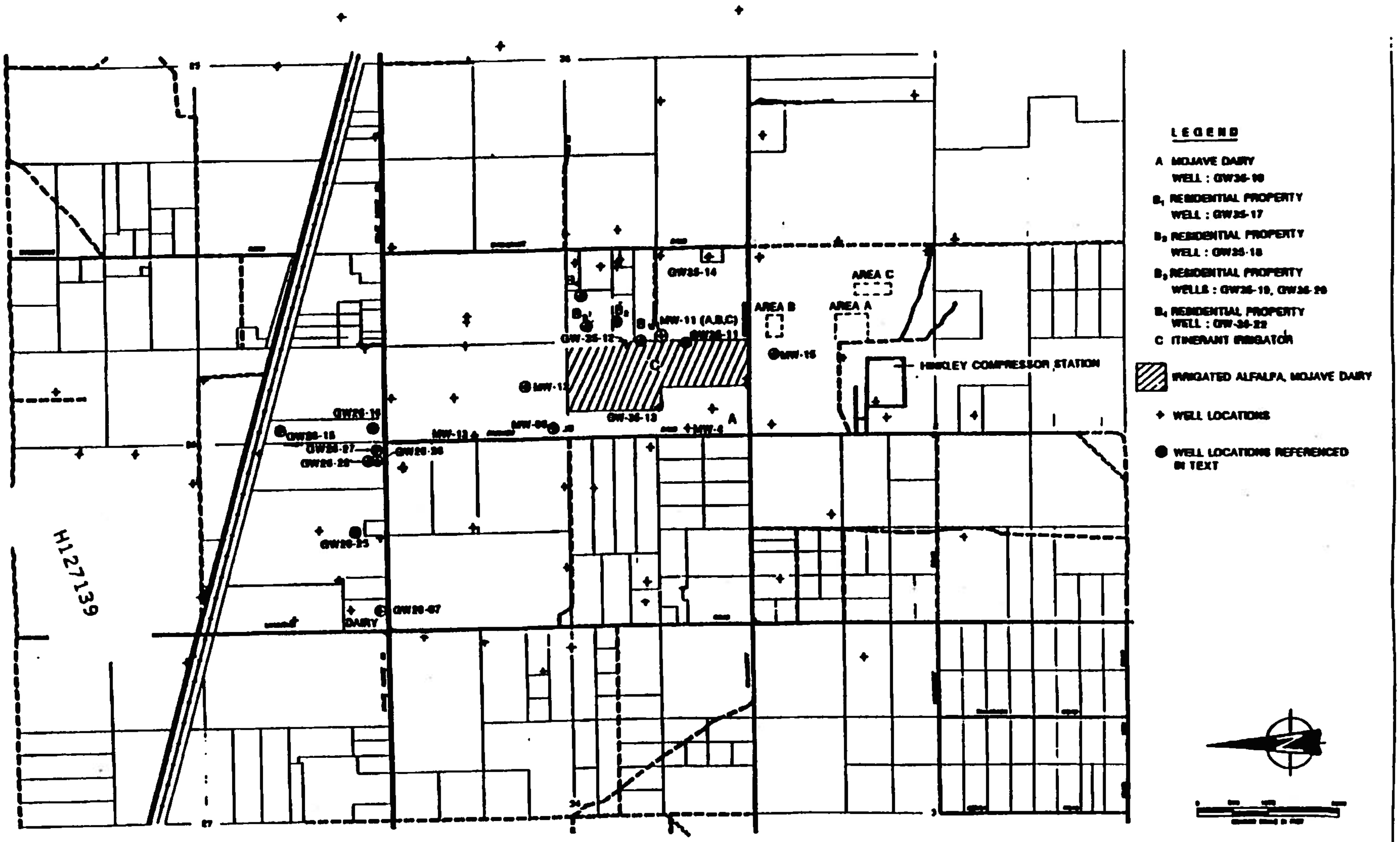
Groundwater sampling has been performed as part of the site characterization in order to define the vertical and lateral extent of chromium contamination in the aquifer.

The first of two groundwater sampling events under the site characterization conducted by E & E occurred in May 1988 (see Figure 3-3 for sample locations). A total of 53 wells were sampled for chromium, including 31 existing domestic and irrigation wells, three PG&E industrial supply wells, and the 19 new monitoring wells (not all wells are shown on Figure 3-3 - only those of concern to this assessment). A total of 65 samples, including blanks and duplicates, were collected. All samples were analyzed for Cr(T), Cr(VI), and selected samples were analyzed for a number of other parameters. A detailed discussion of sampling methods and activities is found in the Site Characterization Report.

Data

The highest concentration of Cr(VI) detected in a private supply well was approximately 0.70 mg/l (0.76 mg/l as Cr(T)), whereas the highest concentration in a monitoring well was 3.70 mg/l (4.2 mg/l as Cr(T)), at MW-11B. The concentrations for selected domestic and irrigation wells are summarized in Table 3-3. (Detailed descriptions of the wells listed in this table are presented in the Site Characterization Report.) As Table 3-3 indicates, concentrations of chromium in the groundwater north of the site vary, ranging from nondetectable to a maximum of 4.2 mg/l (Cr(T)), with the majority at levels below 0.5 mg/l.

In May 1988, the highest concentrations of Cr(T) detected in the monitoring wells was 4.2 mg/l in MW-11B and 2.5 mg/l in



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LOCATIONS OF SAMPLED WELLS AND FORMER ON-SITE POND AREAS

FIGURE 3-3

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Table 3-3
TOTAL CHROMIUM LEVELS FOR SELECTED WELLS NEAR PLUME
MAY 1988

Sample ID No.[a]	Description	Cr(T) Concentration (mg/l)
GW26-07	Domestic	0.02
GW26-15	Irrigation	ND
GW26-16	Irrigation	ND
GW26-25	Domestic	0.02
GW26-26	Domestic	0.13
GW26-27	Irrigation	0.03
GW26-28	Irrigation	0.08
GW35-10	Domestic	0.20
GW35-11	Irrigation	0.76
GW35-12	Irrigation	0.31
GW35-13	Irrigation	0.18
GW35-14	Domestic	ND
GW35-17	Domestic	0.20
GW35-18	Domestic	0.18
GW35-19	Domestic	ND
GW35-20	Domestic	0.07
MW-06	Monitoring	0.17
MW-11A	Monitoring	ND
MW-11B	Monitoring	4.20
MW-11C	Monitoring	ND
MW-12	Monitoring	0.05
MW-15	Monitoring	2.50

Detection Limit (as total chromium) = 0.01 mg/l.

[a] For map locations see Figure 3-3.

Source: Ecology and Environment, Inc., 1988.

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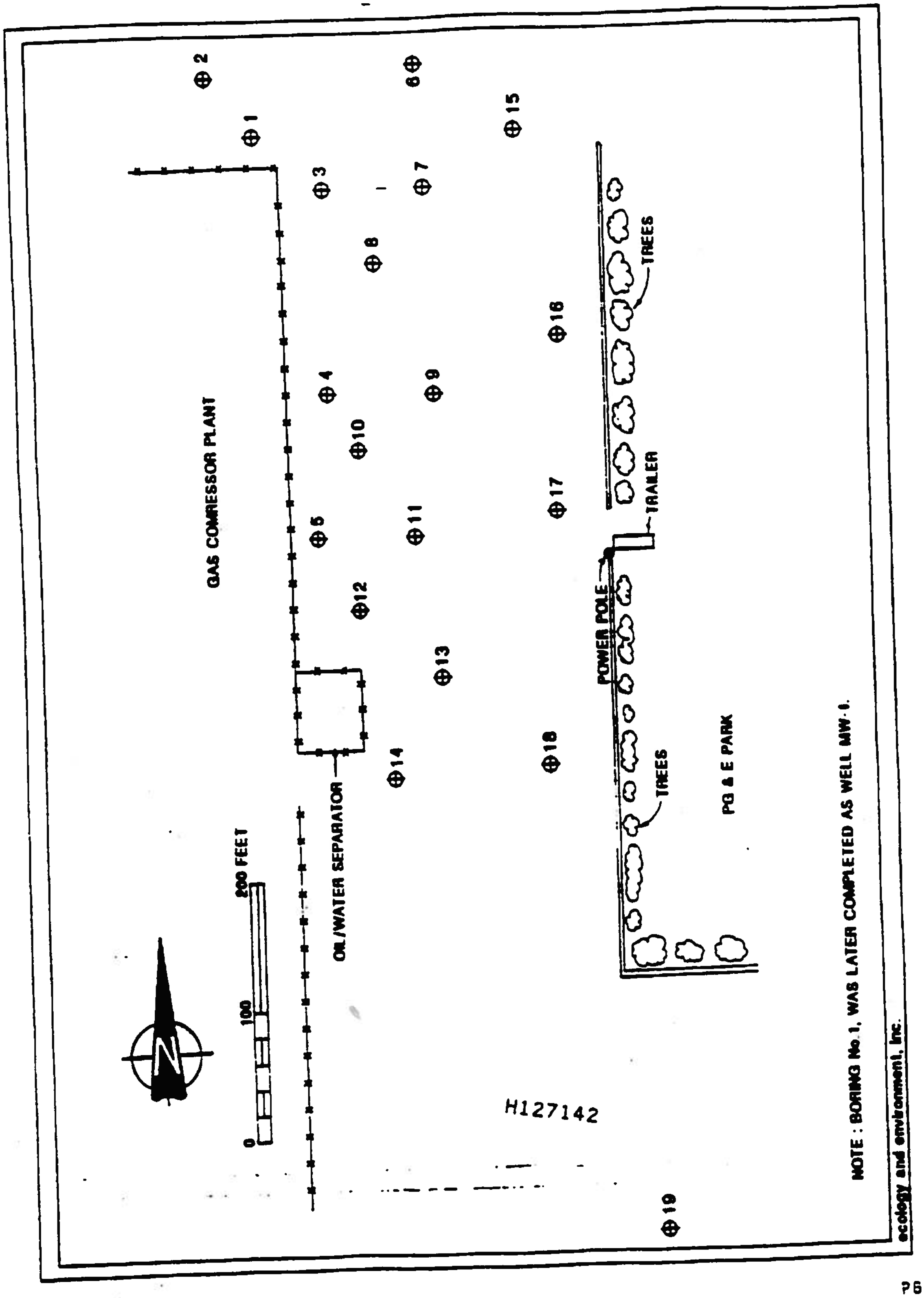
MW-15. Both of these monitoring wells were screened in the fine-grained portion of the shallow aquifer. Groundwater from coarse-grained portions of the shallow aquifer did not exceed 0.46 mg/l. This suggests that there is a strong relationship between grain size and chromium concentrations in the shallow aquifer, with significantly higher concentrations associated with the finer-grained deposits.

Chromium data specific to the deeper, confined groundwater are restricted to information from the two deep monitoring wells (MW-11C and MW-14C) at the cluster sites. Total chromium was not detected in either well.

3.3.2. SOIL DATA

During the site characterization phase of work, potential soil contamination at the site was investigated by collecting surface and subsurface samples. Soil samples were collected from 3 trenches, 5 monitoring wells and 32 soil borings. Soil borings were drilled in three on-site locations referred to as Area A, Area B, and Area C (see Figure 3-3). Area A was the site of the former evaporation/percolation pond for cooling tower discharge, while Areas B and C received chromium residues from the other related operations. The locations of the soil borings in Areas A, B, and C are shown in Figures 3-4, 3-5, and 3-6 respectively. Off-site surface soil samples were also collected (see Figure 3-7). In addition, PG&E collected several surface samples (see Figure 3-8 for these sample locations).

A total of 309 samples (298 from soil borings) were collected from the three on-site areas and analyzed for both Cr(T) and Cr(VI). Selected samples were also analyzed for several additional parameters. Six samples containing elevated levels of chromium were also analyzed using the California Waste Extraction Test (WET), a fairly conservative method applied to assess potential soil leachability (4 to test Cr(T) and 2 to test Cr(VI) leaching). For a detailed discussion of sampling methods and



NOTE : BORING No.1, WAS LATER COMPLETED AS WELL MW-1.

Figure 3-4 AREA A
BORING LOCATIONS AS DRILLED

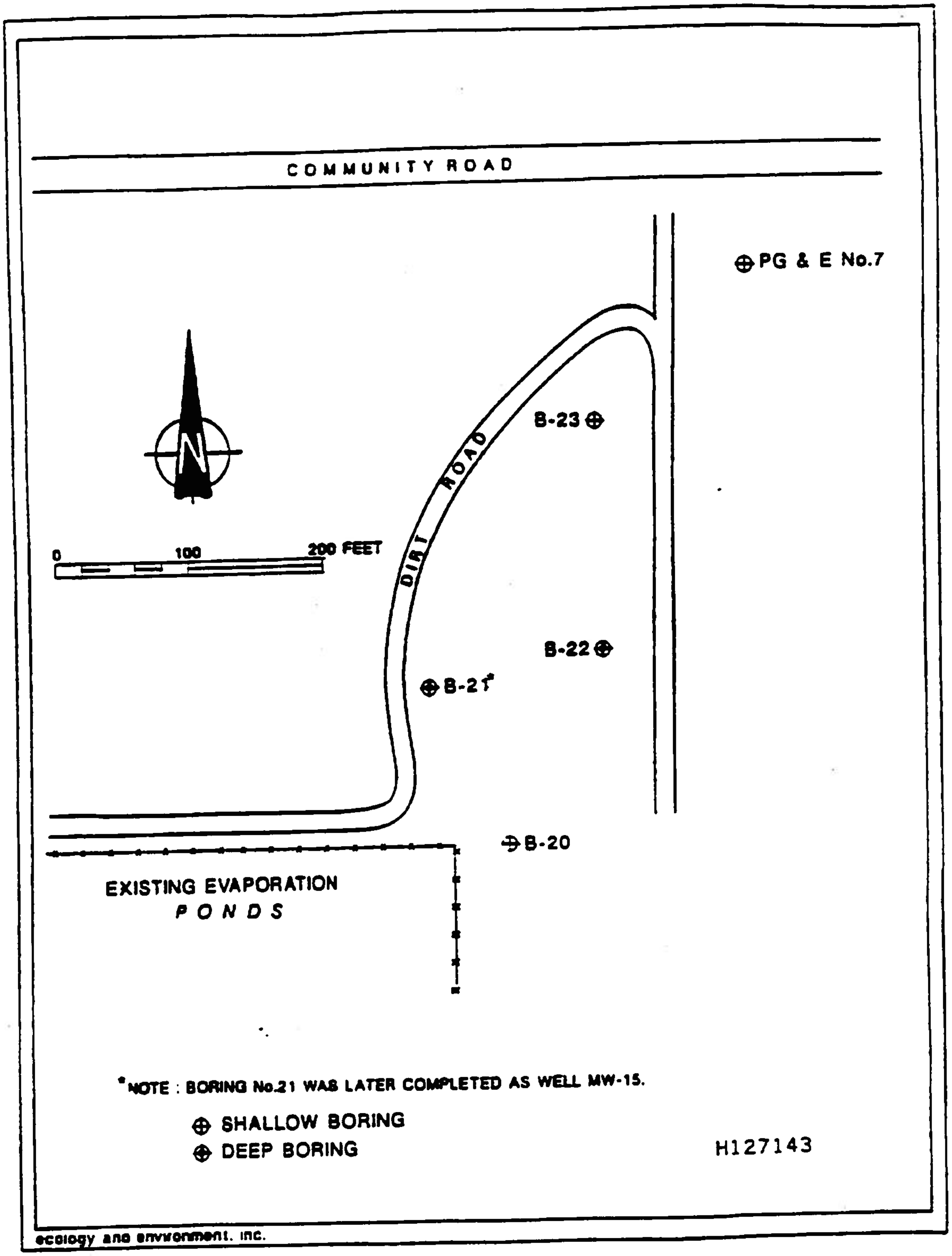


Figure 3-5 AREA B
BORING LOCATIONS

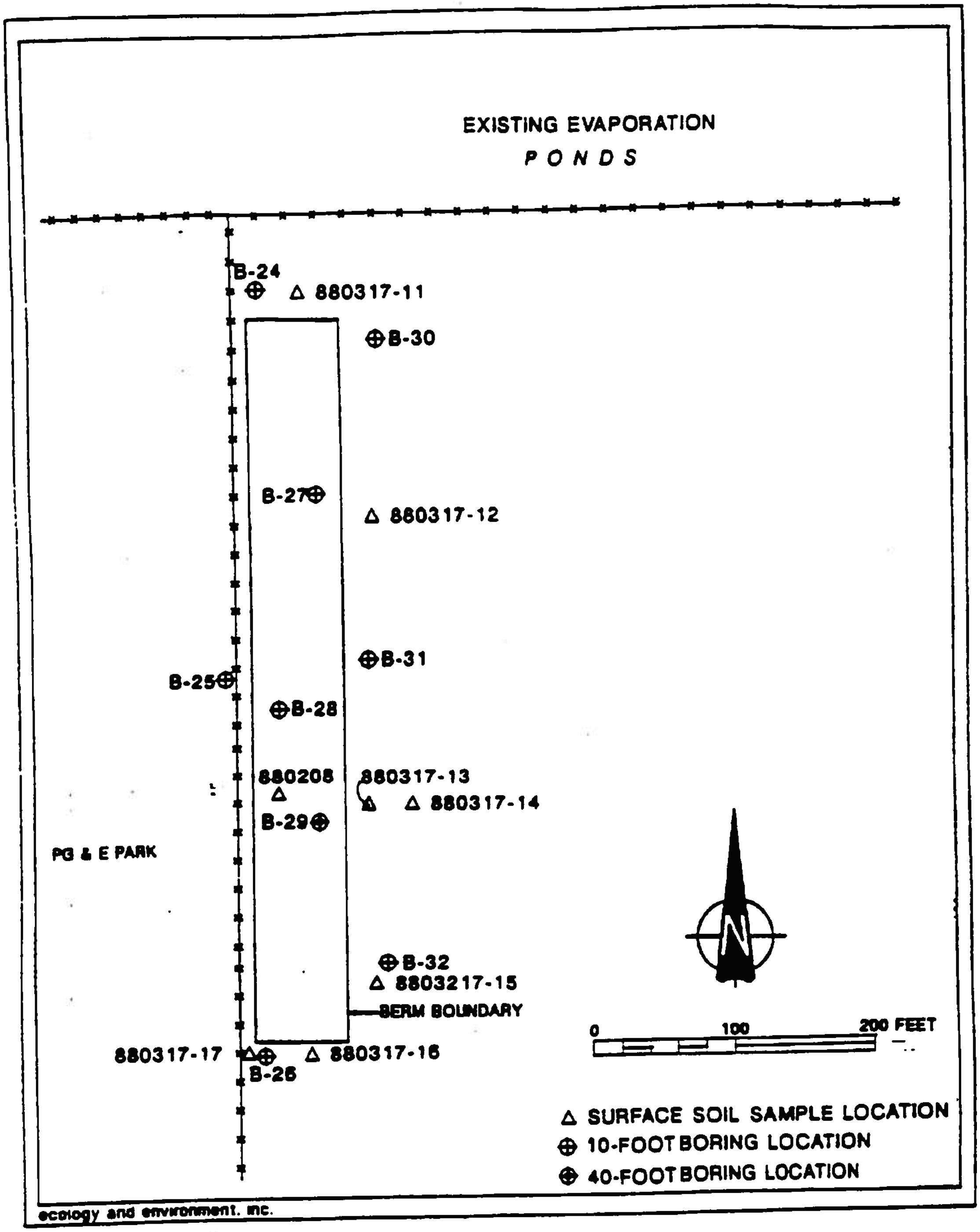


Figure 3-6 AREA C - SAMPLE LOCATIONS

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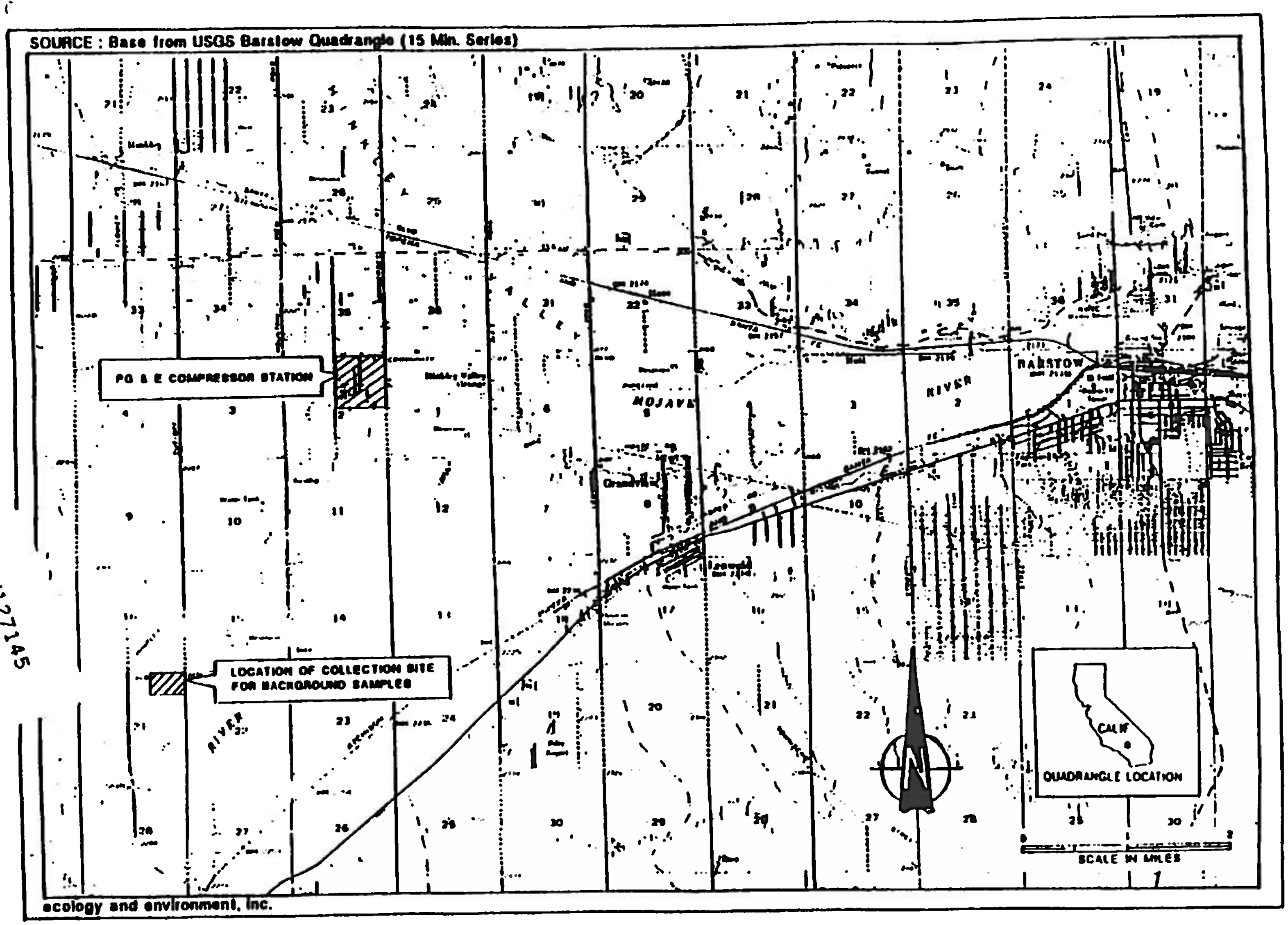

SOURCE : Base from USGS Barstow Quadrangle (15 Min. Series)

ecology and environment, inc.

Figure 3-7 LOCATION OF BACKGROUND SOIL AND VEGETATION SAMPLES

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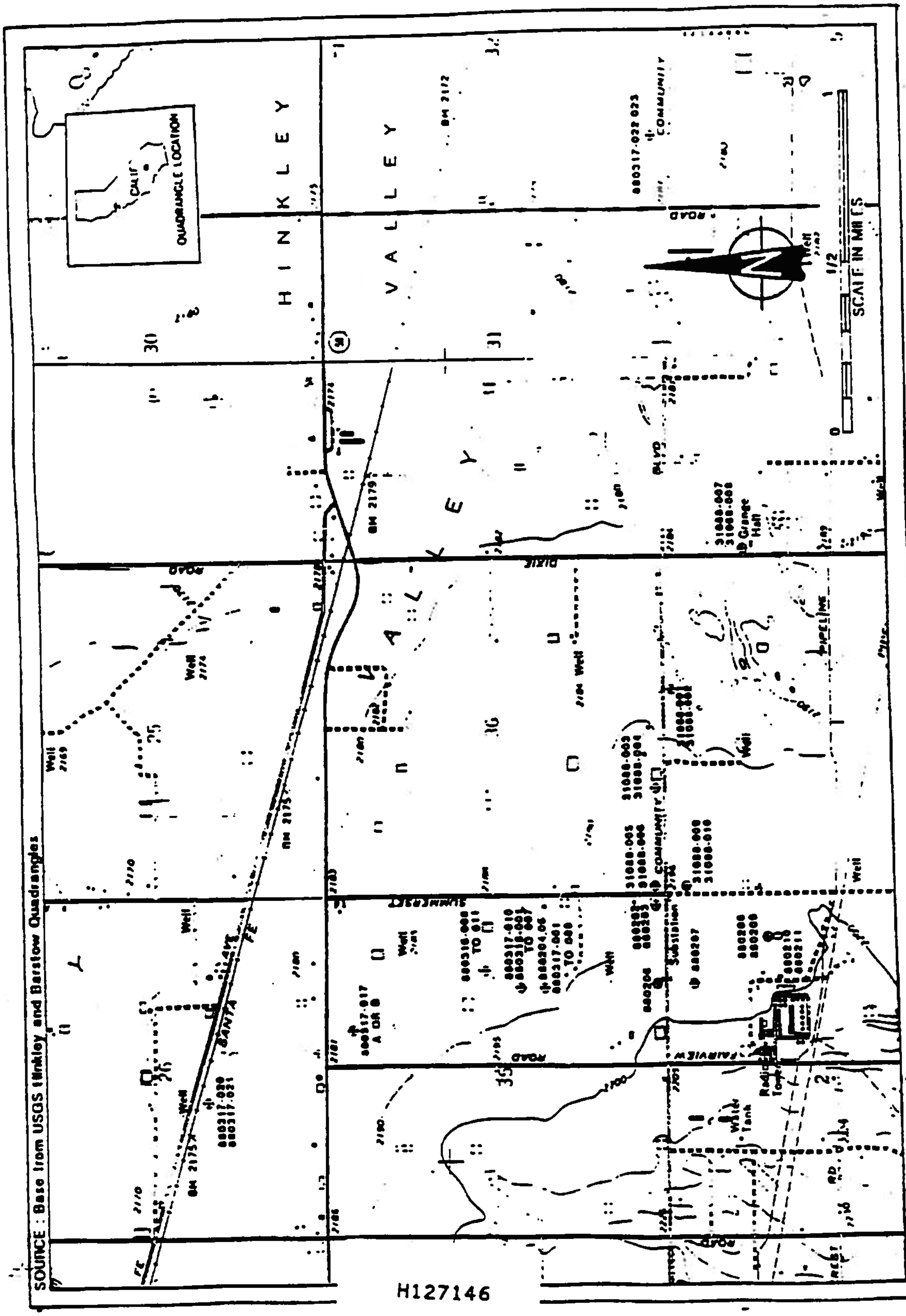

SOURCE : Base from USGS Hinkley and Barstow Quadrangles

Figure 3-8 SOILS AND VEGETATION SAMPLES TAKEN BY PG & E activities conducted under the site characterization phase of work, refer to the Site Characterization Report.

In addition to the soil samples collected during the site characterization, eight additional surface soil samples were collected from Mojave Dairy alfalfa fields. These samples were collected to evaluate the fate of Cr(VI) in irrigation water originating from the plume (see Figure 3-9). The Mojave Dairy is located on Community Blvd., immediately north of the station. These surface soil samples were collected to compare off-site background Cr(VI) concentrations to those present in the soils of the Mojave Dairy alfalfa fields, which are irrigated with groundwater from the plume of contamination. Sampling methodology was consistent with that described in the Site Characterization Report.

Data

Results of lab analyses of surface soil samples are presented in Table 3-4. Cr(T) concentrations varied from nondetectable to a maximum of 4,730 mg/kg. The highest Cr(T) concentration, which was measured in a sample from Pond Area C, is approximately 15 times the maximum of 300 mg/kg reported for typical non-serpentine soils (see Section 3.1.2). From the site characterization, it was determined that elevated levels of Cr(T) in the soil are primarily limited to the upper 3 feet (with the exception of one sample). With few exceptions all chromium measured in the soil was in the insoluble trivalent state. Cr(VI) was only detected in seven surface soil samples, at concentrations ranging from 0.05 mg/kg in Area C to 3.30 mg/kg in Area A.

WET analysis performed on four soil samples containing relatively high concentrations of chromium revealed little if any extractable chromium. As described in the site characterization study the percent soluble fraction of total and hexavalent chromium ranged from <1% to 3.33%. These results indicate that chromium is very insoluble in these soils and is not likely to leach into the groundwater.

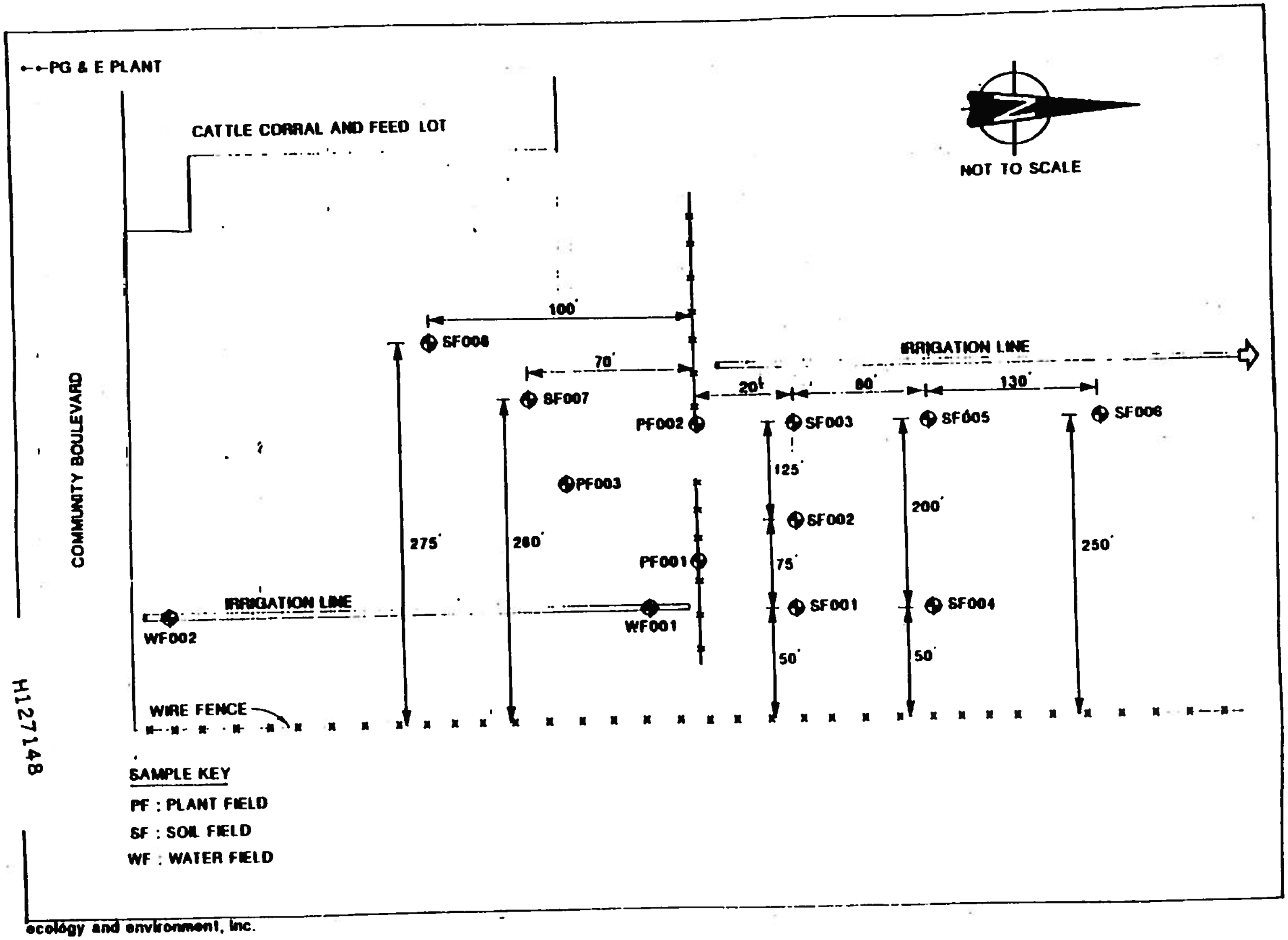

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Figure 3-9 WATER, SOIL, AND VEGETATION SAMPLING LOCATIONS MOJAVE DAIRY FARM - IRRIGATED ALFALFA FIELDS

Table 3-4

CHROMIUM VI AND TOTAL CHROMIUM IN SURFACE SOIL
(Depth Less than or Equal to 1 Foot)

Sample ID No.	Location	Chromium Total (mg/kg)	Chromium VI (mg/kg)
B01-01	Area A	584.00	3.30
B02-01	Area A	6.10	ND
B03-01	Area A	15.30	ND
B04-01	Area A	43.30	ND
B05-01	Area A	12.40	ND
B06-01	Area A	14.90	ND
B07-01	Area A	29.80	ND
B08-01	Area A	51.20	ND
B09-01	Area A	10.80	ND
B10-01	Area A	66.40	ND
B11-01	Area A	12.00	ND
B12-01	Area A	78.60	ND
B13-01	Area A	6.30	ND
B14-01	Area A	8.00	ND
B15-01	Area A	7.00	ND
B16-01	Area A	5.50	ND
B17-01	Area A	9.90	ND
B18-01	Area A	7.40	ND
B19-01	Background	13.60	ND
B20-01	Area B	2.30	ND
B21-01	Area B	7.60	ND
B22-01	Area B	2.50	ND
B23-01	Area B	3.00	ND
B24-01	Area C	171.00	ND
B25-01	Area C	6.70	ND
B26-01	Area C	10.50	ND
B26-02	Area C	4.70	ND
B27-02	Area C	84.30	0.50
B27-03	Area C	ND	ND
B28-01	Area C	13.20	ND
B28-02	Area C	1140.00	0.64
B28-03	Area C	85.20	0.98
B29-01	Area C	4.40	ND
B29-02	Area C	73.80	ND
B29-03	Area C	24.90	ND
B30-01	Area C	10.90	ND
B31-01	Area C	12.30	ND

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Table 3-4 (continued)

Sample VI ID No.	Location	Chromium Total (mg/kg)	Chromium (mg/kg)
PG31088-02	Background	2.96	ND
PG31088-04	Background	6.51	ND
PG31088-06	Background	6.45	ND
PG31088-08	Background	0.56	ND
PG31088-10	Background	5.27	ND
PG8802-02	North of Station	514.00	0.16
PG8802-03	North of Station	2.74	ND
PG8802-04	Irrigated Alfalfa Field	9.12	ND
PG8802-06	Irrigated Alfalfa Field	5.53	ND
PG8802-07	Station Site	15.50	ND
PG8802-08	Area C	4730.00	0.05
PG8802-10	Area A	3940.00	0.93
PG8802-11	Area A	48.30	ND
PG880316-01	Irrigated Alfalfa Field	53.70	ND
PG880316-02	Irrigated Alfalfa Field	13.00	ND
PG880316-03	Irrigated Alfalfa Field	7.93	ND
PG880316-08	North of Station	6.41	ND
PG880316-09	North of Station	5.58	ND
PG880316-10	North of Station	2.33	ND
PG880317-01	Irrigated Alfalfa Field	34.30	ND
PG880317-02	Irrigated Alfalfa Field	11.10	ND
PG880317-20	North of Station	8.12	ND
PG880317-21	North of Station	2.48	ND
PG880317-22	Background	1.57	ND
PG88031717A	North of Station	ND	ND
PG88031717B	North of Station	4.97	ND
SF001	Irrigated Alfalfa Field	37.20	ND
SF002	Irrigated Alfalfa Field	18.90	ND
SF003	Irrigated Alfalfa Field	43.00	ND
SF004	Irrigated Alfalfa Field	29.50	ND
SF005	Irrigated Alfalfa Field	81.60	ND
SF006	Irrigated Alfalfa Field	63.70	ND
SF007	Irrigated Alfalfa Field	42.70	ND
SF008	Irrigated Alfalfa Field	46.50	ND
SF009	Background	6.80	ND
SF010	Background	8.10	ND

Note: Detection limits = 0.01 mg/kg for Cr(T); and 0.05 mg/kg for Cr(VI).
Source: Ecology and Environment, Inc., 1988.

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Cr(T) concentrations in the Mojave Dairy field samples ranged from 5.5 to 81.6 mg/kg, with an average value of 33 mg/kg. This average is approximately three times the average concentration of 9.5 mg/kg Cr(T) in the offsite background soil samples, but falls within the range of 5 to 300 mg/kg Cr(T) typically found in most non-serpentine soils.

Various analyses were performed on site and agricultural field soils; these results are presented in the Site Characterization Report. Based on a review of these results, these surface soils are:

1) typically alkaline;
2) slightly oxidizing;
3) very high in organic carbon in field soils, lower levels in site soils; and
4) with a normal cation exchange coefficient in field soils, somewhat lower in site soils.

These soils have high iron content, and a manganese concentration 3.3 times lower than that necessary to support oxidation of Cr(III) to Cr(VI). Therefore, these surface soils should demonstrate a capability to convert Cr(VI) to Cr(III) and to hold the resulting chromium compounds in the upper few inches of soil. As demonstrated in the data reported in the Site Characterization Report little chromium is found at depth and the majority (>99%) is in the Cr(III) form. Based on the insolubility of Cr(III) and the results of the WET analysis showing little if any extractable chromium, it is very unlikely that chromium in site or agricultural field soils will leach to groundwater.

3.3.3. AIR DATA

<u>Methods</u>

Three phases of ambient air monitoring were conducted at the PG&E Hinkley site, as summarized below:

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Phase 1. During the site characterization, air monitoring data were collected during specified soil boring and monitoring well drilling activities.

Phase 2. During the initial risk assessment field work, sampling of aerosol mist generated by irrigation sprinklers was performed.

NIOSH Method 7600, issued in February 1984, was employed for each of the first two phases of air monitoring for Cr(VI). A description of this method is provided in Appendix A3.

Phase 3. Finally, a second aerosol mist sampling event was conducted with high volume pumps to compare with other analytical techniques and achieve a more representative detection limit.

A brief description of the methods used for each phase of air monitoring is presented below:

Phase 1. Air monitoring was conducted during selected site characterization field activities to test for potential worker exposure to Cr(VI). Since the highest exposure potentials were determined to be associated with trenching and boring activities in the former disposal areas, continuous air monitoring was conducted during these operations to characterize potential exposure levels and, if necessary, to modify health and safety procedures. Two air sample pumps were used with cassette holders containing polyvinyl chloride (PVC) filters with a pore size of 5.0 um. In general, one pump was set up to sample air downwind of work and the second pump was worn by a worker. The second pump was occasionally set up to sample air upwind of the work area to establish background air quality. The pumps sampled air from the breathing zone throughout an 8-10 hour shift. A total of 52 air samples were collected and sent to ATI for Cr(VI) analysis. A detailed discussion of air sampling methods and activities is presented in the Site Characterization Report.

Phase 2. Another set of air monitoring data to support this risk assessment was collected in the irrigated alfalfa fields of the Mojave Dairy. The purpose of this monitoring was to determine the level of airborne Cr(VI) in the water aerosol generated by the irrigation sprinkler heads. This field was selected for testing because the highest Cr(VI) concentrations occur in wells used to irrigate this area. The sampling approach was identical to that described earlier for field monitoring. The filter cassettes were placed on 5-foot-high stakes to allow for monitoring in the breathing zone. Figure 3-10 shows the monitoring locations. Wind direction and speed were recorded periodically using an anemometer. The speed ranged between 0-10 mph with occasional gusts of 15 mph. Wind direction during the first test started from the northwest, but began blowing from the southwest after midday. There was no wind during the second test. In addition, two water samples were collected from the near and far sprinkler heads of the irrigation system. There are a total of 20 sprinklers on this lateral line, each having a flow rate of 2.6 gpm.

Phase 3. Finally, a follow-up sampling of irrigation-system aerosols took place between August 2 and 9, 1988. The area studied was the same irrigated alfalfa field examined during the initial aerosol mist sampling effort. The sampling protocol was modified according to California Air Resources Board (CARB) recommendations; the intent was to optimize low-level detection capabilities for chromium, consistent with the level of sensitivity required for calculating cancer risk as described in Chapter 7.0. The chosen method was similar to the EPA sampling technique for total suspended particulates (Federal Register Vol. 36, 1971).

A total of nine high-volume air sampling pumps were staged at three locations near the Mojave Dairy alfalfa field; one location was established upwind and two locations were established downwind, near residences bordering the field. Volumes of air drawn through the high volume pumps ranged from 6833 m^3 to 9851 m^3. One set of filters from each location were analyzed for Cr(T), and the other two sets of filters from each location were analyzed for Cr(VI). Two water samples were also collected from the sprinkler heads for Cr(T) analysis.

Data

Phase 1. No Cr(VI) was detected in air samples collected during soil boring and well installation activities. These data

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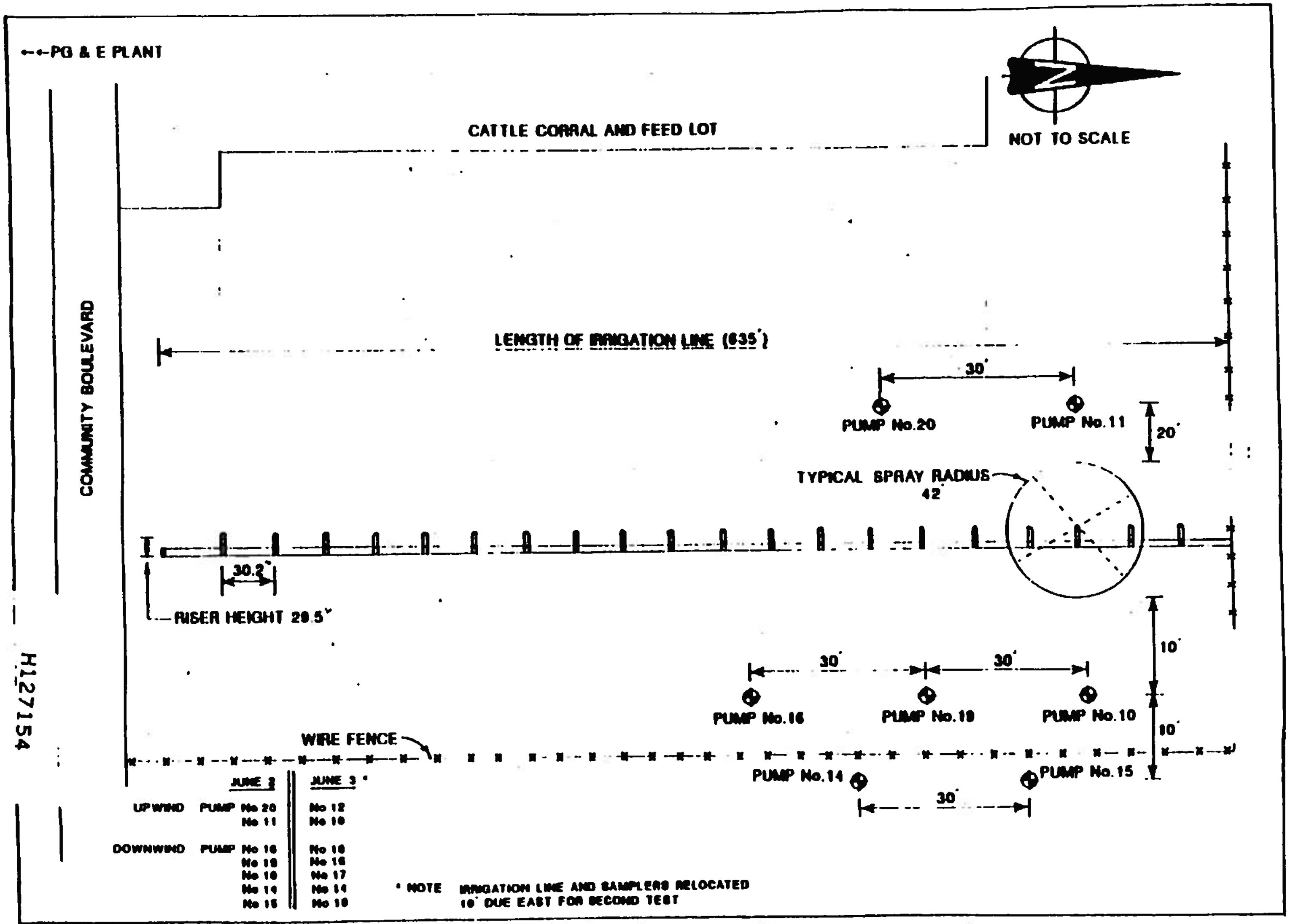

		JUNE 2	JUNE 3 *
UPWIND	PUMP	No 20	No 12
		No 11	No 13
DOWNWIND	PUMP	No 16	No 18
		No 19	No 16
		No 10	No 17
		No 14	No 14
		No 15	No 19

* NOTE IRRIGATION LINE AND SAMPLERS RELOCATED 10' DUE EAST FOR SECOND TEST

ecology and environment, inc.

Figure 3-10 AIR MONITORING LOCATIONS IN IRRIGATED ALFALFA FIELD indicate that even in areas of known soil contamination, no significant Cr(VI) was generated during activities that typically produce dust. Cr(VI) was selected for analysis due to its known carcinogenic potential.

Phase 2. The results of the first air monitoring test conducted in the irrigated alfalfa field are presented in Table 3-5. As in the preceding two tests, no Cr(VI) was detected. Based on the analytical results (Table 3-5) and the detection limit of 5 ug Cr(VI)/filter, possible exposure concentrations were calculated to be approximately 11.7 ug/m^3 (Table 3-6). These results are within the expected range of the analytical method.

Analysis of the water samples collected from the two irrigation sprinklers (samples WF001 and WF002) indicated an average Cr(VI) concentration of 0.285 mg/l in the irrigation water. The control sample contained a Cr(VI) concentration of less than 0.01 mg/l. From these data, the amount of Cr(VI) emitted to the air was calculated at approximately 2.8 milligrams per minute (mg/min) of Cr(VI) from each nozzle. The lateral line of 20 nozzles therefore emitted approximately 56 mg/min of Cr(VI). Assuming a deposition efficiency of 90% for the irrigation system (Ude, 1988; Zoldoske, 1988), approximately 10% of the sprayed water could result as drift (5.6 mg/min.). To calculate the possible instantaneous air concentration at the edge of the spray radius, it was assumed that 0.093 mg/sec of Cr(VI) drifted into a volume of 388m^3 (2m height X 1m width X 194m length). Therefore, the resulting instantaneous concentration would be less than 0.2 ug/m^3, which is over two orders of magnitude less than the detection limit. This simple model provides a possible explanation of why it was not possible to detect any Cr(VI).

Phase 3. The results of the second aerosol sampling are presented in Table 3-7. Analysis for Cr(T) in one set of high volume filter samples (nitric acid digestion and inductively coupled plasma atomic absorption). The total chromium concentrations at the three stations did not vary significantly (range = 5.4 to 6.5 x 10^{-6} mg/m^3), although the higher of the levels was detected at the station immediately downwind of the sprinklers.

Sample No. E & E	Pump No.	Flow Rate (lpm)	x Time (min.)	= Volume (l)	Cr(VI) Amount per Sample Filter (Total ug)
AF001	15	2.05	262	537	<5
AF002*	14	--	--	--	--
AF003	16	2.05	263	539	<5
AF004	19	2.05	263	539	<5
AF005	10	1.58	261	412	<5
AF006	11	2.05	263	539	<5
AF007	20	2.05	262	537	<5
AF008	--	--	--	Field Blank	<5
AF009*	12	--	--	--	--
AF010	10	1.87	306	572	<5
AF011	19	2.05	300	615	<5
AF012	18	1.19	299	356	<5
AF013*	14	--	--	--	--
AF014	17	1.87	298	557	<5
AF015	16	1.85	298	581	<5
AF016	--	--	--	Field Blank	<5

* Sample not analyzed due to pump failure
Detection Limit: 5 ug
Source: Ecology and Environment, Inc., 1988

Table 3-5
AIR MONITORING RESULTS FOR IRRIGATED FIELD

H127156

Sample	Air Volume (L)	Air Volume (m_3)	Test Period (min.)	Cr(VI) (ug)	Cr(VI) (ug/m_3)
6/1/88 Test					
Upwind:					
AF006	539	0.539	263	5	9.3
AF007	537	0.537	262	5	9.3
Downwind:					
AF001	537	0.537	262	5	9.3
AF003	539	0.539	263	5	9.3
AF004	539	0.539	263	5	9.3
AF005	412	0.412	261	5	12.0
6/2/88 Test					
Upwind:					
AF010	572	0.572	306	5	8.7
Downwind:					
AF011	615	0.615	300	5	8.1
AF012	365	0.365	299	5	14.0
AF014	557	0.557	298	5	9.0
AF015	581	0.581	298	5	8.6
TLV-TWA					50.0

Source: Ecology and Environment, Inc., 1988.

Table 3-6
HEXVALENT DHROMIUM EXOSURE CONCENTRATION IN AIR ADJACENT TO AN IRRIGATED FIELD

TABLE 3-7
AIR SAMPLING FOR IRRIGATION AEROSOL
AUGUST, 1988

Sample ID	Volume of Air Sampled (m^3)	Cr(I) Concentration (mg/m^3)	Cr(VI) Concentration (mg/m^3)
U1-1	9851	5.6×10^{-6}	3.8×10^{-7}
U1-2	8362		2.1×10^{-7}
U1-3	9314		
D1-1	8544	6.5×10^{-6}	2.5×10^{-7}
D1-2	8737		3.4×10^{-7}
D1-3	8747		
D2-1	6833	5.4×10^{-6}	2.5×10^{-7}
D2-2	8041		1.3×10^{-7}
D2-3	9036		

<u>Sample Set</u>	<u>Sampling Location</u>
U1	Upwind from sprinkler line
D1	Downwind from sprinkler line, between sprinkler and tree line
D2	Downwind from sprinkler line, behind trees, Near houses

H127158

$$\frac{1 \times 10^{6}\ ng}{mg} \times 3.8 \times 10^{-7} \frac{ng}{m^3} = 3.8 \times 10^{-1}\ ng/m3 = 0.38\ ng/m3$$

Analysis for Cr(VI) in the remaining two sets of filter samples at each station was performed by Truesdail Laboratories. The extraction method at each station involved contacting the filter with an alkaline solution to preferentially remove Cr(VI). The extract was then analyzed according to EPA Method 218.2 (graphite furnace atomic absorption analysis for total chromium). The results, reported as Cr(VI), ranged between 1.3 to 3.8 x 10^{-7} mg/m^3. The variation does not follow any apparent pattern between sample stations. The replicate analysis at each of the three stations showed a relative percent difference ranging from 30 to 80%.

The Cr(VI) concentration in groundwater samples collected during this air sampling task were measured at 0.28 to 0.29 mg/l. A control sample contained less than 0.01 mg/l of Cr(VI). These groundwater Cr(VI) concentration results are similar to the Phase 2 water data previously discussed.

3.3.4. BIOTA DATA

Flora: Methods and Data

Vegetation samples were collected from the Mojave Dairy alfalfa field and an alfalfa field approximately three miles to the southwest of the station (Figure 3-7). The purpose of this sampling was to determine the level of Cr(T) in alfalfa growing within the area of the plume of contamination and to compare this level to off-site background levels.

Both the dairy and background vegetation samples were divided into root and foliage and placed in individual ziplock plastic bags. All samples were custody-sealed and sent via courier to ATI for analysis.

Results of the analyses are summarized in Table 3-8. The foliage of the off-site background samples were found to contain approximately 0.85 mg/kg of Cr(T), which is approximately half the amount found in background root samples (1.6 mg/kg). Average Cr(T) levels in foliage and root samples of the Mojave Dairy alfalfa plants were approximately equal, at 5.4 and 5.3

Table 3-8

CHROMIUM CONCENTRATIONS IN VEGETATION

Sample Chromium ID No.	Location	Tissue	Tot (mg/kg)
PF001R	Mojave Dairy	Vege - Root	8.30
PF001P	Mojave Dairy	Vege - Foliage	2.50
PF002P	Mojave Dairy	Vege - Foliage	1.70
PF002R	Mojave Dairy	Vege - Root	4.50
PF003P	Mojave Dairy	Vege - Foliage	1.50
PF003R	Mojave Dairy	Vege - Root	3.10
PF004P	Background	Vege - Foliage	0.90
PF004R	Background	Vege - Root	1.60
PF005P	Background	Vege - Foliage	0.80
PF005R	Background	Vege - Root	1.70
PG31088-01	E. of PG&E Station	Vege - Foliage	0.64
PG31088-03	E. of PG&E Station	Vege - Foliage	0.43
PG31088-05	E. of PG&E Station	Vege - Foliage	0.40
PG31088-07	E. of PG&E Station	Vege - Foliage	0.19
PG31088-09	E. of PG&E Station	Vege - Foliage	0.26
PG8802-05	Mojave Dairy	Vege - Foliage	12.70
PG8802-09	PG&E/Pond Area A	Vege - Foliage	2.66
PG88317-09	Mojave Dairy	Vege - Foli./Root	8.29
PG88317-10	Mojave Dairy	Vege - Foliage	5.72
PG88317-19	Dairy N. of Hi-58	Vege - Foliage	1.09
PG88317-21	2 mi E. of PG&E Sta.	Vege - Foliage	2.48
PG88317-23	2 mi E. of PG&E Sta.	Vege - Foliage	0.90

Source: Ecology and Environment, Inc., 1988 mg/kg,respectively, which is roughly five times the levels found in background samples.

Fauna: Methods and Data

In order to evaluate a worst-case exposure of fauna residing in the study area, two Holstein cows (#401 and #1066) were purchased from the Mojave Dairy to obtain gross pathological information and tissue samples for chromium analyses. Both of the cows selected were between seven and ten years old. Cow #401 was fresh (producing milk) and cow #1066 was pregnant. These cows had been in residence at the dairy for five years. During this time these cows were potentially exposed to Cr(VI) and Cr(III) from the groundwater. Exposure pathways include:

(1) Drinking water (groundwater);

(2) Water used to wash animals down (groundwater);

(3) Hay (alfalfa grown at the dairy); and

(4) Airborne dust and/or water aerosol (from the fields and spray irrigation system).

Cows provided an easily obtained surrogate for assessing potential body burdens in similar animals and possibly humans. Therefore, these data were obtained for use in the risk assessment.

The cows were injected with a lethal dose of sodium phenobarbital. Dissection, gross pathology, and collection of tissue samples (liver, kidney, adrenal gland, spleen, lung, muscle, bone marrow, and milk) were done by Dr. Tom Porter, DVM (Mobile Veterinarian Service, 16385 Walnut Street, Hesperia, CA 92345). All activities were conducted at the Mojave Dairy. Upon completion of sampling, the carcasses were removed and properly disposed of by a licensed disposal service. These samples were double-bagged in polyethylene bags and shipped (on ice) to the laboratory (Quality Assurance Laboratory, 6555 Nancy Ridge Dr., San Diego, CA) for analysis of Cr(T) (EPA Method 7191).

The laboratory analytical results for Cr(T) levels in the tissues are presented in Table 3-9. Most samples were found to be below the detection limit of 120 ug/kg. However, the lung of #401, and the liver, adrenal gland, and spleen of #1066 had levels slightly above the detection limit. The highest level was 335 ug/kg (wet weight), found in the spleen of #1066. In addition to these tissue analyses, a gross pathological exam was conducted by the attending doctor during dissection. No abnormalities were observed in any analyzed tissue of either cow.

Table 3-9

TOTAL CHROMIUM CONCENTRATIONS IN VARIOUS TISSUES

	Total Chromium (ug/kg, wet weight)	
Tissue/Organ	#401	#1066
Liver	N.D.[1]	158
Kidney	N.D.	N.D.
Adrenal	nc[2]	150
Spleen	nc[2]	335
Muscle	N.D.	N.D.
Bone Marrow	N.D.[3]	N.D.[4]
Lung	202	N.D.
Milk	N.D.	N.D.[5]

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[1] The limit of detection is 120 ug/kg. Values below this limit are reported as non-detectable (N.D.).

[2] Unable to collected samples because of carcass position.

[3] Collected from rib.

[4] Collected from hip.

[5] Cow #1066 was dry due to pregnancy. This sample represents milk in dairy cooling tank.

Source: Ecology and Environment, Inc., 1988

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4.0 DESCRIPTION OF EXPOSED POPULATIONS

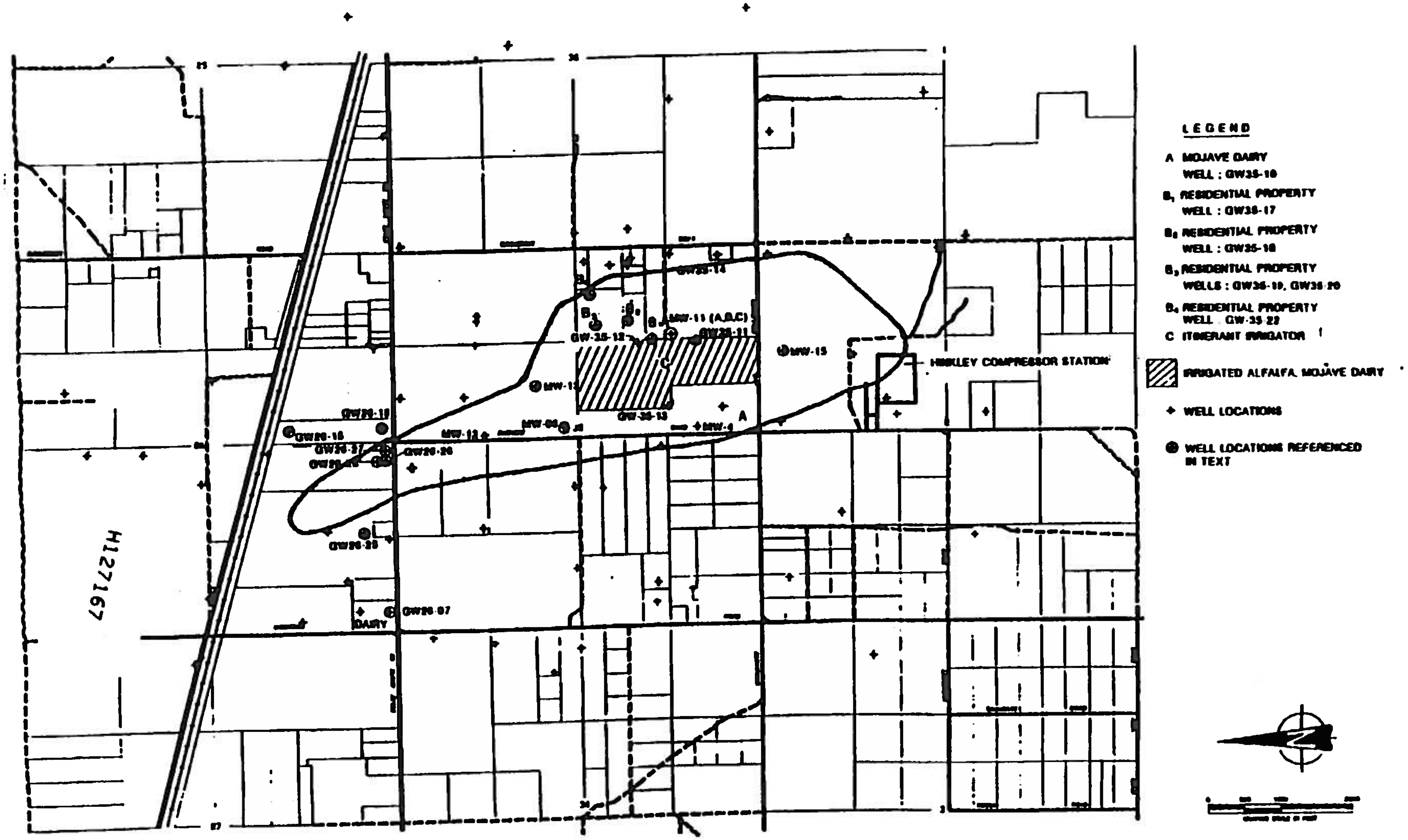
4.1. HUMAN RECEPTORS

A comprehensive review and description of the demography of the Hinkley site and the surrounding region now and in the future has been prepared by E&E. It is presented in Appendix A4. However, only a very small part of this region can be affected by the groundwater or on-site soil concentrations of chromium. This risk assessment therefore addresses only those human and ecological receptors in the limited locale of the compressor station which could be impacted.

The human receptors specifically addressed in this assessment are those local residents and workers who may be significantly exposed to hexavalent and total chromium originating in the groundwater plume. Such exposure can occur from the aerosol generated by alfalfa irrigation employing chromium contaminated groundwater, from soil irrigated with groundwater and from various household and farm uses of domestic water taken from the chromium-contaminated groundwater supply.

The map of Figure 4-1 shows the hexavalent chromium groundwater plume, the principal dairy farm (Point A) and residences (Points B_i) closest to the plume center and most likely to be impacted via the above pathways. Figure 4-1 also shows the domestic and irrigation wells which could provide groundwater to these environmental pathways. Other residences and another farm located further away (e.g., as far north as State Route 58) are also within the zone of influence of the groundwater plume. However, for the remedial alternatives considered, the possible exposures at these more northern sites are reduced relative to those at the sites shown in Figure 4-1. Therefore residents and workers (dairy farmer and alfalfa irrigator) shown in Figure 4-1, who are closer to the plume center, represent worst case exposure scenarios.

The sections immediately following describe the hypothetical receptors considered and their activities which might lead to inhalation, dermal, and ingestion route exposures. The detailed



LOCATIONS OF RECEPTORS AND GROUNDWATER WELLS

FIGURE 4-1

ecology and environment, inc.

assumptions concerning actual exposure time intervals and levels are presented in Chapter 7.0, Human Health Risk Assessment, and in Appendix A7. A general overview of the demography of the area near the Hinkley Compressor Station is presented in Appendix A4, and describes the population now and in the future in an area considerably larger than that depicted in Figure 4-1. The receptors identified in Figure 4-1, however, represent worst-case receptors for assessing the health risks posed by the remedial alternatives under consideration.

4.1.1. DAIRY FARMING RESIDENT

The dairy farm just north of Community Boulevard, the Mojave Dairy (Point A in Figure 4-1), is the dairy located closest to the high concentration part of the plume. This dairy farm has been chosen to represent the maximum exposure/risk associated with this type of operation. The only person evaluated at the dairy is the farmer himself, because he performs various duties using the chromium-contaminated groundwater which are not performed by other persons. It was assumed that the farmer worked at Point A in Figure 4-1, but lived at Point B_3, since the domestic water supply at Point B_3 has maximum Cr(VI) concentrations (this is not the case today, but was assumed as a possibility to represent a worst case.) A homemaker, child, or nonfarmer-laborer located at this dairy would not be exposed at levels equivalent to those experienced by similar persons at the residences just east of the dairy farm (Points B_1 in Figure 4-1) because of downwind proximity to the irrigation aerosol and because of the greater domestic water hexavalent chromium concentration at Points B_1 residences. Therefore, these latter receptors were evaluated at Point B_3 (residence with maximum groundwater concentration of Cr(VI)) rather than at the dairy farm.

The farmer-receptor was assumed to perform two general types of activities involving contaminated groundwater: occupational duties and indoor living activities. The occupational activities were presumed to lead to aerosol inhalation and dermal groundwater and soil absorption exposures, and included washing of cows, barn, and vehicles. Dermal exposure would result from wetting of hands, arms, feet, and legs, and from skin contact with soils contaminated from the ground water. Inhalation exposure would result from aerosols produced during the above operations, and from aerosols produced in the irrigation of nearby alfalfa fields and transported to the ambient air of the dairy farm.

Indoor living activities performed by the farmer were assumed to include washing of hands, sleeping, showering, eating, and miscellaneous free time actions. Dermal exposures would result from wetting of body during some of these activities; inhalation exposures would result from showering and from breathing indoor air throughout the indoor period (air contamination resulting from irrigation aerosol which has penetrated the indoors). Ingestion exposures potentially could result from eating home-grown beef and produce, and drinking milk, which may be contaminated as a result of the groundwater. These foods could be contaminated because the cows drink or are washed with the groundwater, or inhale irrigation spray or other aerosols derived from the groundwater. Exposure due to consumption of beef and ingestion of milk are considered possible, but not likely, and are included in order to be health-conservative.

4.1.2. OTHER RESIDENTS

All the other receptors were located at the residence at Point B_1 in Figure 4-1; five different persons were considered. Point B_1 was used because the domestic groundwater hexavalent chromium concentrations, as well as the irrigation-produced aerosols, would lead to maximum exposure of persons residing in the vicinity of the groundwater plume.

Homemaker

A female, who lived her adult life at Point B_1, was evaluated. Her exposures resulted from both indoor and outdoor activities. Outdoor activities take place in the residence yard, resulting in exposures from dermal contact with contaminated soil, and inhalation of aerosol from alfalfa irrigation and from

Offsite Laborer

A laborer who works offsite was assumed to reside at Point B_1. He had no exposure to local groundwater while working. At home he had the same indoor and outdoor exposures as the irrigator described above.

Children

Children were assumed to reside at Point B_1. Children were assumed to live full lives at that location, growing up to become each of the adult receptors considered. In their childhood these individuals received domestic exposures both indoors and outdoors similar to those of the irrigator (excluding vehicle washing), but with the extent adjusted to reflect different time intervals of activities such as playing outdoors, and with exposure factors such as exposed skin areas and pica soil ingestion appropriately factored in.

4.2. NON-HUMAN RECEPTORS

The risk assessment for non-human receptors focused on those particular receptors (individuals and populations or communities) which are most likely to be exposed and/or impacted by chromium in the study area. The following describes the selection criteria, the animals and plants that were selected, and the justification for their selection.

4.2.1. SELECTION CRITERIA

Specific criteria were used to select wildlife, domestic animals, and plant species for analysis in this risk assessment. The extent to which a species is exposed to a contaminant depends on the species abundance, habitat preferences, food habits, and seasonal occurrence within the contaminated habitat. Factors that formed the basis of the selection criteria are outlined below:

irrigation of the family garden. Indoor exposures result from the indoor activities listed above for the farmer plus those associated with housekeeping duties. Additional inhalation and dermal exposure would result from washing of dishes and clothes.

Irrigator

A laborer whose occupation is to irrigate alfalfa fields utilizing groundwater extracted from the contaminated plume was also assumed to reside at the same Point B_1. This is not the case today, but was assumed as a possibility in order to be health conservative. His indoor (house) exposures were the same as those of the farmer. His outdoor activities would comprise both occupational and domestic actions. Domestic activities included gardening in his own yard, where dermal and inhalation exposures could occur. Dermal exposure would result from skin contact with contaminated soil, inhalation exposure would result from garden and alfalfa field irrigation aerosols. Outdoor activities also included vehicle washing, leading to dermal and inhalation exposure, the latter from irrigation aerosols transported to the ambient air of the residence yard.

Irrigator occupational exposures were assumed to derive from moving the irrigation equipment from one location in the alfalfa field to another. Inhalation exposures resulted from aerosols produced by sprinklers and were assumed to be relatively brief, corresponding to the time during which the irrigator approached the feeder line and disconnected it from the sprinkler line, thereby shutting off the water. It was also assumed that the irrigator avoided entering the denser spray area of the sprinklers as long as possible when approaching the feeder disconnect point. Dermal exposure would result from wetting of the irrigator's hands, arms and legs while walking through the wet alfalfa as he disconnected the piping segments, moved them to the new location, reconnected them and then reconnected the sprinkler line to the feeder line. It was assumed that the irrigator did not wear protective clothing to prevent wetting of hands, arms, or legs.

(1) Is the species designated as rare, threatened, or endangered by state or federal agencies?

(2) Does the species have food habits or food preferences that may expose it to the contaminant?

(3) Does the species have habitat preferences that include habitats found within the contaminated area?

(4) Does the species occur year-round or seasonally in habitats within the contaminated area?

(5) Is the species important in the food chain?

Species of potential concern were selected, using these criteria, during a review of existing information on biological resources of the central and southwestern Mojave Desert. Local, state, and federal agencies were also consulted during this process.

4.2.2. VEGETATION AND HABITAT TYPES OF CONCERN

The project area is within the Mojave Desert Scrub Vegetation habitat, as classified by Rowlands et. al., (1982). Natural vegetation in the area is dominated by creosote bush (*Larrea tridentata*). Other common plant species in the area, associated with the creosote bush, are white bur sage (*Ambrosia dumosa*), the cholla cacti (*Opuntia spp*.), and burrobush (*Hymenoclea spp*.) (Rowlands et al., 1982; MacMahan, 1985). The Hinkley Compressor Station is located approximately 1.5 miles east of an unusual plant assemblage, as designated by the Bureau of Land Management in its California Desert Conservation Area Plan (Bureau of Land Management, 1980). This large area, known as the Western Mojave Desert Mojave Saltbush Assemblage, is dominated by Mojave saltbush (*Atriplex spinifera*), with the following associated species: *Atriplex polycarpa*, *Ceratoides lanata*, *Tectradlymia glabrata*, and *Yucca brevifolia* (Rowlands et al., 1982).

Much of the site area has been converted to pasture (Appendix A4 Demographics Report). The most widespread plant species used for pastureland in the area is alfalfa (Medicago sativa) (Ecology & Environment, 1988). Numerous other species of grasses occur in the pasture areas but are of less economic or agricultural importance. These pasture habitats, some of which lie over the plume, contain elevated levels of chromium due to irrigation with contaminated groundwater (see Section 3.3.2). A search for critical or sensitive habitats near the site, other than those identified by the BLM, was conducted through the California Natural Diversity Data Base (CNDDB). Database printouts are included in Appendix A4. No critical habitats were identified within a 5-mile radius of the compressor station. Also, there are no state or federally owned parks or preserves within 5 miles of the station.

The CNDDB included two listings of rare plant species within 5 miles of the station. The Mojave monkey flower (Mimulus mohavensis) is located within a large area centered approximately 6 miles east of the station. The portion of the monkey flower range nearest to the station is approximately 2.2 miles due east. This large area is indicated on CNDDB maps as a non-specific boundary within which the monkey flower was last collected in 1941. The monkey flower is considered a sensitive species by the CNDDB. The second listing is that of the Barstow woolly sunflower (Eriophyllum mohavense), located approximately 5 miles southwest of the station. A large number of Barstow woolly sunflowers have been observed at this location. The Barstow woolly sunflower is a candidate for federal protection status. Because both the monkey flower and the Barstow woolly sunflower are located within a different drainage system or watershed than the compressor station, these plants will most likely be unaffected by the contaminated groundwater plume.

4.2.3. AQUATIC FAUNA

There are no permanent surface waters in the vicinity of the station. The Mojave River, located approximately 1 mile southeast of the station, is an ephemeral stream that flows only during and after heavy rains.

The CNDDB listed a single aquatic species of concern near the site. The Mojave Tui Chub (Gila bicolor var. mohavensis), a state- and federally-designated endangered species of fish, is located 3.5 miles north of the station. The location is an experimental transplant of the species in a pond at the Desert Research Station of the Bureau of Land Management. It is highly unlikely that this species will be impacted within the near future (20 years) by the groundwater chromium plume. This conclusion is based upon the fact that the plume is lower than the pond and now extends no more than 1.5 miles north of the station, and groundwater modeling of the plume under existing hydraulic conditions shows little movement further north over the next 20 years (see Section 6.2).

4.2.4. TERRESTRIAL BIOTA

The California Department of Fish and Game and its Wildlife Habitat Relationship Program (WHRP) were consulted to determine terrestrial wildlife species that might be present in desert scrub, desert wash, and pasture habitats in the general project area. The WHRP reported that 111 species of birds, 61 species of mammals, eight species of amphibians, and 42 species of reptiles could be found in habitat types near the station. A list of these species is contained in the WHRP printout in Appendix A4.

The CNDDB had no recorded locations of rare wildlife species within 5 miles of the station. However, based on a review of the WHRP data base, there are potentially nine species of concern that use desert scrub, wash, or pasture habitat in the general vicinity of the compressor station. These species are listed in Table 4-1. Based on discussions with a state biologist in the California Department of Fish and Game (CDFG), several of these species were more likely than others to occur near the area of concern (Vernoy, 1988). These include the Mojave ground squirrel (Spermophilus mohavensis), the badger (Taxidea taxus), and the desert tortoise (Gopherus agassizi). The Mojave ground squirrel

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Table 4-1

WILDLIFE SPECIES OF SPECIAL CONCERN IN THE VICINITY OF THE HINKLEY COMPRESSOR STATION

Species	Status	Habitat	Seasoning
Black-shouldered Kite (Elanus caeruleus)	CA Protected	Pasture	Year-long
Golden Eagle (Aquila chrysaetes)	CA Protected Forest Service Sensitive	Desert Scrub Desert Wash Pasture	Year-long Year-long Year-long
Prairie Falcon (Falco mexicanus)	Forest Service Sensitive Pasture	Desert Scrub Desert Wash Year-long	Fall-Spring
Mojave Ground Squirrel* (Spermophilus mohavensis)	CA Rare	Desert Scrub	Year-long
Kit Fox (Vulpes macrotis)	Federally Endangered CA Rare	Desert Desert Wash Pasture	Year-long Year-long Year-long
Ringtail (Bassariscus astutus)	CA Protected	Desert Scrub Desert Wash Pasture	Year-long Year-long Year-long
Badger* (Taxidea taxus)	CA Rare Forest Service Sensitive	Desert Scrub Desert Wash Pasture	Year-long Year-long Year-long
Mountain Sheep (Ovis canadensis)	CA Rare Forest Service Sensitive	Desert Scrub Desert Wash	Year-long Year-long
Desert Tortoise* (Gopherus agassizi)	Bur. Land Management-Sensitive	Desert Scrub Desert Wash	Year-long Year-long

*Species likely to occur in the project vicinity (Vernoy, 1988). Source: California Department of Fish and Game Wildlife Habitat Relationship System, 1988. Refer to Appendix A4.

is a state-designated threatened species (Appendix A4). Although the CNDDB has no recorded locations of Mojave ground squirrels in the vicinity of the station, the area provides suitable habitat for this species and individuals could be present (Vernoy, 1988). The Mojave ground squirrel preferentially inhabits creosote bush scrub in deserts year-round, and feeds on seeds and other plant material (Whitaker, 1980). With respect to the food chain, it is an important source of prey for badgers, canids, and raptors.

The badger is a state-designated rare and protected species, and a U.S. Forest Service designated sensitive species (refer to Appendix A4). The animal reportedly inhabits the area in the vicinity of the station (Vernoy, 1988). It inhabits desert scrub, desert wash, and pastureland on a year-round basis. It is a carnivore that feeds on small mammals, including ground squirrels, pocket gophers, rats, and mice (Whitaker, 1980).

Based on information from the WHRP Database, the project area is within the habitat range of the desert tortoise, a Bureau of Land and Management-designated sensitive species. The desert tortoise inhabits arid sandy or gravelly washes, canyon bottoms, and areas with creosote bush, thorn scrub, and cacti. They feed on grasses and forbs (MacMahon, 1985). Although the CNDDB had no reported listings of the tortoise within 5 miles of the station site, the area does provide suitable habitat for the species, and it is known to occur in the area (Vernoy, 1988). Furthermore, the station and the areal extent of the contaminant plume are within 2 to 3 miles of land designated as crucial habitat for the tortoise in the BLM's California Desert Conservation Area Plan (Bureau of Land Management, 1980).

The desert cottontail rabbit (Sylvilagus audubonii) and California vole (Microtus californicus), although not rare species, were selected because their habitat preferences and food habits suggest they may potentially consume contaminated vegetation. The desert cottontail uses grasslands, creosote bush, and desert wash habitat. It feeds primarily on grasses, mesquite, and cacti. It is a year-round resident in these habitats and is a source of prey for predators. The California vole uses grassy areas, where it feeds on grasses and other green vegetation, including underground roots. The California vole is also a source of prey for raptors and other predators.

In addition to wildlife found near the station, there are domestic fauna that use habitat potentially affected by chromium contamination. The primary domestic animals of concern are dairy cattle which are sited at two farms within the zone of contaminated groundwater. The first farm, which supports over 500 cows, is the Mojave Dairy Farm, located approximately 2,000 feet north of the station, at the corner of Community Boulevard and Fairview Road. The second farm, which supports over 300 cows, is located approximately 1.4 miles northwest of the station at the intersection of Highway 58 and Mountainview Road (Ecology & Environment, 1988).

4.2.5. SELECTED NONHUMAN RECEPTORS

The following species were selected for analysis for potential ecological risk posed by elevated levels of chromium in soils and groundwater:

(1) Alfalfa;
(2) Mojave Ground Squirrel;
(3) Badger;
(4) Desert Tortoise;
(5) Desert Cottontail Rabbit;
(6) California Vole; and
(7) Dairy Cows.

Alfalfa was the sole floral species selected. This plant is of great agronomic importance in the area. In those fields within the plume's areal limits that are irrigated with contaminated groundwater, this species is exposed to both Cr(VI) and Cr(III) and demonstrates elevated levels of Cr(T), compared to off-site background vegetation samples (Section 3.3.4).

The Mojave ground squirrel, badger, and desert tortoise are all either designated rare, threatened, or sensitive species and, therefore, were selected for analysis. The ground squirrel and tortoise are herbivorous and may be exposed to Cr(III) either by consumption of plants with elevated chromium levels or by ingestion of soil during burrowing, grooming, or eating. The badger, however, probably would not be exposed through the food chain, since chromium is known not to biomagnify (Andren et al., 1973). All three species may drink Cr(VI)-contaminated water found in puddles or rivulets generated by irrigation. They may also ingest water when grooming their pelts after becoming wet from irrigation spray. Finally, dairy cows were selected since they represent an economically important domestic species and food source for humans, and are exposed through food (water, alfalfa, hay) and airborne dust and/or aerosol mist.

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5.0 REMEDIAL ALTERNATIVES

5.1. INTRODUCTION

Various options are available to remediate soil and groundwater contamination from the Hinkley Gas Compressor Station. E & E is currently conducting a feasibility study (FS) to investigate these alternatives. This feasibility study follows an iterative approach to identify, develop and screen alternatives, and present detailed analyses of a range of alternatives for remediation of contaminated soil and groundwater at the site.

The feasibility study evaluates, in detail, three soil remediation alternatives: no action, fencing, and surface controls (asphalt capping). Six groundwater remediation alternatives are developed and evaluated in detail in the feasibility study:

- Groundwater Alternative 1 - Current Irrigation Practice
- Groundwater Alternative 2 - Groundwater Management
- Groundwater Alternative 3 - Accelerated Agricultural Treatment
- Groundwater Alternative 4 - Extraction with Electrochemical or Chemical Treatment with Reinjection
- Groundwater Alternative 5 - Extraction with Electrochemical or Chemical Treatment with Displacement of PG&E Use
- Groundwater Alternative 6 - Extraction with Electrochemical or Chemical Treatment with Displacement of PG&E and Mojave Dairy Use

The "pump and treat" alternatives (4,5 and 6) would pose no health or ecological risk because groundwater would be treated to remove hexavalent chromium. Alternative 2, Groundwater

Management, is essentially the same as Alternative 1, Current Irrigation Practice, in terms of end use (irrigation use of water pumped from the plume). Under Alternative 3, Accelerated Agricultural Treatment, water currently used by Mojave Dairy or other nearby agricultural areas for irrigation would be replaced with water pumped from additional extraction wells sited in the concentrated area of the plume. All of the groundwater remediation alternatives include providing a bottled water supply for drinking and cooking purposes. An additional alternative to the bottled water supply consists of the installation of a new community water supply system, providing drinking water and all other domestic (potable) water supplies. In this risk assessment, three groundwater remediation alternatives are evaluated: Groundwater Alternative 1 - Current Irrigation Practice; Groundwater Alternative 3 - Accelerated Agricultural Treatment; and Groundwater Alternative 1 including the complete replacement of residential water supplies. Included are a study and comparison of the present and future risks associated with each alternative. For purpose of the risk assessment, the related alternatives will be designated as Alternatives 1, 2, and 3. Each alternative is described briefly below.

5.2. GROUNDWATER REMEDIAL ALTERNATIVE 1 - CURRENT IRRIGATION PRACTICE

This remedial alternative is a baseline course of action that does not interfere with or change any of the present operational practices at the Hinkley Compressor Station or activities in the surrounding agricultural/residential community. Also, no formal activity would occur to mitigate chromium levels in groundwater. Groundwater would continue to be used for non-drinking/non-cooking purposes, including irrigation and various domestic activities. On-going supply of bottled water to affected residences for drinking and cooking purposes will be maintained as an element of this alternative.

5.3. GROUNDWATER REMEDIAL ALTERNATIVE 2 - ACCELERATED AGRICULTURAL TREATMENT

Under this alternative, untreated groundwater would be used for irrigation, which is consistent with current practice. Chromium concentrations in the groundwater are not expected to increase, because the source of chromium contamination has been eliminated. Based on Waste Extraction Test results and decreases in chromium concentrations with depth, little chromium is expected to leach from the soil (see Site Characterization Report). This alternative relies on the natural reducing capacity of the soil to convert soluble Cr(VI) to insoluble Cr(III). Furthermore, extraction wells would be strategically placed to control the migration of the plume and to remove the most contaminated water. Under this alternative, approximately ten new extraction wells would be installed in the most concentrated area of the plume. (Refer to the Feasibility Study for locations and additional details). One of the three existing Mojave Dairy irrigation wells would also be retained as an extraction well. Contaminated groundwater pumped from these 11 wells would be combined and delivered (untreated) to the Mojave Dairy where it would enter the Dairy's irrigation system. Groundwater withdrawals under this alternative would not exceed current rates. Thus, no additional overdraft (mining) would occur from the basin and the water table would not be impacted beyond existing demands. Bottled water will be supplied to local residents under this alternative.

5.4. GROUNDWATER REMEDIAL ALTERNATIVE 3 - DOMESTIC WATER REPLACEMENT

This alternative is the same as Groundwater Remedial Alternative 1 except that water is supplied to local residents for all domestic uses.

6.0 ENVIRONMENTAL PATHWAYS

6.1. INTRODUCTION

This chapter describes the migration and transformation of chromium in the environment of the site and its vicinity. Based on observations reported in Chapter 3.0, rates of emission into each environmental compartment are estimated and the resulting chromium concentrations defined. In addition, within each compartment, various biotic and abiotic receptors may occur, and the resulting exposure concentrations for these are also estimated. Estimates are presented for current site conditions as well as for predicted conditions, based on the alternatives to remediate the contaminated soil and groundwater compartments as described in Chapter 5.0.

In this chapter the groundwater compartment is addressed first, and changes in water quality over time are described, incorporating the effects of the three remedial alternatives. The removal of groundwater, and concomitantly Cr(VI), creates the potential for the contaminant to be introduced into other environmental compartments. The major uses of groundwater in the area can result in the emission of water as a spray or mist into air. This occurs both indoors in homes, barns, and milking dairies, as well as outdoors in irrigated fields and gardens.

Another source of emission to air is fugitive dust from soils with elevated levels of chromium. The three main types of releases to air are evaluated: irrigation spray, fugitive dust, and personal showering. Other minor emission sources possibly presenting risks to human health are described in Chapter 7.0. After entering the air compartment, the water, airborne mist, or dust ultimately come to rest on soil and other surfaces. Once in soil, chromium typically becomes adsorbed or precipitated in the III state and remains in the soil unless it is reentrained into the air column. Other potential endpoints for chromium in the environment are biological receptors such as those described in Chapter 4.0. These receptors may be exposed through several pathways, including oral, dermal, and inhalation routes. The soil compartment is analyzed to determine the present and future loading of chromium; two receptors are evaluated to consider possible exposure levels and food chain transmission of chromium.

6.2. GROUNDWATER

It is likely that the groundwater Cr(VI) plume commenced at the site around 1952. Release of Cr(VI) continued until 1966. The total amount of corrosion inhibitor used in cooling towers at the Hinkley facility has been estimated at 65 tons, of which 66 percent by weight is believed to be chromate. It has been estimated that as much as 90% of the total released Cr(VI) may have been removed from the aquifer to date by agricultural wells. This fraction was derived by analyzing plume development since 1952 using the groundwater model described below.

The following calculation addresses the mass of chromium which is believed to currently reside within the boundaries of the groundwater plume, based on the amount originally discharged, the fraction remaining in the plume, and the surface area, thickness, and porosity of the aquifer affected. Conversion factors are also included in the equation below:

$$0.66 \times 65 \text{ tons} \times 909 \text{ kg/ton} \times 0.45 \times 0.1 = 1{,}760 \text{ kg}$$

Where: 0.66 = conversion factor (weight fraction of corrosion inhibitor which was chromate)
65 tons = Total amount discharged
909 kg/ton = conversion factor
0.45 = conversion factor (chromate to chromium)
0.1 = fraction remaining in aquifer

This calculation is a modeled mass balance based on available data and basic information concerning the observed characteristics of the plume.

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To confirm the mass balance equation presented above, a calculation based on the measured concentrations of chromium within the plume was derived. This calculation assumes a plume area of 250 acres, an average saturated thickness of 50 feet, and a porosity of 30%. The volume of water within the 0.05 mg/l plume (see Figure 2-2) may therefore be calculated as shown below:

$$250 \text{ acres} \times 50 \text{ feet } (1.23 \times 10^6 \text{ l/acre-foot}) \times 0.3\% = 4.6 \times 10^9 \text{ liters}$$

The average concentration of chromium within the plume can be estimated:

$$1{,}760 \text{ kg}/4.6 \times 10^9 \text{ liters} = 3.8 \times 10^{-7} \text{ kg/l} = 0.38 \text{ mg/l}$$

While this is of course a very rough approximation, it compares favorably with the concentrations reported in Table 3-3, and is within the range of values reported for wells in the plume.

The groundwater model estimation of 90% chromium removal by agricultural wells can also be accounted for by examining chromium concentrations in soils in nearby agricultural fields within the plume boundary, and in particular at the Mojave Dairy. The total mass of chromium present in irrigated soils can be calculated based on:

- an average measured chromium concentration of 33 mg/kg over a three foot depth (see Section 3.3.2.).
- an irrigated area of 60 acres.

The mass of chromium remaining in these soils is estimated as follows:

$$60 \text{ acres} \times 43{,}560 \text{ ft}^2\text{/acre} \times 3 \text{ ft.} \times 28{,}329 \text{ cm}^3\text{/ft}^3 \times 1.5 \text{ gm/cm}^3 \times 10^{-3} \text{ kg/gm} \times 33 \text{ mg/kg} \times 10^{-6} \text{ kg/mg} = 10{,}995 \text{ kg}$$

Where:
$43{,}560 \text{ ft}^2\text{/acre}$ = conversion factor
$28{,}329 \text{ cm}^3\text{/ft}^3$ = conversion factor
1.5 gm/cm^3 = density of soil

10^{-3} kg/gm = conversion factor
10^{-6} kg/mg = conversion factor

This mass of chromium appears reasonable and compares favorably with the amount predicted to have been removed by agricultural wells by the groundwater model, calculated to be (see page 6-2):

0.90 x 65 tons x 0.66 x 909 kg/ton x 0.45 = 15,793 kg

The difference between the calculated and predicted amounts may be due to several factors, including:

1) As indicated is Demographics Report (Appendix A4) the area irrigated with groundwater from the plume over the past 35 years was considerably greater than the 60 acres assumed above (i.e., increasing the land under irrigation by an additional 20 acres is sufficient to account for a majority of the remaining chromium.)

2) The average total chromium concentration (33 mg/kg) is below levels measured in surface soils at the Mojave Dairy, which were reported as high as 81.60 mg/kg (Table 3-4) and;

3) The groundwater model assumes that all chromium discharged with the cooling tower blowdown reached the aquifer. In fact, as indicated by the results of soil boring analysis, Cr(III) was encountered in the upper soil horizon in the area of the abandoned evaporation/percolation ponds (Area A). Chromium was also reported in surface soils in a 3/4 acre disposal area designated as Area C. While the amount of chromium remaining in on-site soils is relatively small (estimated to be less than 2,000 kg), it accounts for a portion of the total originally discharged during cooling tower blowdown disposal.)

A model of the groundwater plume was developed to aid in the prediction of groundwater quality and in the evaluation of potential remediation alternatives. Modeling results were used in estimating risks to humans (Chapter 7.0), to flora and fauna (Chapter 8.0), and in defining chromium concentrations in air and soils, the environmental compartments into which contaminated groundwater is released. A brief description of the model, its assumptions, and methodology can be found in Appendix A6. A more complete description of the model and discussion of the results are provided in the PG&E Groundwater Modeling Report (PG&E, 1988).

There is no known source presently releasing Cr(VI) to the aquifer. The on-site areas (areas A, B, and C, including the former evaporation/percolation ponds) containing soil-chromium residues have no demonstrable leaching, as evidenced by the WET test data described in the Site Characterization Report. Aquifer recharge from contaminated irrigation water is unlikely, considering this water is spread over a large land area (> 60 acres), the high evapotranspiration rate in the area, and the high capacity of the soil to reduce and retain chromium and retard leaching (see Section 3.3).

The groundwater model was used to predict water quality (Cr(VI) concentrations) in domestic, agricultural (irrigation), and extraction wells over the next 20 years for the three remedial alternatives (equivalent for Alternatives 1 and 3). The model was tested for two different hydrologic conditions, high and low water levels projected for the 1990's, based on a stochastic analysis of the Mojave River historical flow record. However, since no significant difference was shown between hydrologic conditions, only the high water levels are presented. Modeling results for the 20-year period beginning in 1989 for domestic irrigation and extraction wells are shown in Tables 6-1, 6-2, and 6-3, respectivly.

The model's analytical limit was taken to be 0.01 mg/l (although it is lower), which is five times below the EPA drinking water MCL. A value of zero (0) is shown when the model output fell below the analytical limit. The cited concentrations reflect well head levels, not those in the aquifer. Locations of the domestic and irrigation wells used in the model are illustrated in Figure 3-3. Coordinates of the extraction wells are given in Table 6-3. The model grid system is illustrated in Figure A6-1.

Table 6-1

PREDICTED WATER QUALITY IN DOMESTIC WELLS

Well ID	Year				
	1989	1993	1998	2003	2008
	Cr(VI) concentration (mg/l)[1]				
Alternatives 1 & 3: Current Irrigation Practice; Domestic Water Replacement					
GW26-07	0	0	0	0	0
GW26-25	0.05	0.01	0	0	0
GW26-26	0.25	0.09	0.02	0	0
GW35-10	0.14	0.06	0	0	0
GW35-14	0.16	0.12	0.11	0.10	0.07
GW35-17	0.25	0.19	0.16	0.14	0.14
GW35-18	0.02	0.02	0.02	0.03	0.04
GW35-19/20	0.02	0.02	0.02	0.03	0.04
Alternative 2: Accelerated Agricultural Treatment					
GW26-07	0	0	0	0	0
GW26-25	0.05	0.01	0	0	0
GW26-26	0.25	0.03	0	0	0
GW35-10	0.16	0	0	0	0
GW35-14	0.19	0	0	0	0
GW35-17	0.25	0.03	0	0	0
GW35-18	0.02	0.04	0.02	0.03	0.02
GW35-19/20	0.02	0.04	0.02	0.03	0.02

[1] concentration is reflective of level at well head; a zero (0) indicates a computed concentration less than the model's analytical limit.

Source: PG&E, 1988

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Table 6-2

PREDICTED WATER QUALITY IN IRRIGATION WELLS

Well ID	Year				
	1989	1993	1998	2003	2008
	Cr(VI) Concentration (mg/l)[1]				
Alternatives 1 & 3: Current Irrigation Practice; Domestic Water Replacement					
GW26-15	0.04	0.02	0.01	0	0
GW26-16	0.01	0	0	0	0
GW26-28	0.25	0.09	0.02	0	0
GW35-11	0.24	0.19	0.16	0.13	0.14
GW35-12	0.29	0.17	0.10	0.05	0.02
GW35-13	0.02	0.01	0.01	0	0
Alternative 2: Accelerated Agricultural Treatment					
GW26-15[2]	0.05	0.01	0	0	0
GW26-16[2]	0.01	0	0	0	0
GW26-28[2]	0.25	0.03	0	0	0

[1] Concentration reflects level at well head; a zero (0) indicates a computed concentration less than the model's analytical limit.

[2] Irrigation wells in relatively lower chromium concentrations of the plume. Irrigation wells in higher concentration areas coincide with extraction wells, given in Table 6-3 following.

Source: PG&E, 1988.

Table 6-3

PREDICTED WATER QUALITY IN FUTURE EXTRACTION WELLS UNDER ACCELERATED AGRICULTURAL TREATMENT ALTERNATIVE[1]

Well Location[2] (I,J)	Year				
	1989	1993	1998	2003	2008
	Cr(VI) Concentration (mg/l)[3]				
11,11	0.34	0.01	0.01	0	0
15,15	0.01	0.01	0	0	0
14,17	0.20	0.01	0	0	0
13,15	0.34	0.04	0.01	0.01	0
13,18	0.25	0.01	0	0	0
15,16	0.01	0.01	0	0	0
14,14	0.01	0	0	0	0
12,19	0.05	0	0	0	0
12,16	0.16	0	0	0	0
14,16	0.19	0	0	0	0
12,15	0.11	0	0	0	0
Average[4]	0.15	0.01	0.01	0.01	0

[1] These extraction wells provide irrigation water for Mojave Diary fields under the accelerated Agricultural Treatment Alternative.

[2] See Figure A6-1 to identify well locations, location given as grid coordinates (I,J).

[3] Concentration reflects well head level; a zero (0) indicates a computed concentration less than the model's analytical limit.

[4] To be conservative, an average of zero is assumed only if all wells are zero; otherwise 0.01 is assumed unless the actual average is higher.

Source: PG&E

Predicted water quality for domestic wells is shown in Table 6-1. Presently, water in five of the wells exceeds the current MCL of 0.05 mg/l (see Table 3-3). Based on current groundwater use in the study area, chromium concentrations will steadily diminish over time, first in the northern (GW26) and then in the southern (GW35) wells. Within 20 years the Cr(VI) concentration should reach the MCL in all but two wells for the current irrigation practice alternative. In contrast, chromium concentrations in these wells would meet the MCL significantly faster, within 5 years, in the accelerated agricultural treatment alternative.

Existing chromium concentrations measured in irrigation wells are higher than measured in the domestic wells (see Table 3-3), particularly in the southernmost wells (GW35-11, 12, and 13) at the Mojave Dairy. Table 6-2 shows irrigation well water quality as predicted by the plume model. Based on current irrigation practices, water quality is predicted to exceed the MCL for more than 20 years in several wells in the southern portion of the plume, while the northern wells are free of contamination within 15 years. As observed for the domestic wells, accelerated agricultural treatment leads to better water quality within 5 years. The southern (GW35) irrigation wells are not shown under the accelerated agricultural treatment alternative, since under this remedial alternative they would not function except for GW 35-12 (12,15 in Table 6-3); under this alternative, irrigation water for the Mojave Dairy is provided from the extraction wells (see Table 6-3).

Simulated water quality estimations for the extraction wells are presented in Table 6-3. These wells were located in the plume to maximize the chromium extraction efficiency and insure effective treatment (as discussed in Chapter 5.0). The locations selected result in relatively efficient treatment, with chromium concentrations decreasing below the MCL (0.05 mg/l) within five years.

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6.3. AIR

Chromium may be introduced into the atmosphere around the site in three ways:

(1) Fugitive dust blowing from the site and/or irrigated farmland contaminated with either Cr(VI) or Cr(III);
(2) Irrigation water drift contaminated solely with Cr(VI); and
(3) Indoor shower and other spray that is contaminated with Cr(VI).

The air pathway of exposure is important in this study since Cr(VI) is a known human carcinogen by inhalation. Emission rates were evaluated from these three sources as well as the resulting Cr(VI) and Cr(III) concentrations. For each of these sources, only the present conditions at the site were measured or modeled, since the current soil and water concentrations of these species can be scaled to other groundwater conditions.

6.3.1. FUGITIVE DUST

Exposure to chromium through fugitive dust is possible in areas around the site due to:

(1) Elevated soil concentrations of Cr(III);

(2) The fine particulate nature of the site's surficial soils;

(3) The lack of soil moisture and precipitation; and

(4) Considerable winds being common in the region.

Candidates for this type of exposure include:

(1) Farm hands working on or near fields irrigated with contaminated groundwater;

(2) Local residents;

(3) PG&E compressor station employees; and

(4) Various animals that frequent the same area.

Particulate air sampling was conducted during on-site soil boring and monitoring well drilling in areas of known or suspected soil-chromium contamination, to document potential contamination of respirable suspended dust (Section 3.3.3). No measurable Cr(VI) was found in the air at any of the boring locations based on a standard occupational (NIOSH) testing approach. This finding is supported by the fact that surficial soils at the site contain little or no Cr(VI) and, therefore, present no source of particulate contamination that could impact human or ecological receptors.

Because air concentration measurements for Cr(III) were not made, an estimate was calculated for site soils. The approach used to develop an estimate was that developed by Cowherd et al. for EPA (1985), as described in Appendix A6. The parametric equation for estimating the respirable fraction of contaminated particulate (PM_{10}, the fraction of particles with aerodynamic diameter < 10 um) from site soils was determined to be:

$$RC = (9.7\ ng/m^3) \times C_s$$

Where:

RC = Respirable concentration (ng/m^3)
C_s = Soil concentration (mg/kg)

The calculated air concentrations are presented in Table 6-4.

Area C showed the highest estimated fugitive dust chromium concentrations due to the high level of soil contamination. According to California Air Resources Board (CARB) data from 1985, the average Cr(T) air concentration in the state was approximately 5 ng/m^3, and in the southeast desert area around Lancaster, California, 2 ng/m^3. The estimated on-site levels were approximately 10 to 100 or more times the CARB ambient level, while the predicted off-site background was 20 to 70 times the CARB levels. This is indicative of the overestimation that was included in the worst-case assumptions, to provide for a health-protective safety margin for determining exposure, as

Table 6-4

ESTIMATED FUGITIVE DUST CONCENTRATIONS OF CHROMIUM (III) IN AIR RESULTING FROM SOIL

	Location				
	Areas				
	A	B	C	Background Station	CARB BACKGROUND
Average Soil Concentration[1] (mg/kg)	53.8	3.9	117	13.6	NA
Air Concentration (ng/m^3)	520[2]	37[2]	1,100[2]	130[2]	2-5[3]

[1] Derived from Table 3-4.

[2] Calculated: $ng/m^3 = 9.7\ ng/m^3 \times$ average soil concentration in mg/kg (derivation is presented in Appendix A6).

[3] Measured by California Air Resources Board (CARB)

Source: Ecology and Environment, Inc. 1988

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discussed in Appendix A6. Therefore, assuming the above analysis overestimates by 20 to 70 times, fugitive dust chromium concentrations from the on-site soils containing residual chromium may more realistically be:

Area A	7.4 to 26 ng/m^3
Area B	0.53 to 18 ng/m^3
Area C	.16 to 55 ng/m^3

There are no applicable air standards for Cr(III) for comparison. It will be seen below that these levels correspond well with ambient air concentrations measured during irrigation at the Mojave Dairy.

6.3.2. IRRIGATION SPRAY DRIFT

The second source of chromium emission to the atmosphere is spray drift from irrigation systems using contaminated groundwater. As discussed in Section 3.3.3, up to 5.6 mg/min of Cr(VI) was emitted in the spray drift from a tested irrigation lateral line. It was estimated that this would lead to an instantaneous air concentration of less than 0.2 ug/m^3 at the edge of the irrigation spray. This value was below the detection limit of the method employed to measure the physiologically relevant (i.e. respirable) air concentration. To obtain an alternative estimation of atmospheric concentrations, a computerized atmospheric dispersion model was used. The modeling approach and assumptions are discussed in Appendix A6.

The maximum predicted concentrations of Cr(VI) in air using these modeling methods and assumptions are summarized in Table 6-5. For each receptor listed in Column 1 of Table 6-5, the wind direction was chosen to blow directly from the spray area toward the receptor. Average concentrations for periods longer than one hour were estimated by following EPA-recommended modeling guidelines, involving the multiplication of maximum 1-hour concentrations, derived from the Industrial Source Complex Short-Term (ISCST) model, by appropriate factors. To estimate maximum 24-hour average concentrations, maximum 1-hour concentrations were multiplied by 0.4 (USEPA, 1977, p.4-21); to

Table 6-5

SUMMARY OF MODELED AEROSOL CHROMIUM CONCENTRATIONS AT SPECIAL RECEPTORS

Description of Receptor	Map Location (Figure 4-1)	Predicted Maximum Ambient Concentration (ug/m^3)		
		1-hr[1]	24-hr[2]	Annual[3]
Residence	A	0.011	0.004	0.001
Residence	B1	0.014	0.006	0.001
Residence	B2	0.014	0.006	0.001
Residence	B3	0.011	0.004	0.001
Residence	B4	0.006	0.002	0.001
Itinerant Irrigator[4] at a distance from line source:	C			
	80 ft	0.044	0.018	0.004
	90 ft	0.048	0.019	0.005
	100 ft	0.048	0.019	0.005

[1] 1-hour average concentrations were calculated by the ISCST model (Appendix A6) using assumed typical meteorology.

[2] 24-hour average concentrations were estimated by multiplying maximum 1-hour concentrations by the factor 0.4 (Appendix A6).

[3] Annual average concentrations were conservatively estimated by multiplying maximum 1-hour concentrations by a factor of 0.1 (Appendix A6).

[4] Model could not calculate distances closer than 80 ft from line source.

Source: Ecology & Environment, Inc., 1988

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estimate worst-case annual average concentrations, a multiplicative factor of 0.1 was used.

As can be seen from Table 6-5, the highest predicted 1-hour concentration was 0.048 ug/m^3, or an annual average concentration of 0.005 ug/m^3. This concentration was estimated to occur immediately downwind of the sprayers, about 100 feet due east of the northern end of the southern lateral line, when the wind was at a low angle (30°) with respect to the line. This value is more than three orders of magnitude below the OSHA occupational permissible exposure level (PEL) of 52 ug/m^3 (29 CFR Part 1910.1000). The highest residential 1-hour concentration occurred at the closest house (labeled B_1 in Figure 3-4), which was predicted at about 0.014 ug/m^3, or 0.001 ug/m^3 as an annual average. For comparison, the California Department of Health Services is presently reviewing a proposed Applied Action Limit (AAL) for an annual average concentration of 0.002 ug/m^3. Therefore, these results suggest that the annual average residential air concentrations would not exceed this AAL, if it is adopted. The AAL may be exceeded in the air within 80 to 100 feet of the spray radius, at the present source concentration. It should be noted that the groundwater source concentration is predicted to decrease (Tables 6-2 and 6-3) under current irrigation practices and even more rapidly with accelerated agricultural treatment; therefore, future air concentrations would decrease.

In order to improve the estimates of airborne aerosol chromium concentrations resulting from irrigation with contaminated groundwater, a second measurement was made. This experiment is discussed in Section 3.3.3, with the results presented in Table 3-7. As can be seen there, estimated Cr(VI) concentrations were in the 1 x 10^{-4} ug/m^3 range, or two orders of magnitude below the modeled values discussed just above. These measured values were employed in the risk assessment, as described in Section 7.4. Note from Table 3-7 that the residential numbers are of the same order as background (up wind) concentrations.

6.3.3. SHOWER-GENERATED AEROSOL

In order to estimate Cr(VI) ambient air concentrations in a shower (bathing) a carefully designed experiment was performed by SRI International (report in preparation). In this experiment, a "standard" shower was built and operated under controlled conditions which simulate a reasonable range of circumstances which might be encountered by an exposed individual. A reservoir and plumbing system was constructed to maintain constant pressure and temperature of the water to the shower. To determine the effect of likely environmental conditions or human choices, two different shower heads were selected and evaluated. A Telledyne low flow shower head was representative of an easily obtainable device which would produce a higher proportion of small droplets. A high flow head was selected for the other extreme. Also, back pressure on the system was considered to be a significant factor. Two pressures were tested, 20 and 40 psig, which are reasonable pressures which might be encountered in the field. The temperature of the shower was maintained at approximately 100° F. A plastic dummy simulating a bather was inserted into the shower stall. A surrogate material for chromium (ammonium fluorescein) was added to the water system to produce a homogeneous concentration. After an apparent equilibrium was reached during the operation of the shower, a sampling device collected liquid droplets of respirable size (less than or equal to 10 microns) within the shower. Comparison of the ammonium fluorescein concentration in the circulation water and in the collected sample allowed calculation of the air concentrations for other shower water concentrations of non-volatile contaminants. The ratio of the ammonium fluorescein concentration in reservoir for the experiment to the actual concentration of Cr(VI) in the groundwater allowed estimation of Cr(VI) concentrations in the shower air.

Results varied from the most stringent case, the low-flow Telledyne head at 40 psig, to the high-flow head at 20 psig. Assuming a Cr(VI) concentration of 0.3 ppm in the groundwater supplying the shower, then for the most stringent case the ambient air concentration was estimated to be 0.04 to 0.08 ug of

Cr(VI)/m^3 of air; for the less stringent case the range was 0.008 to 0.016 ug/m^3. The arithmetic average of the more strigent range of values, or 0.06 ug/m^3 was employed in the health risk assessment, in which the results were scaled to match appropriate groundwater Cr(VI) concentrations.

6.4. AGRICULTURAL AND RESIDENTIAL SOIL

Cr(VI) is introduced to the soil environment exclusively by irrigation with groundwater. The following analysis considers the emission to soil and the increase in chromium levels over time in:

(1) Agricultural field soils; and

(2) Residential garden soils.

Each of these cases is analyzed under each of the three remedial alternatives: 1) current irrigation practice; 2) accelerated agricultural treatment; and 3) domestic water replacement. The analysis employed the following assumptions:

(1) The only source of chromium is irrigation water.

(2) Speciation of chromium:

   A. Cr(VI) to Cr(III) kinetic rate is rapid (minutes).

   B. Cr(III) to Cr(VI) conversion does not occur at appreciable levels.

(3) Leaching is not important.

(4) Uptake by plants occurs at a sufficiently low rate as to not impact soil loading.

(5) No loss of chromium by aerosolization occurs during input.

(6) No loss of chromium occurs by dust entrainment.

(7) Mass of soil: 2.24 x 10^6 kg/ha (top 15 cm, density of 1.5 g/cm^3, Source: EPA, 1980).

Agricultural soils showing the highest chromium concentrations and that have been irrigated with groundwater since the original chromium release are found on the Mojave Dairy (Figure 3-3); they presently have an average of 33 mg/kg of Cr(T). This concentration compares to a measured average background level of 7.4 mg/kg in other off-site irrigated soils. Therefore, over 35 years, a concentration increase of 25.6 mg/kg has occurred, presumably due to irrigation. Assuming equal irrigation activity each year, no loss of chromium, and the same background concentration in all years, then the average loading rate has been approximately 40 kg/year, or an increase in Cr(T) concentration of 0.73 mg/kg/year (assuming a 24.3-ha or 60 acre sized field).

6.4.1. AGRICULTURAL FIELD SOILS

The analysis of chromium buildup in field soils was based on conservative, worst-case assumptions, using the alfalfa field at the Mojave Dairy Farm as the basis for the model. This was a reasonable choice since the field has been under production and irrigation since the early 1950's (Appendix A4, Demography Study Report) and is currently within the contaminant plume (see Figure 4-1). This model had the following parameters:

(1) The field is 60 acres in size.

(2) The current Cr(T) concentration is 33 mg/kg.

(3) The irrigation system is of the lateral line sprayer type, 1,270 feet in total length, with 40 rainbird sprayers (this assumes only two north/south running lines, in operation 24 hours per day, 245 days per year). However, more may be used to irrigate other areas of this property.

(4) Cr(VI) concentrations were based on the water quality of wells GW35-11, 12, and 13 for the Current Irrigation Practice Alternative, because these represent the highest Cr(VI)

concentrations found in irrigation wells over 20 years (Table 6-2).

(5) The current Cr(VI) emission rate from the 40 sprinklers is 112 mg/min or 39 kg/year (assuming a water flow rate of 2.6 gpm for 8 months per year (9.8 lpm) for each sprinkler, and a measured Cr(VI) concentration in the irrigation water of 0.285 mg/l; see Section 3.3.3).

For the accelerated aricultural treatment alternative, the average concentration of all irrigation wells was used as it would realistically reflect the level being applied to the field (Table 6-3).

It is of interest to note that the current emission rate would cause a Cr(T) buildup rate in soil of 0.73 mg/kg/year, which is equivalent to the average rate calculated above from the difference in Cr(T) levels between this field and other off-site irrigated soils. This supports the validity of the analytical data for soils presented in Chapter 3.0.

The results of the analysis for all three remedial alternatives are presented in Table 6-6. There was little difference between the alternatives, except that with Alternative 2 somewhat less chromium per hectare was deposited. The results suggest that within 20 years almost all of the chromium that can be easily removed from the aquifer will be, while under remedial Alternative 2 the same amount will be extracted within the first five years of treatment. In both cases, the emission rate decreases greatly within five to 10 years. This model represents the worst-case for any area soil receiving contaminated irrigation water. Therefore, other agricultural field soils irrigated with water from the plume would have far less Cr(T) buildup.

6.4.2. RESIDENTIAL SOILS

The analysis of chromium emission to and buildup in residential soils was also based on conservative, worst-case assumptions, using a garden as the model. Gardens are the only observed residential irrigation activity in the study area. This model was based on the following parameters:

Table 6-6

PROJECTED CHANGES IN AGRICULTURAL SURFACE SOIL CHROMIUM CONCENTRATIONS OVER TIME

Year	Water Quality[1] (mg/l)	Chromium Emission Rate[2] (kg/year)	Chromium Buildup Rate In Soil[3] (mg/kg/year)	Cr(T) Soil Concentration[4] (mg/kg)
Alternatives 1 & 3: Current Irrigation Practice; Domestic Water Replacement				
Present	0.285	39	0.73	33.0
1988	0.285	39	0.73	33.7
1989	0.14	19	0.35	34.1
1993	0.08	11	0.20	35.3
1998	0.04	5.5	0.10	36.2
2003	0.05	6.9	0.13	36.7
2008	0.05	6.9	0.13	37.4
Alternative 2: Accelerated Agricultural Treatment				
Present	0.285	39	0.73	33.0
1988	0.285	39	0.73	33.7
1989	0.15	21	0.38	34.1
1993	0.01	4	0.07	35.3
1998	0.01	4	0.07	35.6
2003	0.01	4	0.07	35.9
2008	-0-	-0-	-0-	35.9

[1] Cr(VI) concentrations derived from Table 6-2 averages of wells GW35-11, 12, and 13, except for present and 1988 data, which were measured and reported in Section 3.3.1. Predicted data for Alternative 2 from Table 6-3.

[2] Emission Rate = Cr(VI) concentration X 392 lpm X 3.5 x 10^5 min/growing year X 10^{-6} kg/mg.

[3] Buildup Rate = Emission Rate X 1/24.3 ha X 1/2.24 x 10^6 kg/ha X 10^6 mg/kg.

[4] Soil Concentration was calculated for each year using the buildup rate for that year, and for the four consecutive years. For example, for the period 1989 to 1992, the rate for each year was 0.21 for Alternative 2.

Source: Ecology and Environment, Inc., 1988.

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(1) The garden was assumed to cover an area of 25 X 25 feet (0.0057 ha; or 0.014 acres).

(2) The current Cr(T) concentration was selected as 33 mg/kg, to be conservative, which is a worst-case assumption. The actual soil concentration is presently unknown.

(3) Irrigation is done by the resident using 5 gpm (18.9 lpm), 1 hour per day, for 130 days (5 days per week for half of the year).

(4) Groundwater Cr(VI) concentrations were based on the measured level in well GW35-17. This represents the highest and, therefore, worst-case concentration (Table 6-1).

The results of the analysis for remediation Alternatives 1, 2 and 3 are presented in Table 6-7. There was little difference between the alternatives. Gardens are predicted to have a somewhat higher soil Cr(T) level compared to the agricultural case. This is because the chromium is distributed over a smaller area. The accelerated agricultural treatment alternative results in decreasing the soil concentration buildup by 31%. Although the soil concentrations are elevated over background, they are in the range of concentrations observed in other nonserpentine soils (Section 3.1.2). All chromium for both scenarios will be in the trivalent state based on the soil's capacity for rapid reduction of Cr(VI) to Cr(III) (Section 3.3.2). Note that for groundwater remedial Alternative 3 (Domestic Water Replacement) there will be no build-up of chromium in soil because local groundwater is not used for garden irrigation.

6.5. BIOTA

As described in Chapter 4.0, various faunal and floral species are potentially exposed to chromium at or near the site. This metal is not readily accumulated in biological systems (USEPA, 1978) nor is it biomagnified in the terrestrial food chain (Andren et al., 1973; Langard and Norseth, 1979; Steven et al., 1976). Nevertheless, an assessment was conducted to evaluate present and future vegetation tissue burdens.

Table 6-7

PROJECTED CHANGES IN RESIDENTIAL SOIL CHROMIUM CONCENTRATIONS OVER TIME

Year	Chromium Concentration in Groundwater[1] (mg/l)	Chromium Emission Rate[2] (kg/year)	Chromium Buildup Rate In Soil[3] (mg/kg/year)	Cr(T) Soil Concentration[4] (mg/kg)
	Alternative 1: Current Irrigation Practice			
Present	0.20	0.030	2.4	33
1988	0.20	0.030	2.4	35
1989	0.25	0.037	2.9	37.9
1993	0.19	0.028	2.2	48.8
1998	0.06	0.009	0.69	58.3
2003	0.13	0.019	1.5	62.6
2008	0.14	0.021	1.6	70.2
	Alternative 2: Accelerated Irrigation Treatment			
Present	0.20	0.030	2.4	33
1988	0.20	0.030	2.4	35
1989	0.25	0.037	2.9	37.9
1993	0.03	0.004	0.34	46.9
1998	-0-	-0-	-0-	48.3
2003	-0-	-0-	-0-	48.3
2008	-0-	-0-	-0-	48.3
	Alternative 3: Domestic Water Replacement			
Present	0.20	0.030	2.4	33
1988	0.20	0.030	2.4	33
1989	-0-	-0-	-0-	35
1993	-0-	-0-	-0-	35
1998	-0-	-0-	-0-	35
2003	-0-	-0-	-0-	35
2008	-0-	-0-	-0-	35

[1] Cr(VI) concentrations derived from Table 6-1, well GW35-17.

[2] Emission Rate = Cr(VI) concentration X 18.9 lpm X 7.8 x 10^3 min/growing year X 10^{-6} kg/mg.

[3] Buildup Rate = Emission Rate X 1/0.0057 ha X 1/2.24 x 10^6 kg/ha X 10^6 mg/kg.

[4] Soil Concentration was calculated for each year using the buildup rate for that year, and for the four consecutive years. For example, for the period 1989 to 1992, the rate for each year was 3.2 mg/kg/year (Alternative 1).

Source: Ecology and Environment, Inc., 1988.

Table 6-8
BACKGROUND CONCENTRATIONS OF TOTAL CHROMIUM IN VARIOUS PLANT TISSUES

PLANT	TISSUE	CONCENTRATION Cr(T) (mg/kg dry wt)
Corn	grain	0.48
Potato	tuber	0.002
Carrot	root	0.0 - 0.03 (wet)
Onion	bulb	0.1 - 0.02
Squash (summer)	fruit	0.02
Lettuce (garden)	shoot	0.07
Tomato	fruit	0.01
Alfalfa	foliage	0.09

Source: USEPA, 1978.

demonstrated behavior similar to that described above, with the highest chromium concentrations occurring in the roots. In plants irrigated with contaminated groundwater, the ratio was identical for foliage and roots. This may be due to Cr(VI) deposition onto leaf surfaces. In such a case Cr(VI) most likely would undergo reduction to Cr(III) and then either precipitation or complexation to the leaf tissue. It is unlikely that significant uptake occurs through the leaf surface, however, due to the waxy cuticle which covers epidermal cells. Therefore, it is not clear whether the observed five-fold increase in chromium tissue burden over background levels was due to uptake or surficial deposition.

While it is not possible to predict accurately the amount of chromium that could be removed from land irrigated with contaminated groundwater by plants, an estimate can be made based on the available data. The following assumptions were used in calculating the removal rate:

(1) 2,500 kg/ha/cutting (Finkel, 1985);

(2) Average of five cuttings/year; and

(3) Field size (equal to that of the Mojave Dairy field) of 24.3 ha. Therefore, the amount of chromium removed from the soil per year would be calculated as follows:

$$2{,}500 \text{ kg/ha cutting} \times 5 \text{ cutting/year} \times 24.3 \text{ ha} \times 5 \text{mg/kg} \times 10^{-6} \text{ kg/mg} = 1.5 \text{ kg.}$$

This represents a small fraction (presently 4%) of the total chromium loading (39 kg per year) to the soil estimated in Section 6.4.1. As chromium emissions to soil decrease over time (Table 6-6), the level of plant uptake is also expected to decrease because less soluble chromium will be available for uptake or surface deposition.

Table 6-9

DETERMINATION OF UPTAKE RATIO FOR ALFALFA

Matrix	Average Total Chromium Concentration (mg/kg dry wt.) Background	 Test Field
Soil	7.4	33
Vegetation		
- foliage	0.85	5.4
- root	1.6	5.3
Plant:Soil Ratio	0.11-0.22	0.16

Derived from Tables 3-4 and 3-10.

Source: Ecology and Environment, Inc. 1988.

Residential Garden Fruits and Vegetables

Although plants do not readily take up chromium, as discussed above, the fraction which is taken up may increase the total exposure of humans to this substance. This is particularly true if garden fruits and vegetables are irrigated with contaminated groundwater. Table 6-8 lists some reported values for background chromium concentrations in various plant products. No field observations were made. Based on the foregoing discussion about alfalfa and the field observations that were made, it is likely that certain garden plants may also have elevated chromium levels. However, since the reference dose (RfD) (average daily intake) for Cr(III) is 1 mg/kg-day (USEPA, 1986) for an oral exposure route with a chronic endpoint, it is unlikely that a typical person would consume sufficient garden fruits and vegetables to exceed this dose. This is discussed in Chapter 7.0

6.5.2. FAUNA

Fauna may also be exposed at this site and in the surrounding vicinity to both Cr(III) and Cr(VI). Laboratory analyses of various tissues for Cr(T) revealed little if any elevation of chromium body burdens (Table 3-9). Upon comparison of these values with those in Table 6-10, it is clear that the chromium levels in the test cows were within typical ranges. Moreover, these results support the literature, which suggests that chromium is not biomagnified (Andren et al., 1973). Finally, regardless of the exposure pathway (i.e., oral or inhalation), it is evident that the resulting dosage is not significant.

Table 6-10

TYPICAL TOTAL CHROMIUM CONCENTRATIONS IN TISSUES OF CATTLE

Tissue	Concentration[1] (ug/kg)	Source
Liver	50	Cory, 1988
	150	EPA, 1978
	1,830 (200 - 3,800)	Kerr and Edwards, 1981
Kidney	100	EPA, 1981
	160	EPA, 1978
	2,970 (500 - 6,200)	Kerr and Edwards, 1981
Muscle (chuck)	90	EPA, 1978
(round)	570	EPA, 1978
Bone Marrow	30	EPA, 1978
Heart	0.0	EPA, 1978
Blood	0.0	EPA, 1981
	22 (6 - 66)	Kerr and Edwards, 1981
Hair	1,600 ± 5,200	EPA, 1981
Milk	8-13	Cory, 1988

[1] All values measured as wet weight and are listed as they were cited in the references.

Source: Ecology and Environment, Inc., 1988.

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7.0 HUMAN HEALTH RISK ASSESSMENT

7.1. GENERAL APPROACH

This health risk assessment has four major components which follow a now well-established format (NRC, 1983):

(1) Hazard identification--The determination of whether a particular chemical is or is not causally linked to particular health effects.

(2) Dose-response assessment--The determination of the relation between the magnitude of exposure and probability of occurrence of the health effects in question.

(3) Exposure assessment--The determination of the extent of human exposure before or after application of regulatory controls.

(4) Risk characterization--The description of the nature and often the magnitude of human risk, including attendant uncertainty.

As stated earlier, compounds of chromium are the subject of this risk assessment. Attention is focused upon Cr(VI) and Cr(III). Chromium can penetrate the human body via some or all of the three major exposure routes (inhalation, ingestion and dermal absorption) and via many environmental pathways involving all the media (air, surface and ground water, soil) as well as the foodchain. Typical environmental pathways involve inhalation of Cr(VI)-bearing aerosols in the daily shower, or outdoors in the aerosol mist produced by sprinkler irrigation of nearby alfalfa fields. This analysis evaluates the exposure accumulated across all these environmental pathway/exposure route combinations which are believed to be relevant.

Cancer risk is evaluated for Cr(VI), and noncancer risks are evaluated for Cr(III) and Cr(III). For each exposure route/environmental pathway combination, cancer risk is the product of exposure and cancer potency (e.g., unit risk); overall cancer risk is the sum of the risks for all pathway/route combinations. The principal measure of increased risk is taken as the maximally exposed individual's (MEI) increased lifetime probability of developing cancer as a result of Cr(VI) exposures deriving from the contaminated groundwater.

Noncancer risks are evaluated by calculating a hazard index (HI). For a specific exposure route (e.g., inhalation) dose is accumulated across all environmental pathways impinging upon that exposure route, and the hazard index for a specific chromium species is the ratio of estimated dose to acceptable dose (USEPA, 1985a). The overall hazard index for that species is the sum of the HI for all exposure routes. If this cumulative hazard index is less than unity (one), then no hazard is deemed to exist for that species taken alone. For multiple chromium species the overall hazard index is the sum of the HIs for all species. Again, a value less than unity indicates that no hazard is expected. This approach is designed to reflect the possible additivity of Cr(VI) and Cr(III) compounds and exposure routes *in vivo*; neither synergistic nor antagonistic *in vivo* interactions are evaluated.

Where environmental pathways/exposure routes of concern lack well-tested models and input data, compensatory assumptions have been made. Each assumption was made to assure that the resulting estimate of risk is health-conservative. Significant effort was spent improving upon these assumptions and data to improve the accuracy of the final result. This is a standard, iterative process in such risk assessments, designed to minimize the resources dedicated to model and data development. The resulting uncertainty and overconservatism present in the estimated risks are discussed in Section 7.6 of this report.

7.2. HAZARD IDENTIFICATION

This Hazard Identification section summarizes the health effects reported for chromium. It relies upon both primary and secondary (by regulatory and research agencies) documents. A more detailed presentation of the literature upon which this summary is based is presented in Appendix A7.

7.2.1. INTRODUCTION

Chromium is a common element, present in low concentrations throughout nature. Higher concentrations may be created as the result of industrial activities. Its toxicity in the Cr(VI) form has long been recognized, but detailed description of its toxic effects is complicated by the occurrence of different compounds of the metal in different valence states. Hexavalent and trivalent chromium are the most stable and the only important forms of chromium in nature.

This and the next section (7.2 and 7.3) of this report present a review of health effects possibly resulting from exposure to environmental chromium at the Hinkley Compressor Station site. The purpose of this review is to determine if exposure at environmental levels is likely to produce adverse health effects on humans. To do so, data are evaluated on the chemistry, systemic toxicity, genotoxicity, cytotoxicity, developmental and reproductive toxicity, and carcinogenicity of chromium. Dose response relationships for non-carcinogenic effects are reviewed and evaluated. Non-cancer no-observable-adverse-effect-levels (NOAEL) for acute, subchronic, and chronic exposure to chromium are developed. For carcinogenic effects, the potency factors currently employed by the U.S. Environmental Protection Agency (EPA) and the California Department of Health Services (DHS) are evaluated.

7.2.2. CHEMICAL AND PHYSICAL PROPERTIES

The chemical and physical properties of chromium have been discussed in section 3.1. To summarize, the significant forms of chromium in nature are the trivalent and hexavalent, with the trivalent form the most stable; and with hexavalent chromium transforming rapidly (minutes) to trivalent chromium in the environment (containing organic materials).

7.2.3. ENVIRONMENTAL FATE AND TRANSPORT

Air

The behavior of chromium in air has been discussed in section 3.1.3. This behavior is the basis for the typical exposures to airborne chromium discussed immediately below.

For the general public not occupationally exposed, inhalation of chromium is not likely to exceed a mean level of 1 to 2 ug/day, with a typical value of 0.28 ug/day. High concentrations of airborne chromium and chromate have been reported in the working environment, but more recent data showed that current mean levels of airborn chromium are unlikely to exceed 10 ug/m^3 in European and North American factories. Depending on the type of exposure and other working conditions, an occupationally exposed worker may inhale 0.6 to 150 ug/day (Thorne, Jackson & Smith, 1986).

Tobacco smoking is an additional source of inhaled chromium. It has been estimated that tobacco has a mean chromium concentration of 10.7 ug/g. A smoker of 20 cigarettes per day (ca. 20 g tobacco), would inhale an additional 10-15 ug Cr/day (Thorne, Jackson & Smith, 1986).

Water

Section 3.1.3 covers the general behavior of chromium in water. In terms of exposure, relatively little information is available on the concentration of chromium in drinking water. In a survey of chromium levels in public water supplies in the U.S., a median value of 0.43 ug/l was reported. In general, it is considered to be <10 ug/l (Thorne, Jackson & Smith, 1986).

Soil

The behavior of chromium in soil is covered in Section 3.1.3. Some biological characteristics of chromium in soil are covered here.

Cr(III) is not readily removed from soil by living cells because of its low solubility and the tendency to form large hydroxy polymers at neutral pH (Ross, Sjogren & Bartlett, 1981). On the other hand, Cr(VI) penetrates cell membranes easily. Ross et al. (1981) studied the effects of chromium in soil on microorganisms. They found that 10 to 12 ppm Cr(VI) was inhibitory to most bacterial isolates growing in either a soil extract medium and or in a semisynthetic medium. Gram negative bacteria were more sensitive and showed some inhibition of growth at 1 ppm. Toxicity of Cr(III) was not observed at similar levels. The mechanism by which low levels of Cr(VI) may be toxic to gram negative bacteria in soil is the reduction of their ability to perform transformations such as nitrification.

Bioavailability and Bioconcentration in the Food Chain

Chromium is present in plants and animals primarily in the trivalent form. Both plants and animals convert the hexavalent form to the trivalent form. Uptake of Cr(III) by plants is generally low (less than 2%), but proportional to the availability (Sheppard, Sheppard & Thibault, 1984). Bioconcentration of chromium is not expected with the exception of bivalve molluscs (USEPA, 1984a). Chromium levels decrease with higher trophic levels (USEPA, 1984a). Bioavailability and bioconcentration are treated more thoroughly in Section 8.3.

7.2.4. CARCINOGENICITY

Human epidemiological studies have revealed that inhalation of some hexavalent chromium-containing compounds increases the risk of respiratory cancer in occupationally exposed populations (ATSDR, 1987; Sorahan et al., 1987; USEPA, 1984a,b). Exposure was, however, also to Cr(III) compounds. The Mancuso (1951, 1975) epidemiological studies have been used by the EPA and California Department of Health Services (DHS) to generate cancer potency factors for chromium. Animal studies have found an association between exposure to Cr(VI) and cancer. A weak association was found in rats with repeated intratracheal instillation of calcium chromate (IARC, 1980, 1982). Cr(VI) produced a high incidence of tumors when implanted subcutaneously

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intrapleurally, or intramuscularly. When implanted in the same way Cr(III) gave low and statistically insignificant increases in tumor incidence.

On the basis of the total picture seen with the animal studies, <u>in vitro</u> studies, and the epidemiological studies, it has been concluded that Cr(VI) is carcinogenic to the lung in humans by inhalation. Cr(III) is not considered to be carcinogenic by any route.

The hypothesized mechanism of Cr(VI)-induced cancer is thought to involve the reduction of Cr(VI) to Cr(III) in the vicinity of DNA. This reduction may generate reactive intermediate chromium species. In the airways and gastrointestinal tract, Cr(VI) is taken up by diffusion through the epithelial cells. The ability to convert Cr(VI) to Cr(III) is limited in these cells. The unreduced Cr(VI) is released by the epithelial cells, taken up by the red blood cells and reduced to Cr(III). This process does not pose a cancer risk to the organism because mature red blood cells do not contain DNA. This reduction by the red blood cells may be why Cr(VI) has not been found to be carcinogenic by the dermal route. The possible routes of human exposure include inhalation, dermal, and ingestion.

7.2.5. ACUTE NON-CANCER TOXICITY OF CHROMIUM III AND CHROMIUM VI

Cr(III) is acutely much less toxic than Cr(VI). In general the effects are similar but the doses required for Cr(III) toxicity are much higher.

In man, the acute health problems related to chromium are mainly the result of accidental or voluntary ingestion of Cr(VI) salts. Severe irritation and corrosion of the upper digestive tract, kidney and liver damage, and even death by cardiovascular collapse may follow. Langard and Norseth (1986) indicate that doses of 2-5 g Cr(VI) compounds are fatal to humans. Acute effects of inhaled chromium compounds are primarily due to irritation of the upper respiratory tract.

In animals, acute toxicity due to oral administration of hexavalent chromium results in pulmonary congestion, fluid distention of the gastrointestinal tract, and erosion and discoloration of the gastrointestinal mucosa (Gad, 1986).

Acute effects following dermal administration of Cr(VI) include dermal corrosion and necrosis, as well as systemic effects including diarrhea and decreased activity in rats.

Single oral median lethal doses (LD50's, the dose causing 50% mortality in test animals) for Cr(VI) compounds range from 16.7 to 92 mg/kg depending on the compound and the animal species tested (ATSDR, 1987). Sex-specific LD50's show that female rats are more sensitive than males. Acute toxicity due to inhalation of chromium results in respiratory distress and irritation. Median lethal concentrations of inhaled chromium (LC50) range from 33 to 65 mg/kg, females being more sensitive than males. Dermal LD50's ranged from 397 to 677 mg/kg chromium in rats (Gad, 1986).

In man, onetime acute exposures to trivalent chromium compounds have resulted from inhalation of Cr(III)-containing dusts, or accidental or intentional ingestion of Cr(III) salts. Little information on acute effects in man or animals is available in the literature on Cr(III).

In animals, Cr(III) salts have a low acute toxicity. Oral LD50's in rats range from 422 to 11,260 mg Cr(III)/kg body weight (mg/kg). Toxic effects of ingestion of large amounts of Cr(III) salts include diarrhea, cyanosis, tail necrosis, and gastric ulcer. Microscopic or gross morphological changes in the liver and kidney were not found (Smyth, 1969).

7.2.6. CHRONIC NON-CANCER TOXICITY OF CR(III) AND CR(VI)

Most chronic toxicity data have been generated for doses high relative to those found at the Hinkley site. Chronic exposure to workers via the inhalation route has been shown to cause chronic rhinitis, laryngeal congestion, upper respiratory tract polyps, chronic lung inflammation, emphysema, tracheitis, and chronic bronchitis and pharyngitis. Further, X-ray evaluations have shown increased lung markings, enlargement of the lymph nodes and adhesions of the diaphragm (ATSDR, 1987; Alwens and Jonas, 1938 in ATSDR, 1987; Koelsch, 1938 in ATSDR, 1987; Lehmann, 1932 in ATSDR; Rischer-Wasels, 1938; Mancuso, 1951 in U.S. Public Health Service, 1987). Exposure to hexavalent chromium via the oral, inhalation, and direct dermal routes has been shown to result in allergic cutaneous contact dermatitis. Additionally, one case of an anaphalactoid reaction to Cr(VI) vapors has been reported.

Effects have also been documented in the kidney, including damage to the proximal convoluted tubules and increases in enzyme activities in rats (Evan and Dail, 1974; Tandon, 1978 in ATSDR, 1987; Laborda, Diaz-Mayans & Nunez, 1986). Studies of nervous system effects in rabbits have shown neuronal degeneration, neurophagia, neuroglial proliferation, and meningeal congestion (Mathur, 1977 in ATSDR, 1987; Duckett, 1986 in ATSDR, 1987). Studies examining damage to the liver in rats and rabbits show circulatory congestion, discreet necrotic foci, hemorrhage, and changes in cell nuclei (Tandon, 1978; Laborda, Diaz-Mayans & Nunez, 1986). Reproductive effects observed in experimental animals include testicular changes, seminiferous tubule degeneration and inhibition of spermatogenesis in males; and decreased fertility and sterility in females (Behari, 1978 in ATSDR, 1987; Gale and Bunch, 1979; Paschin, 1982 in ATSDR, 1987). Teratogenic effects have also been demonstrated at high dosages (Gale, 1982; Matsumoto, Iijima & Katsunuma, 1976).

7.2.7. PHARMACOKINETICS OF CR(III) AND CR(VI)

The gastrointestinal absorption of chromium has not been studied extensively in man or laboratory animals. Neither the specific site nor the mechanism by which chromium is absorbed are known. Inorganic Cr(III) compounds are generally little absorbed with a fractional absorption of <0.5-2% in man and rats. Hexavalent Cr(VI) compounds are better absorbed. In rats and man, fractional absorption for Cr(VI) has been estimated to be 2.1 to 10%. Following gastric administration, it was demonstrated that Cr(VI) and Cr(III) had a similar gastrointestinal absorption of 2%. But when administered to the duodenum, bypassing the stomach, fractional absorption of Cr(III) and Cr(VI) are 8% and 25%, respectively. These <u>in vitro</u> studies showed that in a highly acidic environment such as gastric juice, reduction of Cr(VI) to Cr(III) may occur, resulting in decreased bioavailability and toxicity of Cr(VI) (Donaldson and Barreras, 1966). This suggests that, under most circumstances, substantial proportions of ingested Cr(VI) would be converted to Cr(III) in the stomach prior to absorption.

7.2.8. DERMAL ABSORPTION

Dermal absorption studies have been conducted both <u>in vivo</u> and <u>in vitro</u> using human and animal skin. The permeability appears to be dependent upon the chromium salt, the pH, and the concentration applied (Mali, 1963; Wahlberg, 1965 in ATSDR, 1987; Samitz and Katz, 1964; Samitz, 1966).

Baranowska-Dutkiewicz (1981 in Thorne, Jackson & Smith, 1986) applied solutions of sodium chromate (Cr(VI)) to the forearm of 27 volunteers at 0.01, 0.1 and 0.2 M. It was observed that initial absorption increased with increasing concentration but the rate of absorption decreased with exposure time, resulting in net absorption being highest at 0.01 M and lowest at 0.2 M. They then proposed the following function to model skin absorption:

$$A = C^{0.7647} T^{0.6407} e^{-2.9785 \cdot u}$$

where,

A = amount of chromium absorbed
C = molar concentration of chromate
T = time of exposure in minutes,
u = residual chromate.

The best quantification of dermal absorption rates was done by Wahlberg (1970), who applied sodium chromate-51 at various concentrations to excised (human) cadaver skin <u>in-vitro</u> measuring disappearance of the chromate from (supply) solution over a 5-hour period. The rate of absorption through the skin was found to be proportional to the chromate concentration and linear at 1.5×10^{-6} mg Cr/cm^2-hr-[mg/l]. Using these data, the mass of chromium absorbed (N) is the product of absorbance rate (Abs) of chromate (1.5 x 10^{-6} mg Cr/cm^2-hr-[mg/l], the area affected (A) (in cm^2), the time in hours (T), and the concentration of the solution ([Cr]) in mg/l, or

$$N = Abs \times A \times T \times [Cr]$$

These parameter values and relationship for dermal absorbance of Cr(VI) were used in the exposure calculations.

The dermal absorption of Cr(III), on the other hand, is insignificant in comparison to Cr(VI), and has not been quantified adequately for exposure determination. Given its absorbance relative to Cr(VI), and its low toxicity relative to Cr(VI), the absorbance of Cr(III) will be considered to be non-existent for the purposes of this risk assessment.

7.3. DOSE-RESPONSE ASSESSMENT

7.3.1 NON-CARCINOGENIC EFFECTS

The no observed adverse effect level (NOAEL) is the dose or exposure level at which there is no statistically significant increase in frequency or severity of any adverse effect between the exposed population and an appropriate control. The lowest observed adverse effect level (LOAEL) is the lowest dose or exposure level at which statistically significant increases in frequency or severity of adverse effects between the two populations are observed in a given study or group of studies. Adverse health effects are defined as functional impairments and /or pathological lesions which may affect the performance of the whole organism, or reduce an organism's ability to respond to an additional challenge (USEPA, 1980).

Short Term Exposures

Toxicity of chromium compounds upon short term exposure is described under Acute Non-Cancer Toxicity in Section 7.2.5. Generally, chromium in the metal state is biologically inert and does not produce toxic or other harmful effects in man or laboratory animals. Compounds of Cr(III) have no established toxicity either. When taken orally, they are poorly absorbed and do not give rise to local or systemic effect. There are therefore insufficient data to establish a short term Cr(III) NOAEL. However, it would be expected to be 100 to 1,000 times greater than a Cr(VI) NOAEL.

Concerning the Cr(VI) NOAEL for the ingestion route, Gross and Heller (1946) exposed young rats for two months to 300 or 500 mg K_2CrO_4/l in drinking water. The ingested dose of Cr(VI) was calculated to be 8.3 and 14.4 mg/kg-day. A NOAEL of 14.4 mg Cr(VI)/kg-day is noted (USEPA, 1985b). This NOAEL for the rat is translated to a NOAEL of 0.224 mg/kg-day for humans, employing surface area scaling and a 10 fold safety factor for intra-human population variation. Surface area scaling employs the assumption that mammalian skin surface area varies with the one-third power of body weight.

For the inhalation route, there are insufficient data available for quantification of a NOAEL. Early historical recognition of the ulcerative property of Cr(VI) compounds in humans is evidenced by many studies in occupational settings. Generally, no concentrations <0.12 mg/m^3 are observed. Threshold limit values (TLV) are permissible exposure levels for occupational settings and are not necessarily applicable to the general public. However, taking the existing TLV (the time-weighted 8-hour average to which a worker may be exposed 8 hours per day and 5 days per week without adverse effects) of 0.05 mg/m^3, modifying it to 24 hrs per day and 365 days per year exposure, and applying a 100 fold safety factor, results in a "population threshold" of 100 ng/m^3 (DHS, 1985).

Long Term Exposure

Ivankovic (1975 in ATSDR, 1987) fed Cr(III) as Cr_2O_3 to three groups of male and female inbred BD rats (15-20 rats/sex/dose group) in diets containing 1, 2 or 5% Cr_2O_3 for five days per week for two years. Body weight, general appearance and histological measurements were examined. A NOAEL of 1,466 mg Cr(III)/kg-day was established.

Anwar et al. (1961) studied Cr(VI) chronic effects in female dogs (five doses, 2 dogs/dose). Doses ranged between 0.012 and 0.3 mg Cr(VI)/kg-day. No significant changes were observed in physical condition, organ weights, biochemical measurements of the blood and urinalyses in any of the dose groups. A NOAEL of 0.3 mg Cr(VI)/kg-day is noted.

MacKenzie, Byerrum and Decker (1958) investigated chronic effects of Cr(III) and Cr(VI) in drinking water on male and female Sprague Dawley rats. No significant adverse effects on appearance, weight gain or blood biochemistry were observed in any of the dose groups. The highest dose, 25 mg/l, is calculated to be a 2.41 mg Cr/kg-day NOAEL for male rats.

Quantification of Noncarcinogenic Effects

For quantification of the chromium NOAEL and LOAEL, relevant literature has been reviewed. Based on the scientific data on chromium, it is well established that Cr(VI) is more toxic than Cr(III) and metabolically, Cr(VI) and Cr(III) are in dynamic equilibrium. As discussed in a previous section, Cr(III) is rapidly hydrolyzed and precipitated. A NOAEL calculation based on Cr(VI) data is therefore sufficiently health protective and a separate NOAEL for Cr(III) is not necessary.

Since most human data were collected via epidemiological studies in the occupational setting where exposure levels are generally high, animal studies have been used in which a dose-response relationship was elucidated and a NOAEL identified. NOAELs for test animals are translated to human dose employing surface area scaling. This is accomplished by multiplying the animal NOAEL by the third power of the ratio of animal body weight to human weight (skin area is assumed to vary with the one third power of body weight for mammals). A safety factor of 10 is applied to cover interhuman variation.

Acute/subchronic and chronic NOAELs for Cr(VI) are calculated as follows.

Human Acute and Subchronic NOAELs.

$NOAEL_h = {}^1/_{10}[NOAEL_a \times (\text{wt. of animal in kg}/70\ \text{kg})^{1/3}]$ Equation (1) where subscripts h and a correspond to human and animal, respectively. The Gross & Heller $NOAEL_a$ was 14.4 mg/kg-day; their average rat weight was 265 gm.

Therefore, from Equation (1)

$$NOAEL_h = {}^1/_{10}\ [14.4\ \text{mg/kg-Day} \times (0.265\ \text{kg}/70\ \text{kg})^{1/3}]$$

$$NOAEL_h = {}^1/_{10}\ [14.4\ \text{mg/kg-day} \times 0.156] = 0.225\ \text{mg/kg-day}.$$

Chronic NOAEL.

Of the two Cr(VI) studies, the study by MacKenzie, Byerrum and Decker (1958) is used for the chronic NOAEL calculation because the study by Anwar et al. (1961) was limited by small test group size (2 animals per group).

The MacKenzie, Byerrum and Decker (1958) NOAEL is 2.41 mg/kg-day; assumed rat weight is 375 gm. Applying Equation (1) the $NOAEL_h$ with a safety factor of 10 is 0.042 mg/kg-day.

This chronic $NOAEL_h$ is well supported by a human study of chromium in drinking water. A family of four consumed water from a private well containing approximately 1 mg Cr(VI)/l which is equivalent to 0.03 mg/kg-day for a 70 kg man assumed to drink two liters of water per day. No adverse health effects were detectable by physical examination in any of the family members (USEPA, 1985b).

7.3.2. CARCINOGENIC EFFECTS

General carcinogenic effects of chromium in man and animals is discussed under <u>Carcinogenicity</u> in Section 7.2.4 and Appendix A7. Concerning the quantitative risk assessment of chromium, EPA and the California Department of Health Services have both recently published health assessment documents. Their carcinogenic risk calculations are based on inhalation of

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hexavalent chromium. This is in agreement with the conclusion reached from the literature review presented in the previous sections: Cr(VI) compounds demonstrated both mutagenic and carcinogenic effects, while Cr(III) compounds generally fail to demonstrate such effects. These studies are reviewed below.

Epidemiologic Studies

Many epidemiologic studies have demonstrated the carcinogenicity of chromium, but only a few have been able to quantify the exposure and thus qualify for a dose-response assessment. Of the four studies used by EPA, only two were adequate for quantifying dose-response. They are discussed below.

Mancuso (1975) reported on the cancer mortality of 332 white male workers who were employed in a chromate plant at Painesville, Ohio between 1931 and 1937 and were followed to 1974. Data from a 1949 industrial hygiene study of the plant were used to derive weighted average exposures to insoluble, soluble and total chromium, which were then applied to each member of the worker cohort. Of the 332 employees, 173 (52%) had died by 1974, and 41 deaths were from lung cancer. The age-adjusted data showed an increase in lung cancer rate with increasing exposure to chromium. Smoking habits were not factored out of these results.

Pokrovskaya (1973 in ATSDR, 1987) compared cancer mortality of a group of male ferroalloy workers in the Soviet Union to the population of similar age in the city where the plant was located for the time period 1955-1969. Exposure was estimated by ambient air concentrations of hexavalent chromium which were reported to exceed the so-called "marginally allowable value (0.01 mg/m^3)" by 2 to 7 times on the average. This allows an estimation of worker exposure level of 0.02 to 0.07 mg/m^3. The lung cancer mortality ratios were 4.4 for the age group 30-39 and 6.6 for the age group 50-59. Neither the numbers of workers nor the criteria by which workers were included were defined for the cohorts.

Animal Studies

Animal studies have not been successful in demonstrating a significant increase in tumor incidence following inhalation or ingestion exposure to either Cr(VI) or Cr(III). Increased tumor incidence has been observed at site of contact, but it has been difficult to quantify dosages; hence these studies are not useful for quantitative dose-response assessment, but are useful in supporting the qualitative identification of chromium as a potential carcinogen.

The study by Steinhoff, Gud and Hatfield (1983) is useful for examining the possibility of non-linearity of the chromium dose-response relationship. Steinhoff, Gud and Hatfield (1983) studied the carcinogenicity of sodium dichromate and calcium chromate in Sprague-Dawley rats via intratracheal administration. There were 40 rats/dose/sex with 10 treatment groups. The treatments were as follows: 0, 0.05, 0.25, 1.25 mg/kg (sodium salt) and 1.25 (calcium salt) mg/kg at 1 administration/week; 0, 0.01, 0.05, 0.25 mg/kg (sodium salt) and 0.25 (calcium salt) mg/kg at 5 administrations/week for 32 months. Statistically significant increases in combined lung tumors were found only in the 1.25 mg/kg (one administration per week) sodium dichromate and calcium chromate groups and the 0.25 mg/kg (five administrations per week) male calcium chromate group. In other words, weekly exposure of sodium chromate at 1.25 mg/kg yielded carcinogenic effects while exposure at one-fifth the dose at 0.25 mg/kg for five times/week failed to result in increased tumors. This differential in the carcinogenic response, together with short term genotoxicity studies and metabolism studies, have been viewed as possible support for a chromium carcinogenic threshold (Hathaway, 1985), although the concept of a threshold level for carcinogens is controversial.

Quantification of Carcinogenic Effects

Quantification of the carcinogenic risk factor based on these epidemiologic studies was performed by the EPA and the DHS. Since chromium exposures in the occupational settings were in the mg/m^3 range, which is about 4-5 orders of magnitude higher than ambient levels, a model for extrapolating to ambient levels is needed. Based on radiation induced leukemia studies, the health agencies have adopted the linear non-threshold model for this high dose-tc-low dose extrapolation.

Two dose-response extrapolation models were used by the agencies to calculate carcinogenic potency (q_1^*, the increased lifetime probability of developing cancer from lifetime exposure to 1 mg substance per kg of body weight per day) based on the epidemiologic studies.

The first extrapolation method employed the competing risk model, which requires age-specific mortality data (that tends to be log-log in form). The incidence I(T) by time T is assumed to follow a "competing risks" formulation:

$$I(T) = bT^{k-1} \qquad \text{Equation (2)}$$

where T is time (USEPA, 1984a). It is called the competing risk model below.

The second extrapolation method employed a crude model which equates the risk among the exposed individuals (R_e) to a function of the incremental dose (d) and the background cancer rate (R_b). In this model the relative risk (RR) is taken as equal to R_e/R_b and then incremental risk per unit dose, B (equivalent to q_1) is calculated as follows (USEPA, 1984a):

$$B = [(RR - 1) \times R_b]/d \qquad \text{Equation (3)}$$

where:

B = q_1^* = cancer potency slope = increased lifetime probability of developing cancer from lifetime exposure to 1 mg/kg-day of Cr(VI)

R_e = total lifetime probability of developing cancer for the exposed group

R_b = total lifetime probability of developing cancer for the unexposed general population

d = incremental dose to exposed population in mg/kg-day
RR = R_e/R_b

This model does not require age-specific mortality rate data, and is referred to below as the crude model.

Since the Mancuso study is the most highly regarded chromium carcinogenic data base, values for q_1^* derived from this study have been promulgated by the agencies. Calculations and assumptions applied by the EPA and the DHS to the Mancuso study in order to arrive at a potency slope estimate have therefore been reviewed.

Risk factors were presented by the EPA and the DHS in terms of unit risk (life time cancer risk due to lifetime exposure to average ambient air concentrations of 1 ug carcinogen/m^3) in units of $(ug/m^3)^{-1}$. They have been translated here to q_1^* in terms of $(mg/kg\text{-}day)^{-1}$ as well.

7.3.3. IDENTIFICATION OF A RANGE OF POTENCY SLOPE VALUES

The Mancuso study has been reviewed and critiqued by industrial hygienists (DHS, 1985). The results of these reviews can be summarized as follows:

(a) Lung cancer mortality is reported for total chromium. Since available data suggest that only hexavalent chromium compounds are carcinogenic, use of total chromium data results in an overestimation of exposure (and therefore an underestimation of cancer potency).

Bourne and Yee (1950), who conducted the industrial hygiene survey in 1949, estimated the ratio of Cr(VI) to Cr(III) in the airborne dust in the nine major departments of the industrial facility. From their data, EPA estimated that the Cr(VI) to total chromium ratio is not less than one-seventh (1/7). Overestimation of exposure due to speciation is therefore not likely to be more than seven fold (leading to an underestimation of potency).

(b) According to Hathaway, Mancuso had assumed that worker exposure post-1949, after the plant initiated a program to reduce worker exposure, was zero. Failure to account for post-1949 exposure might result in underestimation of exposure (and therefore an overestimation of cancer potency).

(c) It was assumed that smoking habits of chromate workers were similar to those of white male members of the general population. This factor may contribute to overestimation of cancer potency because chromate workers probably smoke more than the general (background risk) population (see Equation (3) above).

In view of the above factors, EPA concluded that underestimation of risk due to factor a) is balanced out by the overestimation of risk contributed by factors b and c). EPA thus judged that the unit risk of 1.2×10^{-2} $(ug/m^3)^{-1}$ ($q_1^* = 42$ $(mg/kg\text{-}day)^{-1}$), calculated on the basis of total chromium by the Mancuso study employing the competing risk model, is the best estimate of cancer potency from hexavalent chromium exposure. This value for the Cr(VI) cancer potency is employed by EPA in evaluating cancer risk under its regulatory programs such as Superfund (USEPA, 1986).

In view of the above factors the DHS concluded that underestimation of risk due to factor a) is not more than seven fold, and that overestimation of risk due to factor b) may be 5.6 fold. Point c), the possible contribution to higher background risk (and therefore overestimation of cancer potency) by the potentially higher smoking rate among workers, was not considered. In addition to the competing risk model, the DHS calculated the cancer potency factor by the crude model using the Mancuso study. Maximum likelihood estimates of potency factors were obtained for the crude model. Different combinations of factors a) (7 fold) and factor b) (5.6 fold) were applied to the best estimates thus creating the array of unit risks displayed in Table 7-1. Ultimately, the DHS chose to promulgate a range of unit risk values with the upper limit the 95% upper confidence limit (UCL) of the unit risk derived from the crude model corrected only for Cr(VI) speciation; and the lower limit the best estimate 1.2 x 10^{-2} $(ug/m^3)^{-1}$ preferred by EPA. The upper value is obtained by calculating the 95% UCL of the maximum likelihood unit risk and multiplying by 7 to result in a unit risk of 1.46 $(ug/m^3)^{-1}$ (q_1^* = 511 $[mg/kg\text{-}day]^{-1}$).

The scientific evidence is strong that estimation of cancer risk by the Mancuso study is influenced by the uncertainty in exposure data represented by factors a) and b); that points a) and b), if considered at all, should be treated as one overall entity. Unit risk calculated by EPA represents the latter in the way that the factors cancel each other. When correction factors of 7 and 1/5.6 are applied to the maximum likelihood estimate derived from the crude model, a unit risk of 1.8 x 10^{-2} $(ug/m^3)^{-1}$ (q_1^* = 63 $[mg/kg\text{-}day]^{-1}$) is obtained (the DHS_2 potency shown in Table 7-1). The 95% UCL of this risk value is 2.6 x 10^{-2} (q_1^* = 91 $[mg/kg\text{-}day]^{-1}$). Correction for smoking habits is not appropriate because sufficient data to support an appropriate correction factor are lacking.

A comparison of the unit risk and q_1^* values discussed above is presented in Table 7-1.

California Department of Health Services guidelines for chemical carcinogen risk assessment suggest that a range of unit risk values be used to reflect the uncertainty present therein. Based upon the previous discussion, the following has been employed as the most reasonable range in this risk estimate:

TABLE 7-1

COMPARISON OF CHROMIUM CANCER POTENCY SLOPES

Data Base	Best Estimate		95% Upper Confidence Limit	
	Unit risk $(ug/m^3)^{-1}$	q_1^* $(mg/kg\text{-}day)^{-1}$	Unit risk $(ug/m^3)^{-1}$	q_1^* $(mg/kg\text{-}day)^{-1}$
EPA (competing risk model)	1.2×10^{-2}	42	NA	NA
DHS (competing risk model)	1.16×10^{-2}	41	NA	NA
DHS/EPA (crude model)	1.44×10^{-2}	50	2.1×10^{-2}	73
DHS_1 (crude model)	10.08×10^{-2}	353	14.6×10^{-2}	511
DHS_2 (crude model)	1.8×10^{-2}	63	2.6×10^{-2}	91

DHS_1 = DHS (crude model) x 7

DHS_2 = DHS (crude model x $^{7}/_{5.6}$

7 multiplier <=> factor a)

$^{1}/_{5.6}$ multiplier <=> factor b)

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	Best Estimate	95% UCL
q_1^*:	42 $(mg/kg\text{-}day)^{-1}$	91 $(mg/kg\text{-}day)^{-1}$

The lower end of this range (42 $(mg/kg\text{-}day)^{-1}$) is the competing risk model maximum likelihood estimate preferred by EPA. The upper end of this range (91 $(mg/kg\text{-}day)^{-1}$) results from multiplying the crude model best estimate by 7/5.6 and taking the 95% UCL. This range is believed to be health conservative and well supported by the available scientific data. However, calculations have also been performed employing the upper end of the DHS range, a value for q_1^* of 511 $(mg/kg\text{-}day)^{-1}$.

7.4. EXPOSURE ASSESSMENT

7.4.1. SPECIFIC ENVIRONMENTAL PATHWAYS ADDRESSED

In order to adequately quantify exposures due to chromium in ground water, it is necessary to consider all significant exposure routes and environmental pathways which might lead to exposure to the Cr(VI) or its reduction product Cr(III). These include: direct contact with groundwater or groundwater-contaminated soil; inhalation of aerosolized groundwater; and ingestion of groundwater-contaminated soils, or food products grown with contaminated groundwater or in groundwater-contaminated soils. The following activities and routes of exposure were considered in this risk assessment. Some of the ingestion pathways, such as ingestion in home grown beef and milk (the latter without central processing) are considered possible but not likely. They are are included in order to be health-conservative. One possible pathway via evaporative coolers has not been addressed because it has not been possible to quantify its impact; this pathway is not considered to be significant.

Dermal Route

Showering
Washing hands
Washing dishes

Washing cars and/or trucks
Washing cows
Washing barn
Commercial irrigation
Domestic irrigation
Domestic gardening (soil)
Outside play
Unspecified outdoor activities (soil)

Inhalation

Showering
Washing dishes
Washing clothes
Washing cows
Washing barn
Commercial irrigation
Domestic irrigation
Domestic gardening
Outside play
Unspecified indoor activities, including sleep
Unspecified outdoor activities

Ingestion of:

Locally produced fruits and vegetables
Locally produced milk
Locally produced beef
Soil contaminated with Cr(VI)-containing groundwater.

7.4.2. EXPOSURE CALCULATION

A generic equation was utilized to quantify exposure through each route of exposure. The equation utilized several parameters which are not relevant for every route. These factors were set equal to one when not used, in order to not effect the calculation.

$$DOSE = A \times \%Exp \times [Cr] \times ABS \times T \times R \times VorM \times 1/BW$$

Where:

A = TOTAL BODY SURFACE AREA (cm^2)
%Exp = PERCENT OF TOTAL BODY SURFACE AREA EXPOSED
[Cr] = CHROMIUM CONCENTRATION (mg/l or mg/kg)
ABS = DERMAL ABSORPTION RATE (mg/cm^2/day/[mg/l])
T = TIME (fraction of a day)
R = RATE ([units] per day)
VorM = VOLUME OR MASS (l or kg)
BW = BODY MASS (kg)

For the inhalation route, absorption rate and volume or mass were set to unity. For the dermal route, the rate and volume or mass terms were set to unity. For the ingestion route, the area, absorption rate, time, and rate terms were set to unity.

The doses were calculated for each of the situations listed in 7.4.1. as part of a computerized computation of the risks for each of the exposure scenarios.

7.4.3. COMPUTATION OF CANCER RISKS

Since Cr(VI) is considered carcinogenic only by the inhalation route, cancer risks were calculated for inhaled Cr(VI) only (see section 7.2). The risk was computed for each situation using the following equation.

RISK = DOSE x CANCER POTENCY FACTOR

Where:

DOSE = DAILY DOSE OF Cr(VI) (mg/kg-day)
CANCER POTENCY FACTOR = CANCER POTENCY SLOPE, q_1^* $(mg/kg\text{-}day)^{-1}$

The risk was calculated for each individual in each year in the exposure model. These annualized risks were time-weighted and summed to reflect the total estimated lifetime risk from exposure to the individual subjected to site conditions described in Chapter 6 for a 70-year lifetime and for a 50-year adult lifetime. This was computed for conditions of groundwater concentrations for a twenty-year period at five year increments, beginning in 1988 (see Chapter 6 for groundwater data).

The maximally exposed individual's (MEI) lifestyle was identified on the basis of risk assessment results. For remedial Alternative 1, that MEI would be an adult performing domestic tasks, living at the ranch at Point B_3 in Figure 4-1 throughout a 70-year lifetime from birth through adulthood. For Alternative 2, the MEI would be a dairy farmer, living at Point B_3, and working at point A in Figure 4-1 throughout a 50-year adult life. For Alternative 3 the MEI would be the dairy farmer, as described for Alternative 2. If Alternative 3 is extended to replace the water used to wash cows and barns, all individuals considered become the MEI's. The excess lifetime risk resulting from a 50-year adult lifetime exposure to the maximally exposed individual was computed by extrapolating the risk incurred by that individual in 1988 to the first year of adulthood, the risk incurred in 1989 to the following four years, the risk incurred in 1993 to the next five years, the risk incurred in 1998 to the next five years, the risk incurred in 2003 for the next five years, and the risk incurred in 2008 to the remaining 30 years of a 50-year adult life span. Lifetime risks for living a 70-year lifetime at the site were also calculated on a time-weighted basis. This considered the exposure to the 2-1/2 year-old child for the first five years as above, the 10 year-old child for the following 10 years, and each adult over each of the remaining five-year periods, extrapolating the risks for the year 2008 over the rest of the life of the individual.

7.4.4. NON-CANCER RISKS

Non-cancer risks were computed by comparing the Cr(VI) and Cr(III) doses to an allowable daily intake for chronic exposures (AIC) for Cr(VI), and expressing this as a hazard index (USEPA, 1985):

$$\text{HAZARD INDEX} = \frac{\text{DOSE Cr(VI) + DOSE CR(III)}}{\text{AIC Cr(VI)}}$$

Because the Cr(VI) AIC is health conservative for Cr(III), it was used for both Cr(VI) and Cr(III). This hazard index was computed for background and incremental doses from each of the compartments. The incremental hazard index for each compartment was summed to generate an overall incremental hazard index. The same was done to generate the background and total overall hazard indices. A total overall hazard index less than one indicates the absence of a risk, whereas a total overall hazard index greater than one indicates the presence of a risk.

Hazard indices can also be computed for shorter-term exposures, utilizing acute or subacute AIC's. As the chronic hazard index is, by design, always at least as stringent as the acute or subacute, only the chronic hazard index was computed.

Unlike cancer risk, the hazard index reflects day-to-day, month-to-month, year-to-year risks, and are not additive through time. Thus, adjustment for lifetime exposures are not appropriate.

7.4.5. SPECIFIC HUMAN RECEPTORS ADDRESSED

Several assumptions affecting exposure and dose modeling apply to all of the individuals considered, although exceptions are noted for some specific receptors. The values used for body weight, surface area, ventilation rate, and ingestion rate are those reported in Report of the Task Group on Reference Man (Snyder, et al., 1975). These values were developed by the International Commission on Radiation Protection, for use in computing radiation doses. They are appropriate for computing doses of chemical toxicants as well. These assumptions include:

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(1) the receptors are typical people, reflected by statistical averages of body weight, surface area, ventilation rates, etc.

(2) except for off-site work or school, the receptors are considered to be on-site 24 hours per day, 365 days per year.

(3) exposure times reflect a 5-day work week, with 2 weeks vacation per year, or a 3-month school vacation.

(4) exposure times reflect 8 hours of work (play for children), 8 hours of sleep, 4 hours of other indoor time, and 4 hours of other outdoor time.

(5) the dermal absorbance (ABS) of Cr(VI) = 3.5×10^{-5} mg/cm^2/day/[mg/l] (Wahlberg 1970).

(6) the skin is impermeable to Cr(III) (dermal absorbance (ABS) of Cr(III) = 0 mg/cm^2/day/[mg/l]).

(7) drinking/cooking water not containing Cr(VI) is supplied and used.

(8) no other sources of Cr(VI) exposure via the ingestion route apply, because it is transformed to Cr(III) before exposure (see Chapter 6).

(9) ingestion rates for produce, milk and meat were assumed to be the per capita consumption rates in the case of adults, and were scaled to children by body mass, assuming a 70 kg adult.

(10) the domestic water source considered was the single most contaminated domestic well, as presented in Chapter 6.

(11) outdoor air Cr(VI) concentrations result from commercial irrigation overspray, and from domestic irrigation, as presented in Chapter 6.

(12) indoor air Cr(VI) concentrations reflect outdoor air concentrations reduced by a factor of two.

(13) breathable shower air concentrations of aerosol water are represented by the experimental air concentrations described in Chapter 6.

(14) breathable air concentration of aerosol water while washing dishes and clothes are one tenth of those found in the shower.

(15) breathable air concentrations of aerosol water while washing cattle, vehicles and barns are two tenths of those found in the shower.

(16) water from irrigation wells was used for washing cattle, vehicles, and barns.

(17) the allowable daily intake for chronic exposures (AIC) to Cr(VI) is 0.042 mg/kg-day, as described in Section 7.3.

(18) the allowable daily intake for chronic exposures (AIC) to Cr(III) is 0.042 mg/kg-day, as described in Section 7.3.

(19) chromium is carcinogenic only when in the hexavalent state [Cr(VI)], and only via the inhalation route, as described in Section 7.2.

(20) the most reasonable cancer potency factor q_1^* for Cr(VI) via the inhalation route is 91 $(\text{mg/kg-day})^{-1}$, the upper end of the range of potency factors developed in Section 7.3; other values developed in Section 7.3 are also employed (42 and 511 $(\text{mg/kg-day})^{-1}$).

Exposures to six different individuals (receptors) were evaluated to determine the risks presented to each. They include the following:

Dairy farmer

Exposures to an adult farmer living at Point B_1 and working at Point A of figure 4.1 were evaluated. Assumptions about the dermal exposure route include: a body mass of 70 kg, a total body surface area of 18,000 cm^2. The dairy farmer was assumed to work 7 days per week, with two weeks' vacation per year. This is a very conservative assumption. Assumptions regarding the variables for each activity affecting the dermal route include:

Activity	Body Surface Area (% Total)	Time (day)
Showering	100%	0.007 (10 min/day)
Washing hands	5%	0.01 (15 min/day)
Washing vehicles	50%	0.003 (1 hr/wk)
Washing cows	50%	0.04 (1 hr/day)
Washing barn	50%	0.04 (1 hr/day)
Domestic irrigation	10%	0.018 (1 hr/day 4 day/wk, 9 mo/yr)

The 50% of body surface area exposed during washing of vehicles, cows and barn represent wet clothing on that portion of the body. It is conservative but reasonable.

Assumptions regarding the inhalation route include a ventilation rate of 23 m^3/day for light work, 10.8 m^3/day for non-exertion time. Time reflects the same assumptions as for the dermal route. Assumptions regarding the variables for each activity affecting the inhalation route are described above.

Assumptions regarding the variables for each source affecting the ingestion route include:

Source	VorM/day
Locally produced fruits and vegetables	0.516 kg
Locally produced milk	0.3 l
Locally produced beef	0.248 kg
Soil	3.9×10^{-4} kg

<u>2-1/2 year-old child, residing at location B_1</u>

This receptor was assumed to have a total body mass of 17 kg, and a total body surface area of 5,300 cm^2. Assumptions about activities related to dermal absorption are as follows:

Activity	Body Surface Area (% Total)	Time (day)
Showering	100%	0.007 (10 min/day)
Washing hands	5%	0.004 (5 min/day)

The inhalation route assumes a ventilation rate of 6.7 m^3/day for light work, and 2.5 m^3/day for resting time; and outside play time was assumed to be 8 hrs/day.

Quantities of contaminated materials ingested were assumed to be as follows:

Source	VorM/day
Locally produced fruits and vegetables	0.125 kg
Locally produced milk	0.45 l
Locally produced beef	0.06 kg
Soil	1.3×10^{-4} kg

<u>10 year-old child, residing at location B_1</u>

This receptor was assumed to have a total body mass of 33 kg, and a total body surface area of 9,600 cm^2. Assumptions about activity times relevant to dermal exposures are:

Activity	Body Surface Area (% Total)	Time (day)
Showering	100%	0.007 (10 min/day)
Washing hands	5%	0.007 (10 min/day)

Assumptions regarding the inhalation route include ventilation rates of 13 m^3/day for light work, and 4.8 m^3/day for resting time. The child was presumed to be off-site at school 8 hrs/day during school months.

Assumptions of consumption of contaminated materials include:

Source	VorM/day
Locally produced fruits and vegetables	0.243 kg
Locally produced milk	0.45 l
Locally produced beef	0.117 kg
Soil	3.7×10^{-5} kg

<u>Adult performing domestic tasks ("homemaker"), residing at location B_1</u>

This receptor was assumed to have a total body mass of 58 kg, and a total body surface area of 16,000 cm^2. Assumptions about activities resulting in dermal exposure include:

Activity	Body Surface Area (% of Total)	Time (day)
Showering	100%	0.007 (10 min/day)
Washing hands	5%	0.01 (15 min/day)
Washing dishes	5%	0.02 (30 min/day)
Washing clothes	5%	0.04 (60 min/day)

Assumptions regarding the inhalation route include ventilation rates of 23 m^3/day for light work, and 10.8 m^3/day for non-exertion time. Assumptions about activities contributing to inhalation include:

Activity	Time (day)
Showering	0.007 (10 min/day)
Washing dishes	0.02 (1/2 hr/day)
Washing clothes	0.04 (2 x 1/2 hr/day)

Assumptions about quantities of ingested contaminated materials include:

Activity	VorM/day
Locally produced fruits and vegetables	0.516 kg
Locally produced milk	0.3 l
Locally produced beef	0.248 kg
Soil	3.9×10^{-4} kg

Adult residing at location B_1, employed as an irrigator

Assumptions about specific activities affecting the dermal route include:

Activity	Body Surface Area (% of Total)	Time (day)
Showering	100%	0.007 (10 min/day)
Washing hands	5%	0.01 (15 min/day)
Washing vehicles	50%	0.006 (1 hr/wk)
Commercial irrigation	40%	0.222 (8 hr/day) 7 day/wk, 8 mo/yr)
Domestic irrigation	10%	0.018 (1 hr/day, 4 day/wk, 9 mo/yr)

Assumptions regarding activities contributing exposures via the inhalation route include:

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Activity	Time (day)
Commercial irrigation	0.007 (15 min/day)
Domestic irrigation	0.018 (1 hr/day, 4 day/wk, 9 mo/yr)
Domestic gardening	0.05 (4 hr/day, 2 day/wk, 9 mo/yr)

Assumptions about consumption of contaminated materials include:

Source	VorM/day
Locally produced fruits and vegetables	0.516 kg
Locally produced milk	0.3 l
Locally produced beef	0.248 kg
Soil	3.9×10^{-4} kg

Laborer

This receptor was considered to live at the site (Point B_1), but work off-site, away from the contamination 8 hours per day. Assumptions about the activities affecting the dermal route include:

Activity	Body Surface Area (% Total)	Time (day)
Showering	100%	0.007 (10 min/day)
Washing hands	5%	0.01 (15 min/day)

Assumptions regarding the activities affecting exposures via the inhalation route include:

Activity	Time (day)
Domestic gardening	0.05 (4 hr/day, 2 day/wk, 9 mo/yr)

Assumptions regarding exposure to contaminated materials via the ingestion route include:

Activity	VorM/day
Locally produced fruits and vegetables	0.516 kg
Locally produced milk	0.3 l
Locally produced beef	0.248 kg
Soil	3.9×10^{-4} kg

7.5. ESTIMATED HEALTH RISKS UNDER DIFFERENT REMEDIAL ALTERNATIVES

7.5.1. INCREMENTAL CANCER RISKS

The method of computation of the cancer risks related to the Cr(VI) in the groundwater at Hinkley are summarized in section 7.4.3. The results of those projections are summarized in Table 7-2. For the preferred cancer potency slope q_1^* value of .91 $(mg/kg\text{-}day)^{-1}$, for example, Table 7-2 indicates as follows. The table indicates that continuing the current irrigation practice Alternative 1 results in the maximally exposed individual being the "homemaker" living at Point B_1 (See Figure 4-1) with an estimated cancer risk of 1.3×10^{-5} arising from a 70-year lifetime exposure at the site. In the case of the accelerated agricultural treatment Alternative 2, maximal exposures occur at Point B_1, resulting in an estimated lifetime risk of 2.1×10^{-6} to the dairy farmer exposed over a 50-year adult life. For the domestic water replacement Alternative 3, maximal exposures are incurred by the dairy farmer over a 50-year adult life, resulting in an estimated lifetime risk of 5.8×10^{-6}. If Alternative 3 is extended to the water used to wash cows, barns and vehicles, all individuals become MEI's with estimated lifetime risks of 2.9×10^{-7}.

Since one application of risk assessments is to be protective of the health of individuals, the maximally exposed individual (MEI) is addressed in the previous paragraph. Typically, individuals other than the MEI are also considered in risk assessments to address the potential for community impacts (excess cancer burden). Given the small number of exposed individuals (fewer than 100) the excess cancer burden in the exposed population is computed to be less than 10^{-3} (no excess cancers predicted).

7.5.2. NON-CANCER RISKS

Evaluation of the hazard indices (presented in Table 7-2) for each of the individuals through time indicates the absence of non-cancer risks. The total hazard indices range from 0.01 to 0.024. These primarily reflect exposures to normal concentrations of Cr(III) in ordinary foods, and cannot be construed as presenting a health risk.

There is a possibility of subpopulations being inordinately sensitive to Cr(VI). Its presence in the domestic water could cause allergic dermatitis. Due to difficulties in quantifying a dose-dependent response to such exposures, it is not possible to quantify the risks associated with this effect. The effect is a nuisance, and is not life-threatening. Furthermore, medical examinations of exposed individuals at the site revealed no such contact dermatitis effects (Lowengart, 1988).

7.5.3. DISCUSSION OF HEALTH RISK ESTIMATES

The conclusions which can be drawn from this risk assessment are as follows:

(1) Adverse non-cancer health effects are not expected.
(2) Assuming continuation of the current irrigation practice Alternative 1, the upper-bound lifetime cancer risk to a maximally exposed individual is estimated to be 1×10^{-5}, or one-in-one-hundred-thousand.
(3) Assuming implementation of the accelerated agricultural treatment Alternative 2, the upper-bound lifetime cancer risk to a maximally exposed individual is estimated to be 2×10^{-6}, (two-in-one-million.)
(4) Assuming implementation of the domestic water replacement Alternative 3, the cancer risk to the maximally exposed individual is estimated to be 6×10^{-6}, or six-in-one-million.

(5) Considering the risk to the maximally exposed individual, and the population at the site, the excess cancer burden in the local population is expected to be non-existent.

Tables presenting more complete results, along with calculations and explanations are presented in Appendix A7.

The hazard index, which measures adverse non-cancer health effects, was less than 1 in all cases (range: 0.01-0.024). This indicates the non-cancer health risks from the groundwater contamination is insignificant under any of the remediation alternatives.

The maximally exposed individual under the current irrigation practice alternative 1 is an individual living at the site throughout a 70-year lifetime. This individual (performing domestic tasks) has an expected cancer risk of 1×10^{-5}, or one-in-one hundred-thousand. This utilizes the q_1^* of 91(mg/kg-day)$^{-1}$.

Under the accelerated agricultural treatment Alternative 2, the maximally exposed individual lives at the site through a 50-year adulthood, with an expected cancer risk of 2×10^{-6}, or two-in-one-million. (For a thorough description of the assumptions about this individual (the "dairy farmer") and others considered, see section 7.4.5.) This risk value reflects a cancer potency factor of 91 (mg/kg-day)$^{-1}$. If a cancer potency factor of 42 (mg/kg-day)$^{-1}$ is used, the risks are 0.46 times those discussed here; if a cancer potency factor of 511 is used, the risks are 5.6 times those discussed here (see Table 7-2).

Under the domestic water replacement Alternative 3, the maximally exposed individual is the dairy farmer. His cancer risk is 6×10^{-6}, or six-in-one-million, resulting from a 50-year adult life of exposures. This risk is based on the 91 (mg/kg-day)$^{-1}$ q_1^*.

The maximally exposed individual is not intended to be representative of the average person at the site. The MEI is analyzed to determine if an unacceptable risk is borne by any exposed individual. There is a tendency in risk assessments such as this to overestimate the risk to the MEI by assuming that individual engages in all activities possibly posing a risk. Efforts were made in this risk assessment to avoid such overestimation by considering realistic daily habits and behaviors. Even so, this approach is conservative, and the average person at the site would be expected to have a substantially lower risk. The computation of the risk to the average person is utilized in the determination of the population cancer burden. Due to the small population exposed and low individual risks, population cancer burden is insignificantly small.

7.6. UNCERTAINTY ANALYSIS

Due to the number of assumptions, data points, and calculations, a degree of uncertainty is necessarily associated with the risk estimates from any risk assessment. These uncertainties systematically and intentionally bias the risk estimates upward (greater risk). This is because if an error is to be made due to uncertainty, it is to be protective of human health. It is also important to not unnecessarily overestimate the risk by making unrealistic assumptions. In an attempt to clarify the effect of these uncertainties, the assumptions made in this risk assessment are classified below as of conservative (C), neutral (N), or indeterminant bias (I). The degree of uncertainty on an arbitrary scale of 1 to 3 (1 being least uncertain, 3 being more uncertain) is also indicated.

Assumption	Bias	Degree
Cancer Potency Slope	C	2
Non-Cancer AIC	C	1
Body Mass	N	1
Total Body Surface Area	N	1
Percent Surface Area Exposed	N	2
Time On-Site	C	1
Dermal Absorbance Cr(VI)	I	3
Dermal Absorbance Cr(III)	N	1
Ingestion Volumes and Masses	N	2
Irrigation Aerosol Production	C	2
Shower Aerosol Production	N	1
Dishwashing Aerosol Production	C	2
Clothes Washing Aerosol Production	C	2
Cow Washing Aerosol Production	N	3
Barn Washing Aerosol Production	C	3
Time Showering	N	1

Time Washing Hands	C	2
Time Washing Vehicles	N	2
Time Washing Barns and Cows	N	2
Time Watering Garden	N	2
Irrigator's Maximal Exposure Time	N	2
Time Domestic Gardening	N	2
Time Commercial Gardening	N	2
Time Indoors	N	1
Time Outdoors	N	1
Mass of Produce Consumed	C	1
Source of Produce	N	2
Ventilation rates	N	2
Soil Mass Ingested	N	3
Chromium Concentration, Produce	N	2
Chromium Concentration, Meat	N	2
Chromium Concentration, Milk	N	2

In light of this analysis, the individual exposure scenarios (behavior patterns) used in this model were designed to be realistic, yet conservative enough to be protective of health in a foreseeable situation. No one individual was considered to engage in all available high-risk activities, since such behavior by any given individual is highly unlikely.

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8.0 ECOLOGICAL RISK ASSESSMENT

8.1. INTRODUCTION

Chromium is known to be toxic to a wide variety of organisms, with Cr(VI) exhibiting the greatest biological activity, particularly as an inhalation carcinogen. Tissue concentrations of Cr(VI) elevated above background have been associated with abnormal enzymatic activities, altered blood chemistry, lowered resistance to pathogens, behavioral modifications, disrupted feeding, histopathology, osmoregulatory upset, alterations in population structure and species diversity indices, and inhibition of photosynthesis (Eisler, 1986). In the present case, elevated quantities of Cr(VI) and Cr(III) occur in the local site environment. Therefore, it is appropriate to determine the likelihood or probability for ecosystem toxicity. The study was approached in the following fashion:

(1) Identification of toxicological criteria;

(2) Development of environmental exposure concentrations (EECs) to which nonhuman receptors may be exposed; and

(3) Analysis of risk to those receptors.

Information on the toxicity of chromium to the various receptors of interest was first reviewed to identify appropriate toxicological standards for comparison to estimated EECs. These standards are laboratory-determined doses measured under conditions consistent with exposures that may occur at the site, at which no observable biological toxicity was noted. This approach is used when thresholds are assumed for toxic response or when detailed dose-response relationships have not been determined. Some common thresholds include the Lowest Observable Effect Level (LOEL), the No Observable Effect Level (NOEL), and the No Observable Adverse Effect Level (NOAEL), which are favored by EPA for use in ecological risk assessments. These effect levels are used to define a reference concentration (RfC) or dose (RfD) below which no toxicity is assumed to occur. Differences between RfCs and RfDs result from the toxicological data used to establish them.

The data used for microbes and flora are based on concentration (unit mass of a toxicant per unit mass or volume of some environmental medium); whereas the data for fauna are typically based on dosage (unit mass of toxicant per unit body weight per unit time). Thus RfC was calculated using, for example, a NOEL which is based on concentration, while an RfD relates to a threshold which is based on dosage. RfDs (or RfCs) are generally calculated by dividing a given effect level by various safety factors (e.g., 10, 100, 1,000) to account for uncertainties resulting from interspecies variation, or short-term testing (less time than chronic exposure), for example. The RfC or RfD therefore represents the safe upper limit of exposure reflecting uncertainties for the receptors of interest.

The second step was the development of an EEC for each receptor. This required the definition of realistic scenarios for exposure. The particular scenarios for each receptor were designed to generate levels considered conservative enough (i.e., worst-case) to provide a substantial safety margin.

The final step of the assessment was evaluation of risk. As described by Barnthouse et al. (1986) there are five possible approaches to this analysis: the quotient method or hazard index [HI]; analysis of extrapolation error; fault-tree analysis; analytic hierarchy method; and ecosystem uncertainty analysis. The method applied in the present study was that suggested by the Ecological Effects Branch of EPA, which is similar to the quotient or HI method (USEPA, 1986). This method compares the EEC to the RfC or RfD by ratio, to test for possible adverse effects, that is, HI = EEC/RfC (or RfD). According to Barnthouse et al. (1986), if the ratio or HI of the EEC to the RfD was:

(1) HI < 0.1, then adverse effects are considered unlikely;

(2) 0.1 < HI < 10, then adverse effects are considered possible; or

(3) HI > 10, then adverse effects are considered probable.

The EPA (USEPA 1986) applies somewhat different criteria to determine chronic risk. This test is based on the following:

(1) If the Environmental Exposure Concentration (EEC) < chronic NOEL (the HI <1.0), then there is the presumption of no risk;

(2) For non-endangered species, if the EEC > chronic NOEL (the HI ≥ 1.0), including reproductive effects, then there is the presumption of unacceptable risk; or

(3) For endangered species, if the EEC > chronic NOEL (the HI ≥ 1.0), including reproductive effects or any adverse habitat modification, then there is the presumption of unacceptable risk.

For this analysis, both test criteria were evaluated. The EPA criteria were used following standard practice. The criteria suggested by Barnthouse et al. were included because they represent a more stringent test with an order of magnitude lower limit for identifying possible risk.

This chapter addresses the potential for risk to non-human receptors. The analysis begins by considering the effects of chromium on the soil ecosystem. An important feature of remedial alternative 2 (accelerated agricultural treatment) involves the use of the natural capacity of the soil to adsorb and reduce Cr(VI) to Cr(III). Since chromium can potentially impact organisms that inhabit soil, the viability of the soil ecosystem is of concern and was included in the assessment. The second receptor which is analyzed is alfalfa, the single floral indicator species identified in Section 4.2. The chapter concludes with an analysis of risk to the various faunal indicator species selected in Section 4.2, namely

(1) Mojave ground squirrel;

(2) Califoria vole;

(3) Desert cottontail;

(4) Desert tortoise;

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(5) Badger; and

(6) Dairy cow.

8.2. SOILS

The assessment of risk to soil microflora and infauna is presented in three sections: criteria, estimation of exposure concentrations, and analysis of risk and associated conclusions.

8.2.1. CRITERIA

Toxic reactions of microorganisms to chromium are highly varied. EPA (USEPA 1978), in a review of the limited available literature, found that microbes (algae, fungi, protozoa, and bacteria) from aquatic and soil environments varied in their toxic reactions. The review concluded that a concentration of between 0.05 and 5 mg/l or mg/kg represented a reasonable toxic threshold for microorganisms (no differentiation was made between ionic species or environmental compartment). This threshold seems conservative for most soils, since the average chromium concentration ranges from 5 to 300 mg/kg for nonserpentine, vegetated soils worldwide (Table 3-1). In fact, this threshold probably reflects the more sensitive aquatic environment and species, such as algae. Moreover, background concentrations of Cr(T) in the study area range from 13.6 mg/kg for site soils to 7.45 mg/kg for alfalfa field soils, and these soils are fertile and readily support agriculture (Appendix A4, Demographics Report). No Cr(VI) was detected in these samples.

A more reasonable threshold value may be the lowest available LC_{30} for bacteria (<u>Staphlococcus aureus</u>) exposed to Cr(VI) of 76 ppm (Eye, 1974). This value is also lower than toxic levels reported for protozoans and fungi (USEPA, 1978). However, the toxicity of chromium to bacterial isolates in soil has been more recently studied in culture with various salt supplements. A solution concentration of 10 - 12 mg/l of Cr(VI) has been found to inhibit growth in many soil isolates, while Cr(III) shows no toxicity at these levels (Ross, Sjogren & Bartlett, 1981). Gram negative (G-) staining bacteria are apparently more sensitive than positive (G+) staining ones, most likely because the thick cell wall of G+ species interferes with metal ion transport.

Toxicity data for terrestrial invertebrates are also limited. Two studies have shown that Cr(VI) concentrations of 10 to 15 mg/l in irrigation water was lethal to two species of earthworms within 58 to 60 days (Soni and Abbasi, 1981; Abbasi and Soni, 1983). Beetles and crickets collected near cooling towers charged with chromium-tainted water contained 9 to 37 mg/kg Cr(T) in the gut contents versus 0.5 to 0.8 mg/kg for controls (Taylor, 1980). High accumulations of chromium have been recorded among organisms from the lower trophic levels, but there is little evidence of biomagnification through the food chain (Eisler, 1986).

It is interesting to contrast the values discussed above with the EPA (USEPA 1980) loading limit for chromium in soil. The suggested level is 1,000 mg/kg for hazardous waste land treatment units, and assumes all chromium is converted to Cr(III). This value was based on a National Academy of Sciences study conducted in 1972, which assumed an irrigation water quality of 20 ppm Cr(T). It appears that this loading limit was probably based on physical soil loading capacity and not toxicological endpoints, and thus would not be an appropriate criterion for this assessment.

From the foregoing review, the selected RfC for effects used in the following evaluation of risk is based on the NOEL of 10 mg/l. This threshold is considered not to be species-specific.

8.2.2 EXPOSURE

<u>Approach</u>

The toxicological data discussed above are based on tests conducted with readily available or soluble forms of chromium. In soil, most chromium is adsorbed to soil particles or organic matter, or precipitated as an insoluble complex, and is, therefore, unavailable to various soil microflora and fauna.

Thus it would be inappropriate to compare actual soil concentrations to the selected toxicological threshold. Bioavailable soil concentrations were estimated from waste extraction test (WET) data described in the Site Characterization Report.

Estimated Exposure Concentration The estimated exposure concentration (EEC) was determined in the following manner. The following average soil concentration data, derived from either Chapters 3.0 or 6.0, were used:

(1) Site soils Cr(T) = 277 mg/kg.

(2) Site soils Cr(VI) concentration = 0.16 mg/kg.

(3) Alfalfa field soils Cr(T):

Present level = 33 mg/kg;

Alternative 1 = 37.4 mg/kg (highest level in 20 years);

Alternative 2 = 35.9 mg/kg (highest level in 20 years); and

Alternative 3 = not applicable.

(4) Residential soils Cr(T):

Alternative 1 = 70.2 mg/kg (highest level in 20 years);

Alternative 2 = 48.3 mg/kg (highest level in 20 years); and

Alternative 3 = 35.0 mg/kg (highest level in 20 years).

The WET data for site soils demonstrated an average extractable fraction of 0.75% for Cr(T) and 1.6% for Cr(VI) (Site Characterization Report). Therefore, the EECs for the various soils and test scenarios were calculated as:

EEC (in mg/l) = soil chromium concentration(in mg/kg) x
0.0075 (for Cr(T)) or 0.016 (for Cr(VI))
(in (mg/l)/(mg/kg)),

and determined to be:

Site soils

Cr(T) = 2 mg/l;

Cr(VI) = 0.002 mg/l;

Alfalfa field soils Cr(T):

Present = 0.25 mg/l,

Alternatives 1 and 3 = 0.28 mg/l,

Alternative 2 = 0.27 mg/l; and

Residential soils Cr(T):

Alternative 1 = 0.53 mg/l,

Alternative 2 = 0.36 mg/l; and

Alternative 3 = 0.27 mg/l.

8.2.3. RISK ESTIMATION

Risk

Hazard Indices (HIs) were calculated for soil microflora or infauna; results are summarized below:

Site soils

Cr(T) = 0.2;

Cr(VI) = 0.0001;

Alfalfa field soils-Cr(T):

Present = 0.025,
Alternative 1 = 0.028,

Alternative 2 = 0.027; and

Alternative 3 = 0.028.

Residential soils Cr(T):

Alternative 1 = 0.053,

Alternative 2 = 0.036; and

Alternative 3 = 0.027.

In all cases, the HIs are below one and therefore meet the EPA criteria. However, site soils do contain elevated levels of Cr(T), which may have an ecological impact on microflora but not infauna, according to the criteria of Barnthouse, et al. (1986).

The estimation of risk through the HI is sensitive to the modeled exposure concentration, which was derived from soil concentration data and WET analyses. It was assumed that the WET data reflected the extractable portion of chromium from the soil, which is bioavailable. The test involves the extraction of chromium from soil samples with water containing citric acid at a pH of 5.0. The extract is considered to represent that fraction of the Cr(T) in the sample that is bioavailable. It is unlikely that it underestimates the amount. In any case, the EEC and the HI would not change substantially without a +/- 100 % change in the WET data.

<u>Conclusion</u>

No significant toxicities are expected based on these results; therefore, no ecological risk is anticipated. However, in one case (i.e., site soil), the bioavailable soil concentration presents a possibility of an ecological impact to soil microorganisms based on the most stringent criteria. There is no evidence to suggest that the implementation of any of the three groundwater remedial alternatives would result in adverse impacts to agricultural or residential soils.

8.3. FLORA

The assessment of risk to floral species focused on alfalfa, because of its economic importance, although other species are potentially exposed to both Cr(III) and/or Cr(VI) on-site, in nearby agricultural fields, and in residential gardens. This assessment first reviews the pertinent literature addressing chromium toxicity to plants, then presents exposure scenarios for the present conditions in irrigated fields, as well as for the remedial alternatives. Finally, the risk potential is analyzed.

8.3.1. CRITERIA

Introduction

Literature on chromium impacts exists for a limited number of floral species; comprehensive toxicological criteria are lacking. The majority of research concentrates on absorption rates and capacities, soil interactions, and resulting plant tissue concentrations. Few data are available regarding chromium concentrations which actually affect plants. In any case, the dose-response data which are available must be interpreted carefully due to variations in research methods and in the type of chromium compound used in any particular study. Consistent studies were not found.

The primary form of chromium in vegetation is trivalent. Chromium forms polyfunctional anionic complexes in higher plants, including alfalfa, wheatgrass, beans, and wheat (Starich and Blincoe, 1982). Hexavalent chromium absorbed by the plant will be readily converted to the trivalent form. The typical chromium levels in most vegetation are extremely low. Fishbein (1984) determined mean concentrations of chromium in vegetables (20-50 ug/kg), fruits (20 ug/kg), and grains and cereals (40 ug/kg).

Chromium (VI) is more soluble than Cr(III), theoretically allowing it to be absorbed and translocated within plants more readily (but see Section 6.5.1). It is also known that Cr(VI) is more toxic to plants than Cr(III). Due to the complexity of the variables influencing chromium toxicity to vegetation, there are few consistent criteria available against which to gauge toxic effects. The following information was derived from the literature. The data are typically presented according to effects or to organ-specific accumulation. Clearly, chromium uptake and effects vary from species to species (see Section 6.5.1; Sheppard, Sheppard, and Thibault, 1984).

Roots

Dijkshoorn, van Broekhoven and Lampe (1979) researched plaintain, clover, and ryegrass and determined that chromium remained in the root and did not translocate to aerial portions. This suggested that animals eating the tops of plants may not ingest as much chromium as they would if they ingested the root portion. Chromium was found to have a shoot:root partition ratio of 0.004 in bush bean, a value lower than for other heavy metals (Wallace, Alexander and Chaudrey, 1977). In all cases, however, chromium was absorbed proportionately as the metal's soil concentration increased. It is frequently reported that only a fraction of chromium in soil is bioavailable for uptake. Research data suggest that uptake is increased in acidic soils (Dijkshoorn, van Broekhoven and Lampe, 1979). Plant yield was not affected by the depth of placement of chromium in the soil (Sheppard, Sheppard and Thibault 1984). Finally, the portions of Cr(VI) and Cr(III) translocated throughout a plant are essentially the same (Dijkshoorn, van Broekhoven and Lampe 1979).

Leaf

Due to the lack of translocation from the root, little chromium is typically found in the leaves in plants like the bush bean. The ratio of chromium versus other metals in leaves was proportionately lower (Wallace, Alexander and Chaudrey 1977). Dijkshoorn, van Broekhoven and Lampe (1979) reported that as chromium translocates to the top of plants, the plants become more sensitive to increased environmental concentrations of chromium.

Tissue

Sheppard, Sheppard and Thibault (1984) reported relatively high tissue levels in alfalfa and chard. Soil concentrations of

20 and 50 mg/kg resulted in tissue concentrations of 2.6 and 6.8 mg/kg in a loam soil, and 18.0 and 57.0 mg/kg in a sandy soil. These values represent an average for chard and alfalfa.

Shoot

Chromium concentrations in shoots of chard and alfalfa increased proportionately with the metal's concentration in soil, over eight orders of magnitude.

General Plant Data

Chromium is more toxic than zinc, nickel, cadmium, copper, and lead; however, uptake is slower than with these other metals. On balance, chromium tends to have less impact on plants than other metals.

Toxic Effects

Phytotoxic levels are poorly defined; nevertheless, pertinent dose-response data are presented in Table 8-1. A soil treatment concentration of 50 mg/kg resulted in a tissue burden of 57 mg/kg in alfalfa and chard, producing no adverse effects (Sheppard, Sheppard and Thibault 1984). Toxic effects were observed in oats, corn, and cabbage at 16.0, 10.0, and 10.0 mg/kg, respectively (National Research Council, 1974 and Dijkshoorn, van Broekhoven and Lampe, 1979), indicating that these species are more sensitive than alfalfa and chard. It has been suggested by Sheppard, Sheppard and Thibault (1984) that a NOEL for chromium in soil for alfalfa and swiss chard is 50 mg/kg. The metal has been reported to be toxic to plants at 100 mg/kg when added to soil (Wallace et al., 1976). These data suggest a range of 50 to 100 mg/kg in soil as a safe level, for at least alfalfa and chard. In contrast, EPA (USEPA 1980) has made a suggestion for what is essentially a NOEL for plants of 10 mg/kg. It is based on toxicity data for various species, and to be conservative is based upon the minimal NOEL of any species. A 10 mg/kg NOEL is surprisingly low since many vegetated soils around the world have natural chromium concentrations above this level.

Table 8-1

CHROMIUM RESPONSE DATA FOR FLORA

Plant	Chromium Location	Dose (mg/kg)	Response	Cr(T)	Reference
Alfalfa Swiss Chard	Tissue	57.0	Non-toxic	Cr^{52}	Sheppard et al., 1984
Alfalfa Swiss Chard	Soil	50.0	Non-toxic	Cr^{52}	Sheppard et al., 1984
Buckwheat	Soil	5.3	None	$CrCl_3$ & K_2CrO_4	Cary et al., 1977
Swiss Chard	Soil	57.0	None	Cr^{52}	Sheppard et al., 1984
Plaintain Clover Ryegrass	Soil	10.0	Growth Inhibited	Cr	Dijkshoorn et al., 1979
Cabbage	Soil	10.0	Yield Decreased	Cr	Dijkshoorn et al., 1979
Bush Bean	Soil	100.0	Yield Decreased	$Cr_2(SO_4)_4$	Wallace et al., 1976
	Soil	50.0	Yield Increased	$Cr_2(SO_4)_4$	Wallace et al., 1976
Oats	Soil	16.0	Growth	Chromate	NRC, 1974
Corn	Soil	10.0	"Toxic"	Chromate	NRC, 1974
Barley	Soil	50.0	"Standard Growth"	Cr(VI)	EPA, 1983

Source: EHA, 1988

It must be remembered that symptoms of chromium phytotoxicity at the low concentrations cited above include chlorosis ("yellowing") and stunting, as cited by EPA (USEPA 1980). These effects may lead to reduced plant growth, and in an agronomic context, possibly reduced crop yield, but will not necessarily cause death or substantially decrease the plant community or habitat. Therefore, while individual plant health may be somewhat impaired by an elevated chromium concentration in soil, the overall ecological impact would be slight, perhaps insignificant.

Based on the foregoing discussion it was concluded that an RfC of 50 mg/kg (Cr(III)) be applied to alfalfa. However, with regard to other species, in particular those commonly found in gardens, a more stringent RfC of 10 mg/kg was applied to be conservative.

8.3.2. EXPOSURE

Approach

An exposure model was not required to generate EECs, as observed field soil concentrations (Table 3-4) and predicted future levels (Tables 6-6 and 6-7) provided the necessary data.

Estimated Exposure Concentrations

The EECs (for Cr(III)) which were used in this analysis are summarized below:

(1) Background Soils	7 mg/kg
(2) Agricultural Field Soils	
Present	33.0 mg/kg
Alternative 1 (predicted 20 year high)	37.4 mg/kg
Alternative 2 (predicted 20 year high)	35.9 mg/kg
Alternative 3 (predicted 20 year high)	37.4 mg/kg

(3) Residential Garden Soils

Present	33.0 mg/kg
Alternative 1 (predicted 20 year high)	70.2 mg/kg
Alternative 2 (predicted 20 year high)	48.3 mg/kg
Alternative 3 (predicted 20 year high)	35.0 mg/kg

8.3.3. RISK ESTIMATION

Risk

HIs for plants were calculated and the findings are presented below:

(1) Background Soils 0.14 (based on RfC of 50 mg/kg)
0.70 (based on RfC of 10 mg/kg)

(2) Agricultural Field Soils (based on RfC of 50 mg/kg)

Present	0.66
Alternative 1	0.75
Alternative 2	0.72
Alternative 3	not applicable

(3) Residential Garden Soils (based on RfC of 10 mg/kg)

Present	3.3
Alternative 1	7.0
Alternative 2	4.8
Alternative 3	3.5

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According to these calculations and the EPA criteria, there is no presumption of risk to individual alfalfa plants in either background soils or agricultural field soils irrigated with contaminated groundwater. However, there is a presumption of risk in the case of the garden soils according to EPA criteria. On the basis of the criteria of Barnthouse, et al., there is a possibility of risk for all scenarios, including background. Field observations by an E & E plant pathologist revealed no apparent toxicological effects in any field crop. No similar observations, or chromium concentration data, were collected for residential gardens. These findings reflect potential risk to individual plants rather than to a community (i.e., alfalfa field) as discussed previously. Desert and crop land will function without an impact to the community as a whole, while there may be some impact to individual plants. This impact, if it occurs, would be expressed as reduced growth rate, and leaf discoloration. Furthermore, it is highly unlikely that such an impact would have any economic effects regarding a crop. However, such may not be the case with a garden, since gardens are ecosystems designed for individual or few plants. Therefore, any toxicological impact in affected gardens may be readily observed and thus considered adverse. However, under Alternative 3 (Domestic Water Replacement) chromium addition to residential soil ceases resulting in no increased risk above current levels.

<u>Conclusions</u>

Risk calculations for floral species indicate that no adverse impact on agricultural plants such as alfalfa is likely. More importantly, a presumption of risk exists for plant varieties likely to be raised in a garden under Alternatives 1 and 2. While the data suggest significant toxicity for garden species, any conclusions must be considered tentative because of the uncertainty of the literature-based standards. No risks above current levels will result under remedial Alternative 3.

8.4. FAUNA

The risk assessment to faunal species follows the same approach of: definition of toxicological criteria, exposure concentration estimation, and, finally, analysis of risk.

8.4.1. CRITERIA

Introduction

Once ingested by an animal, hexavalent chromium is expected to be readily converted to the trivalent form. There is no evidence of the reverse conversion *in vitro* or *in vivo*, i.e., oxidation of trivalent to hexavalent chromium (ATSDR, 1987). Chromium concentrations appear to decrease with higher trophic levels; i.e., chromium is not concentrated appreciably as it moves up the food chain (EPA, 1984). Lack of absorption of chromium is probably the reason that the more advanced animals contain lesser amounts of chromium (EPA, 1984). Mean concentrations of chromium in meas and fist is estimated to be 0.11 to 0.23 ppm (ATSDR, 1987).

Bioconcentration factors for Cr(VI) in the edible portion of most aquatic animals is less than 1.0. The exception is that bivalve molluscs such as clams, oysters, scallops and mussels have a bioconcentration factor 125 to 192. Bioconcentration values for Cr(III) in bivalve molluscs are similar, 86 to 116 (USEPA, 1984). Estimates of bioconcentration factors for meat animals were not available, but would be expected to be similar to that of fish, i.e. around 1.0. Exceptions are the liver and kidneys of animals fed diets high in chromium, which may have higher concentrations.

The following studies indicate that chromium is not secreted in large quantities or concentrated significantly in milk. The valence state of chromium in milk is III. Van Bruwaene et.al. (1984) studied the secretion into milk of orally administered Cr(VI) in lactating dairy cows and found only about 0.0035% of an oral chromium dose in the milk. About 3.6% of an intravenously administered dose was secreted in the milk. Mean concentrations of chromium in dairy products in the U.S. are estimated to be around 0.1 ppm. Kumpulainen et al. (1980) did not find a correlation between chromium in the diet and in the milk of lactating human mothers, however, their diet was low in total chromium. These data agree with those reported in Table 3-9 showing no increase of chromium levels in either meat or milk.

Effects

The majority of research reported in the literature pertains to rats, mice, and rabbits. The primary effect to animals from ingested chromium is acute renal tubular necrosis, whereas the most important chronic effect is cancer of the respiratory system. Hexavalent chromium is corrosive, causing chronic ulceration and perforation of the nasal septum and other skin surfaces (Goyer, 1986). Toxicity is primarily attributed to Cr(VI), which has been shown to induce liver and kidney damage, internal hemorrhage, dermatitis, and respiratory problems (Langard and Norseth, 1979; USEPA, 1978). Inconsistent test methods and variation in the type of chromium compound used make it difficult to determine toxic doses for the animals tested, much less for other fauna.

Table 8-2 presents dose-response data for several test species. Toxic exposure levels can be estimated based on these data. MacKenzie et al. (1958) reported the effects of drinking water containing chromium on rats, indicating that doses below 0.4 mg/kg-day caused no systemic effects or organ damage. Between 0.4 and 0.8 mg/kg-day, indications of spleen damage occurred after one year of exposure. Approximately 0.6 mg/kg-day, therefore, might be considered to be a minimum NOEL. Gross and Heller (1946) reported maximal nontoxic levels of 83.8 mg/kg-day for potassium chromate, a dose far greater than that reported by MacKenzie. From these data, a NOEL range of 0.6 to 83.3 mg/kg-day is thus established for chromate (Cr[VI]). Lehmann (1914) reported a NOEL for dogs, cats, and rabbits of 1.5 to 5.5 mg/kg-day, which falls within the previous range. Data based on potassium salts are more appropriate since they are more soluble and, therefore, more bioavailable than zinc salts. Therefore, to be conservative, the lowest Cr(VI) dose was accepted as the RfD for small mammals (Mojave ground squirrel, California Vole, Desert Cottontail) for this assessment (i.e., 0.6 mg/kg-day).

Cr(VI) toxicological data are unavailable for the badger and dairy cow. While mammals, these species are potentially different toxicologically when compared to small mammals, for which data exist. Therefore, the small mammal RfD of 0.6 mg/kg was adjusted with a safety factor of 10 to provide an RfD of 0.06 mg/kg-day.

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Table 8-2

ORAL CHROMIUM EXPOSURES TO FAUNA

Species	Cr Source	Average Dose or Concentration[1]	Duration	Effects	References
Dog, Rabbit	Chromate Dichromate	1.9-5.5 mg/kg-day	29-685 day	Non-harmful	Lehmann, 1914
Dog	K_2CrO_4	2.8-5.7 g/day	90 day	Fatal	Sullivan, 1969
Rabbit	K_2CrO_4	500 ppm	?	Digestion unaffected	Gross et al., 1946
	$ZnCrO_4$	10,000 ppm	?	Lowered digestion	Gross et al., 1946
Rat	K_2CrO_4	500 mg/l-water 83.8 mg/kg-day	60 day	Max. Non-toxic level	Gross et al., 1946
Rat & Mouse, mature	$ZnCrO_4$	10,000 mg/kg-feed 500 mg/kg-day	56 day	Max. Non-toxic level	Gross et al., 1946
Rat, young	$ZnCrO_4$	1200 mg-kg-feed 62.5 mg/kg-day	69 day	Max. Non-toxic level	Gross et al., 1946
Rat, young	K_2CrO_4	1200 mg/kg-feed	Daily	Max. Non-toxic level	Gross et al., 1946
Rat, young	?	125 ppm	?	Sterility	Gross et al., 1946
Rat	Chromate	0-5 mg/l-water 0.4 mg/kg-day	365 day	No effects after 1 yr[2]	Mackensie, 1958

1) The data were presented in units such as ppm. Conversions were made using data supplied with the references.

2) Observed organs: liver, kidney, spleen, femur tissues.

Source: EHA, 1988

A Cr(VI) RfD for the tortoise was not available. Instead it was derived from mammalian data by correcting for uncertainty between the toxicological reactions of mammals and reptiles using a safety factor of 50 (a factor of 10 for interspecies variation and a factor of 5 for extrapolation to reptiles). This uncertainty may be expressed, for example, by the fact that reptile metabolism is somewhat slower than mammalian, particularly in the case of the tortoise, since it "hibernates" from about November to March (Ernst and Barbour, 1972; MacLaine 1988). Therefore, chromium may build up in the tortoise and thus lead to an increased body burden. It is standard EPA practice to include safety factors when comparing animal data across phyletic lines. Therefore, the RfD used for the tortoise was 0.012 mg/kg-day.

The Cr(III) RfD was based on the maximum tolerable dietary level for all animals, cited by the Veterinary Toxicological Information Service, of 1,000 mg/kg food ($CrCl_3$), inclusive of water and feed. The RfDs for each animal species were calculated and are presented in Table 8-3.

8.4.2. EXPOSURE

Approach

Exposures to Cr(VI) and (III) by ingestion of contaminated water or feed were modeled. Other exposure scenarios are not addressed by EPA when conducting ecological risk assessments, due to a substantial paucity of toxicity data for other routes of exposure (USEPA, 1986). This was true in the present case, as discovered during the literature review.

Intake of chromium may occur from the ingestion of water from contaminated agricultural wells, vegetation with elevated chromium levels, and/or contaminated soil. Exposure to Cr(III) will occur only by ingestion of vegetation or soils. Badgers were assumed not to be exposed to elevated Cr(III) levels through their food, since chromium does not biomagnify through the food chain. Therefore, a dosage was not estimated for this indicator species. Exposure to Cr(VI) will occur only through ingestion of water. It was assumed that all ingested water and food consisted

Table 8-3

CALCULATED REFERENCE DOSES FOR CR(III) FOR SELECTED FAUNAL RECEPTORS

Animal	Body Weight[a] (kg)	Total Dietary Intake[b] (kg/kg-day)	RfD[c] (mg/kg-day)
Mojave Ground Squirrel	0.16	0.096	96
California Vole	0.071	0.198	198
Desert Tortoise	7.2	0.0067	67
Desert Cottontail Rabbit	1.0	0.15	150
Badger	8.6	0.047	47
Dairy Cow	1,200	0.125	125

a) Median body weights

b) Includes water and food intake (see Tables 8-4 and 8-5); food intake for badger was taken as 0.014 kg/kg-day (Harlow, 1981).

c) Maximum tolerable dietary level = 1,000 mg/kg (see text). RfD (in mg/kg-day) = 1,000 mg/kg X Total Dietary Intake (in kg/kg-day).

Source: Ecology and Environment, Inc., 1988.

of materials contaminated at the cited levels. This approach was used to insure a worst-case exposure. Also, it was assumed that the exposed animals spend 100% of their time in the area of contamination, again to insure a worst-case exposure. Food and water intake data were derived from laboratory or caged animal studies except for the badger and desert tortoise. Intake data for animals in the wild are not generally available, according to three sources contacted (Bleich, 1988; MacLaine, 1988; Douglas, 1988). Animals in the wild, and particularly desert fauna, drink and eat much less than laboratory animals. Therefore, these data will cause chromium dosage to be overestimated leading to health protective conclusions. Literature data for the badger and desert tortoise are cited in Tables 8-4 and 8-5.

Estimated Exposure Doses

EEDs for each chromium species by animal are presented in Tables 8-4 and 8-5.

8.4.3. RISK ESTIMATION

Risk

Following standard EPA protocol for the calculation of HIs, values for each species were derived and are presented in Table 8-6. The EPA presumes no chronic toxicity risk to animals if the EEC is less than the RfD. The badger and dairy cow may be adversely impacted by present conditions, according to the criteria of Barnthouse et al., but not by EPA criteria. In both cases, particulary the tortoise, the exposures were greatly overestimated, representing a worst case scenario. The tortoise and small mammals are at no risk according to this analysis. The biomonitoring data for dairy cows (Section 6.5.2) supports this finding, as it demonstrated no measurable increase in body (tissue) burden in maximally exposed individuals. Therefore, it is unlikely that the Barnthouse et al. criteria are valid for this case.

The uncertainty of the HIs is primarily related to the exposure model, its assumptions, and the level of contamination parameter. The latter is most important since it influences all

Table 8-4

CALCULATION OF ESTIMATED CR(VI) EXPOSURE FOR SELECTED FAUNAL RECEPTORS

Animal	Remedial Alternatives	Cr(VI) Concentration[a] in water (mg/l)	Water Intake[b] (l/kg-day)	Dose[c] (mg/kg-day)
Mojave Ground Squirrel	Present	0.285	0.064	0.018
	1,3	0.17	0.064	0.011
	2	0.096	0.064	0.0061
California Vole	Present	0.285	0.018	0.051
	1,3	0.17	0.018	0.031
	2	0.096	0.018	0.017
Desert Tortoise	Present	0.285	0.0022	0.00063
	1,3	0.17	0.0022	0.00037
	2	0.15	0.0022	0.00021
Desert Cottontail	Present	0.285	0.1	0.028
	1,3	0.17	0.1	0.017
	2	0.15	0.1	0.0096
Badger	Present	0.285	0.033	0.0094
	1,3	0.17	0.033	0.0056
	2	0.15	0.033	0.0032
Dairy Cow	Present	0.20	0.083	0.017
	1,3	0.04	0.083	0.033
	2	0.03	0.083	0.025

a) Cr(VI) concentration derived from Table 6-2, well GW 35-11 concentrations averaged over 20 years unless otherwise stated. Present case value based on samples WF001 and 002. Concentration for dairy cow based on well GW 35-10, (Table 6-1), which feeds dairy, averaged over 20 years.

b) Intake values derived from laboratory animal data: squirrel value was based on rat data; vole value on mouse; rabbit and cow on their respective values found in the literature. Extrapolations were made by linearly scaling the data according to the ratio of body weights (median for rats = 250g, for mice: 60g). Uptake values for rat = 0.10 l/kg/day; for mice: 0.15 l/kg/day. Value for badger from Harlow (1981). Value for tortoise based on observations of Nagy and Medica (1986).

c) Dose calculation -
Oral dose from water = Cr(VI) concentration x water intake

Source: Ecology and Environment, Inc., 1988.

Table 8-5

CALCULATION OF ESTIMATED CR(III) EXPOSURE FOR SELECTED FAUNAL RECEPTORS

Animal	Remedial Alternatives	Cr(III) Concentration (mg/kg) vegetation	soil	Food Intake[a] (kg/kg-day)	Dose[b] (mg/kg-day)
Mojave Ground Squirrel	Present	5	33	0.032	0.21
	1,3	5	37	0.032	0.21
	2	5	36	0.032	0.21
California Vole	Present	5	33	0.18	1.2
	1,3	5	37	0.18	1.2
	2	5	36	0.18	1.2
Desert Tortoise	Present	5	33	0.045	0.030
	1,3	5	37	0.045	0.031
	2	5	36	0.045	0.031
Desert Cottontail	Present	5	NI	0.05	0.25
	1,3	5	NI	0.05	0.25
	2	5	NI	0.05	0.25
Dairy Cow	Present	5	NI	0.042	0.21
	1,3	5	NI	0.042	0.21
	2	5	NI	0.042	0.21

NI: No intake.

a) Intake values derived from laboratory animal data: squirrel value was based on rat data; vole value on mouse; rabbit and cow on their respective values found in the literature. Extrapolations were made by linearly scaling the data according to the ratio of body weights (median for rats = 250g, for mice: 60g). Uptake values for rat = 0.05 kg/kg-day; for mice= 0.15 kg/kg-day. Value for tortoise based on observations of Nagy and Medica (1986).

b) Dose calculation - total dose was the sum of the following two doses:
Oral dose from vegetation = chromium(III) concentration x food intake.
Oral dose from soil = chromium(III) concentration x food intake x fraction soil associated with food[c] x fraction of bioavailable Cr[d].

c) Fraction soil associated with food = 0.05, (according to Dr. G. Batzli, University of Illinois).

d) Fraction of bioavailable chromium in soil = 1.0, assumed conservative value.

Source: Ecology and Environment, Inc., 1988.

Table 8-6

HAZARD INDICES FOR SELECTED FAUNAL RECEPTORS

Animal	Chromium Species	Hazard Index Present Conditions	Remedial Alternatives 1,2	3
Mojave Ground Squirrel	III	0.0002	0.0002	0.0002
	VI	0.03	0.02	0.01
California Vole	III	0.0061	0.0061	0.0061
	VI	0.08	0.051	0.0028
Desert	III	0.004	0.005	0.005
Tortoise	VI	0.052	0.03	0.018
Desert Cottontail Rabbit	III	0.0017	0.0017	0.0017
	VI	0.047	0.028	0.016
Badger	III	0.00	0.00	0.00
	VI	0.16	0.093	0.053
Dairy Cow	III	0.0017	0.0017	0.0017
	VI	0.28	0.055	0.42

Source: Ecology and Environment, Inc., 1988.

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calculations and its effect is linear. The model assumptions, designed for a reasonable worst-case scenario, were that: all food and water consumed are contaminated; the time spent in a contaminated area is 100%; and the intake (food and water) of animals at the site vicinity is equivalent to that of laboratory or captive animals. All of these numbers could be decreased, thereby lowering the HI, but none could be justifiably increased. A decrease in any of these values would be transmitted linearly through the calculations, resulting in a concomitant decrease in the HI. Estimations of exposure for wild species to Cr(VI) are based upon the assumption that free water is available. This is unlikely on site or at local irrigated fields considering: the hot, dry climate; porous surface soils; and the method of irrigation (sprinkler). During extensive E & E field operations in the site vicinity, no standing water was observed. In fact, during well pump tests, water released to localized areas over limited time spans resulted in no observed pooling. Therefore, the potential for exposure to contaminated groundwater is remote.

Conclusions

Of the six indicator species analyzed, none were determined to be at risk of exposure. The possiblity of pooling or rivulets of water forming on irrigated land is remote, and exposure to such water would be for a limited time regardless of the remedial alternative. Finally, risk to these animals, particularly the tortoise, from cars is probably of greater significance than from limited exposure to chromium. Therefore, ecological risk to fauna is concluded to be unlikely.

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9.0 SUMMARY AND CONCLUSIONS

The assessment reported here evaluates potential risks associated with three alternatives being considered for remediation of groundwater contamination identified near the Hinkley Compressor Station:

- Alternative 1 - Current Irrigation Practice. This alternative involves ongoing agricultural irrigation with contaminated groundwater, combined with supply of bottled water to local residents for drinking and cooking purposes.
- Alternative 2 - Accelerated Agricultural Treatment. Additional wells would be added within the plume to accelerate chromium removal, and to manage withdrawal and application of contaminated groundwater. Bottled drinking and cooking water would also be supplied as part of this alternative.
- Alternative 3 - Domestic Water Replacement. This alternative is an extension of Alternative 1, with the addition of new residential water supplies for each of the dwellings within the plume boundary. This alternative would remove all domestic use of water including showering, dish washing and garden irrigation, which are not addressed by bottled water supply alone.

The risk assessment approach employed to evaluate these groundwater remediation alternatives is health-conservative, and is believed to over-estimate the true risk significantly. For example, the analysis employed the most conservative results from the shower experiment, exposed the farmer to residential groundwater Cr(VI) levels from a neighboring residence with maximum concentrations, and used a cancer potency slope designed to be health conservative. The analysis evaluates possibly significant environmental pathways from the groundwater to human and ecological receptors through water, air, soil and the foodchain; it addresses inhalation, oral ingestion and dermal absorption exposure routes for all potential receptors.

9.1 GROUNDWATER PROTECTION

Investigation of the original source of hexavalent chromium groundwater contamination leads to the conclusion that chromium is no longer entering the groundwater. Based upon the results of physical and chemical tests, hexavalent chromium is no longer of concern in soils, and trivalent chromium which is present will not be transported to groundwater. In the near term, proposed extraction of groundwater with subsequent irrigation treatment will reduce the groundwater concentrations of hexavalent (and total) chromium to zero, or to concentrations below the state/federal drinking water standard. Groundwater in the vicinity of the Hinkley Compressor Station is therefore no longer being contaminated, and will be restored to acceptable conditions under the contemplated remedial alternatives.

9.2 HEALTH RISKS

Health risks which might result from domestic and other use of local groundwater during remediation have been estimated for the three groundwater remedial alternatives introduced above. Both cancer and noncancer effects have been evaluated. Noncancer health effects are extremely unlikely under all three groundwater remediation alternatives. The estimated cancer risks for the three remedial alternatives are shown in Table 9-1. The table shows cancer risks corresponding to two different hexavalent chromium cancer potencies: 42 $(mg/kg\text{-}day)^{-1}$ and 91 $(mg/kg\text{-}day)^{-1}$. The lower potency is that employed by the U.S. Environmental Protection Agency in its regulatory decision making regarding remedial actions. The higher potency value of 91 $(mg/kg\text{-}day)^{-1}$ is a health-conservative estimate, based upon all the known uncertainty factors in the epidemiological data from which these chromium potencies have been derived. It is the 95% upper confidence limit for a value lying in the potency range promulgated by the California Department of Health Services.

Remedial Alternative	Cancer Risk To Maximally Exposed Individual (per million)		Expected Cancers in Exposed Population		Cancer Risk to Other Individuals Near Plume (per million)	
	q_1^* (mg/kg-day)$^{-1}$		q_1^* (mg/kg-day)$^{-1}$		q_1^* (mg/kg-day)$^{-1}$	
	42	91	42	91	42	91
1) Current Irrigation Practice	6	13	0	0	2-5	5-11
2) Accelerated Agricultural Treatment	1	2	0	0	0.5-0.8	1-2
3) Domestic Water Replacement	2	5	0	0	0.05-2	0.1-4

Table 9-1
ESTIMATED ADDED LIFETIME CANCER RISK FOR GROUNDWATER REMEDIAL ALTERNATIVES

Risk management decisions and designs of remedial strategy historically have been made by regulatory agencies based upon three criteria:

- the additional risk to the maximally exposed individual;
- the expected additional cancer burden in the exposed population; and
- the cost of increased remediation.

Federal regulatory agencies have required remedial action only when cancer risk to the maximally exposed individual exceeds 10- to 100-in-a-million and when the expected number of cancers in the exposed population exceeds one (Crouch, et al., 1987). California regulatory agencies require remedial action when the individual risk exceeds 1- to 10-in-a-million or the expected number of cancers in the exposed population exceeds one (CAPCOA, 1987; HWA, 1988).

For all three groundwater remediation alternatives evaluated here, no additional cancers are expected in the exposed population. Maximum individual risk for all alternatives was estimated to fall below the federal regulatory agency guidelines for both cancer potencies. Only Alternative 1 fell above the range of guidelines practiced in California, for the larger cancer potency.

9.2.1 Alternative 1 - Current Irrigation Practice

In Alternative 1, the analysis estimates that the lifetime cancer risk to the maximally exposed individual is 6 to 13-in-a-million, depending upon the cancer potency slope used. This is below the federal regulatory agency remedial action level and under these guidelines further remedial action would not be required. It is within the California regulatory agency range of action levels for the lower potency factor. Also shown in Table 9-1 are lifetime cancer risks to other exposed individuals living or working near the center of the groundwater plume. These risks are seen to vary to significantly lower values than those for the maximally exposed individual. If the extremely conservative Cr(VI) cancer potency factor of 511 (mg/kg-day)$^{-1}$ is employed, then the MEI risk is 72-in-a-million.

9.2.2 Alternative 2 - Accelerated Agricultural Treatment

In Alternative 2, maximum individual risk is estimated to be 1 to 2-in-a-million, again below the federal regulatory agency guidelines and within the California range of guidelines. Additional remedial action is therefore not indicated. Again estimated risks for other exposed individuals can be significantly less under this alternative. If the extremely conservative Cr(VI) cancer potency factor of 511 (mg/kg-day)$^{-1}$ is employed, then the MEI risk is 12-in-a-million.

9.2.3 Alternative 3 - Domestic Water Replacement

Individual cancer risk for the third remedial option is estimated to be 2 to 5-in-a-million, depending upon the cancer potency factor employed. This alternative also meets both federal and state regulatory agency remedial action levels. Risks estimated for other exposed individuals can be significantly less than those for the maximally exposed individual under this alternative. Use of the 511 (mg/kg-day)$^{-1}$ potency factor increases the MEI risk to 33-in-a-million. If the replacement of domestic water is extended to the supply of water for dairy purposes, then the MEI risks become 0.1, 0.3 and 2-in-a-million for the three cancer potency slopes, respectively.

9.3 ECOLOGICAL RISKS

Ecological risks have been evaluated for soil (microflora and infauna), flora and fauna. Risks to soil are not expected to be significant under any alternative except for microflora at one limited on-site area (area C), where soil remediation is being evaluated in the feasibility study. Risks to fauna are likewise expected to be insignificant (evaluated for the Mojave ground squirrel, California vole, desert tortoise, desert cottontail rabbit, badger and cow).

The assessment of risk to flora indicates that impacts upon some crops grown in agricultural soils are possible, but that crops such as alfalfa should not be affected. Field observations confirm that alfalfa grown in the study area is not adversely affected by current irrigation practices. The assessment also indicates that impacts upon individual plants in family garden plots, while not presently occurring, are possible under remediation alternatives 1 and 2 (which provide bottled drinking and cooking water only), but not under alternative 3.

9.4 CONCLUSIONS

The risk assessment reported here is believed to overestimate risks significantly. Based upon this conservative assessment the following conclusions may be drawn.

1. Groundwater quality critical to the protection of local human and ecological health will be achieved and maintained under all of the remedial alternatives considered.

2. Estimated health risks possibly resulting from the hexavalent groundwater plume near the Hinkley Compressor Station are not significant for any of the evaluated remedial alternatives under federal regulatory agency practices. Only for alternative 1 might they not meet California regulatory agency guidelines using a potency factor of 91 $(mg/kg\text{-}day)^{-1}$.

3. Ecological risks to soil are possible under all three alternatives only in a limited on-site area; soil remediation is anticipated for this area. Some agricultural species other than alfalfa may be at risk under all three alternatives. Individual family garden plants may be at risk under Alternatives 1 and 2, but not under Alternative 3. Because of the conservatism of the risk assessment, these possible ecological risks may not exist.

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