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**Colorado Department
of Public Health
and Environment**

PROPOSED SOIL REMEDIATION OBJECTIVES POLICY DOCUMENT

The Hazardous Materials and Waste Management Division has developed a method for calculating soil remediation objectives for making site-specific remedial action decisions. It is the Division's goal to ease the process for establishing site-specific objectives by providing a structured set of alternatives which can be used and the necessary guidance for each alternative. The attached is the policy document of the procedure that we are proposing to use to achieve this goal. We are very interested in getting the views of all interested stakeholders on the proposed policy. The Division invites comments and/or questions concerning this document. These should be sent to:

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Attn: Walter Avramenko (303) 692-3362

Following a public comment period, which will be concluded on March 2, 1998, comments and recommendations will be reviewed and, to the extent possible, incorporated into the final policy document. Thank you for your interest.

Original signed by: _____ 12-31-97
Howard Roitman, Division Director Date
Hazardous Materials and Waste Management Division

ADMIN RECORD

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SOIL REMEDIATION OBJECTIVES

**A Policy Outlining The Process For Developing
Site-Specific Soil Remediation Objectives**

Colorado Department of Public Health and Environment
Hazardous Materials and Waste Management Division

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December 1997

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Section 1.0 Intent and Purpose

The Hazardous Materials and Waste Management Division (the Division) hereby presents a method for calculating soil remediation objectives that may be used to make efficient, cost effective and site-specific remedial action decisions at sites where hazardous substances are present or suspected in the soil. This methodology, as described in this policy document, was developed in order to ease the burden of establishing site-specific standards by providing a structured set of alternatives which can be used and the necessary guidance for each alternative. The purpose of the procedures described herein is to provide for the adequate protection of human health and the environment based on risks to human health posed by environmental conditions while incorporating site related information, to the extent practicable, which may allow for more cost-effective site remediation.

This policy will benefit the public by providing a system which allows an implementing party to chose from a series of options for establishing soil remediation objectives at a site. The four options are:

- ! Tier 1 - Background/Method Detection Limit Objectives;
- ! Tier 2 - Table Value Objectives;
- ! Tier 3 - Site-Specific Adjustments to the Table Value Objectives; and,
- ! Tier 4 - Site-Specific Risk-Based Soil Remediation Objectives.

Tier 2 lists generic soil remediation objectives in a table that may be used at most sites without having to collect excessive site-specific data or perform exhaustive risk evaluations. These numeric soil remediation objectives were established using conservative assumptions about contaminant migration in the subsurface and evaluating potential exposures through direct contact (dermal, ingestion, inhalation) and migration to groundwater. The numeric levels streamline the process at sites because the analysis to determine cleanup levels for each site is no longer required, and cleanup level "goals" are known from the outset.

The policy, under Tier 3, also provides for a means of modifying the Tier 2 table values when site-specific information indicates that values other than the table values would be more appropriate and still be protective. Tier 4 allows a facility to conduct a traditional site-specific risk evaluation to develop soil remediation objectives. Overall, the Division believes that the flexible process described in this policy will remove or significantly reduce the need for risk assessments at many facilities, allowing resources to be directed at cleanup rather than site studies. Requiring fewer steps will expedite the cleanup process while protecting human health and the environment.

In addition to soil remediation objectives that protect potential human receptors who come in direct contact with soils, the Division has chosen to develop soil objectives that protect underlying

groundwater. Protection of groundwater must consider 1) present use of the water, 2) potential future uses of the water, 3) whether the contamination can be contained within the facility boundaries, 4) whether it may discharge into an aquifer that currently is or has the potential for being used as a drinking water source, 5) whether it may discharge into a surface water body, or 6) whether it may pose a threat to human health or the environment by way of other exposure pathways (e.g., generation and exposure to soil vapors). All these factors should be taken into consideration when applying soil remediation objectives calculated using this policy. Even in broad areas of groundwater contamination (e.g., highly industrialized areas), the Division believes that actions should be taken to minimize or eliminate future release to this natural resource in order to prevent further degradation of water quality and minimize the potential for exposure to contamination. Consequently, the Division felt it was essential that a procedure which addressed that threat to groundwater be a prominent part of this policy.

The Division's preference will always be that remediation programs, including the selection of soil remediation objectives, be designed such that the performance standard results in clean closure of the facility, i.e., implementation of a permanent remedy resulting in no actual or potential threats to human health and the environment with no future land use restrictions. Permanent remedies are to be used to the maximum extent feasible. Realizing that this goal will not be feasible or practical in all cases, the Division has structured this policy so that the implementing party has the option of selecting or calculating soil remediation objectives suited to the objectives of the remediation program, ranging from the establishment of clean closure standards that allow the facility owner/operator to "walk away" from the site with no future environmental commitments, to the development of soil objectives that require long term institutional controls to manage risks posed by residual contamination. If risk evaluations are used to develop remediation objectives other than clean closure standards, the remedy selected will not be "final". Closure of such a site would be based on the condition that institutional controls ensuring the safe use of the property are in place and are maintained.

This policy is limited to the selection and/or calculation of soil remediation objectives. This policy does not define the procedures for determining the minimum level of data collection and the necessary protocols for comparison with the soil remediation objectives calculated using this policy. Nor does this policy advocate a specific remedy or propose acceptable remedial alternatives. These decisions are left up to both the implementing party and the Division program responsible for overseeing the environmental work performed at the facility.

This policy and its attached guidance are intended to be used at sites being remediated under Division oversight. The policy is, however, available for use by an implementing party as they perform site investigations or undertake cleanup work independent of Division oversight. The risks to parties performing independent cleanups are that a) certain programs (RCRA) require notification when releases have been identified and failure to do so may constitute a violation of applicable regulations or permit requirements and b) when review of the cleanup occurs at some later date, additional or revised work may be required. We recommend that you contact the applicable program within the Division to determine the corrective action procedure and the need for and/or level of required oversight.

The procedures set out in this policy document are intended solely for the use and guidance of both Division personnel and implementing parties. They are not intended to create any substantive or procedural rights, enforceable by any party in administrative or judicial litigation with the Division. The Division reserves the right to act at variance with these procedures to address site specific circumstances and to change them at any time (e.g., addition of new constituents to the Tier 2 table values, modification of Tier 2 table values using more current toxicity data, etc.).

Section 2.0 Definitions

When used in this policy, the following terms have the meaning given below:

Anthropogenic Background - The ambient concentrations of hazardous substances consistently present in the environment in the vicinity of the site which are the result of human activities unrelated to releases at the site.

Carcinogen - Any substance or agent that produces or tends to produce malignant tumor growth (cancer) in humans. "Carcinogen" as applied to this policy means any substance that has been classified by the U.S. Environmental Protection Agency (EPA) as a "A" (known human), "B" (Probable human) or "C" (Possible human) carcinogen in the EPA Integrated Risk Information System (IRIS) database.

Clean Closure - Sites where remedial actions were taken to eliminate threats or potential threats posed to human health and the environment, and the post-closure release of hazardous substances to the ground or surface waters or to the atmosphere. These actions must result in residual contaminant concentrations that are a) equal to natural background levels, b) the excess cancer risk for the sum of all carcinogens is less than or equal to 1×10^{-6} , assuming a residential exposure scenario, c) the hazard quotient for each noncarcinogen is less than or equal to one, assuming a residential exposure scenario, d) post-closure releases will be incapable of degrading water quality in excess of health-based standards, and e) no restrictions (i.e., institutional controls) are placed on the future use of the site.

Commercial Property - Any real property designated or in use for stores, business enterprises of both a retail or wholesale nature. These entities may include facilities such as insurance or real estate offices, service stations, car dealers, hair dressers, auto repair shops or any of the myriad facilities that constitute a "business enterprise" in the common sense of the phrase. Workers would be the primary individuals of contact, however, customers could potentially spend several hours per day at certain facilities.

Constituent - One of two or more hazardous substances that may compose a waste stream or waste streams.

Contamination - A release of a hazardous substance or substances into the environment resulting in measured concentrations in excess of natural background levels.

Facility - All contiguous land, structures and other appurtenances and improvements to the land under the control of the owner or operator of the property.

Hazardous Substance - For the purposes of this policy, a hazardous substance is defined as 1) any hazardous substance as defined under section 101(4) of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (P.L. 96-510); 2) any material that meets the definition of a hazardous waste or hazardous waste constituent, as defined in 6 CCR 1007-3 and 40 CFR; 3) radioactive materials, and; 4) petroleum products including crude oil or any fraction thereof, natural gas, natural gas liquids, liquified natural gas, or synthetic gas usable for fuel (or mixtures of natural gas and synthetic gas).

Hazard Quotient - The ratio of the exposure of a single hazardous substance over a specified time period to a reference dose for that hazardous substance derived for a similar exposure period.

Implementing Party - Any facility landowner or operator, intentional purchaser of a property, individual, trust, firm, corporation, partnership, association, governmental agency, voluntary party or any other party conducting an investigation of and/or remediation at a site that may be contaminated with hazardous substances.

Industrial Property - Any real property designated or in use for facilities where the primary purpose of the endeavors conducted on the site is the manufacturing of commodities. Such facilities might include power generation facilities, foundries, machine shops and the like. Workers would spend approximately an average of 8 to 9 hours per day at such sites and be the primary individuals on any site.

Leachate Reference Concentration - A benchmark concentration against which the results of a site-specific leaching test are compared to determine whether certain levels of inorganic constituents in soil are protective of groundwater quality. There is a potential for adverse impacts to underlying groundwater resources if the leachate concentration exceeds this model calculated reference concentration.

Method Detection Limit- The minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a given matrix containing the analyte.

Natural Background - The concentration of a hazardous substance, if any, existing in the environment at the site before the occurrence of any past or present release or releases.

Remediation - The act of implementing, operating and maintaining an action taken to rectify the effects of a release of hazardous substances, so that it does not cause significant risk to present or future public health or welfare, or the environment.

Residential Property - Any real property that is used for habitation by individuals or properties where more sensitive populations, such as children or the elderly, have the opportunity for exposure to contaminants. For the purposes of this policy, soil remediation objectives calculated using a residential exposure scenario are also protective of educational facilities, health care facilities, child care facilities, and playgrounds.

Risk Additivity - The process for assessing potential health effects of simultaneous exposure to more than one chemical. For carcinogens, a joint probability of an individual developing cancer (the incremental individual lifetime cancer risk) is assessed by summing all chemical-specific cancer risks together. For non-carcinogens, dose additivity is assumed for all chemicals that induce the same toxicological effect by the same mechanism of action.

Risk Assessment - The characterization of the potential adverse health effects of human exposures to environmental hazards. Risk assessment is a structured method consisting of an organized assembly of information on toxicity (i.e., potential adverse health effects of chemicals) and exposure (i.e., contact of an organism with a chemical) of individuals at or near a hazardous substance site or potential future receptors to such site. Risk assessment is based on the current level of understanding about the site characteristics, potential exposures, and health effects information.

Sensitive Environment - An area of particular environmental value where a hazardous substance could pose a greater threat than in other non-sensitive areas. Sensitive environments include but are not limited to: critical habitat for federally endangered or threatened species; National Parks; National Monuments; National Recreation Areas; National Wildlife Refuges; National Forests; campgrounds; recreational areas; game management areas; wildlife management areas; designated federal Wilderness Areas; wetlands; Wild and Scenic rivers; state parks; state wildlife refuges; habitat designated for state endangered species; fishery resources; state designated natural areas; county or municipal parks; and other significant open spaces and natural resources.

Soil - The layer of loose, coarse to fine earthen material, of whatever origin, that nearly everywhere forms the surface of the land and rests on bedrock. All natural and man-made material above the bedrock surface would be considered, including mine waste and structural fill, would be considered by this policy. It does not include man-made materials such as concrete and asphaltic rubble, debris, scrap metal, sludge, etc.

Section 3.0 The Soil Remediation Objectives Development Process

A team of Colorado Department of Public Health and Environment (the Department) representatives was assembled with the intent of developing a soil standard policy that could be used to make decisions involving the characterization and remediation of sites where hazardous substances are present in the soil. The project goal presented in the team charter was to "develop cleanup standards to be used as guidance by the division, and identify a standard process for

developing site specific standards." The Oil Inspection Section of the Department of Labor and Employment assisted the Department in the attainment of this goal.

The team first reviewed information available in house on what other states, the U.S. Environmental Protection Agency (EPA) and national programs have done to establish soil cleanup standards. Based on the information gathered during this review, the team concluded that the Hazardous Materials and Waste Management Division's (the Division) needs would be best served by developing a Colorado specific approach which combines the best parts of several other state and EPA procedures. Using this approach, a multiple tier methodology was developed as the conceptual framework for the soil remediation objectives process.

The team identified, discussed, and evaluated potential issues and concerns under the conceptual framework. The issues were categorized into five groups: administrative, land use, health risk, groundwater protection and background/sampling issues. Subgroups of two to five team members met to discuss and resolve the issues. The full team then reviewed and further discussed each subgroup's findings and recommendations. Following these discussions, the team developed an initial concept document outlining the soil standards policy. The team then met with Division management to present their draft policy proposal in order to get their comments, resolve certain outstanding issues, and seek their approval of the approach being taken. The draft concept document was subsequently presented to all staff within the Division for their review and comment. Following their review, the concept document was modified and was presented to other outside governmental agencies, citizens and private business parties for their review and comment of the proposed concept and process.

The second half of the team's efforts was spent developing the actual policy document which contains a detailed description of how the process will be applied, including: calculation of the direct exposure soil remediation objectives using accepted risk assessment methodologies; evaluation, selection, and testing of computer models that were used to calculate soil remediation objectives for organic compounds that are protective of groundwater quality; selection of a method to calculate soil remediation objectives for inorganic compounds that are protective of groundwater quality; selection of land use objectives; development of a method to address the additivity of risk to multiple hazardous substances, and; drafting of supporting background documents. The various elements of the policy were subsequently assembled in a draft document that was circulated within the Department and sent to other outside governmental agencies, citizens and private business parties, for their review and comment. Comments and recommendations were reviewed and, to the extent possible, incorporated into the final policy document.

Section 4.0 Applicability and Administrative Issues

This policy is intended to have widespread applicability to all sites and programs within the Division. Because each of the programs within the Division operate under distinct statutory and regulatory structures, different methodologies have historically been applied to the selection of

remedies and cleanup levels. This document describes a process that will be followed by all remedial programs within the Division to achieve greater consistency in the development of soil remediation objectives. Specific programs covered include, but are not limited to:

- ! RCRA hazardous waste corrective actions;
- ! Solid Waste corrective actions;
- ! Superfund remediation projects;
- ! Uranium Mill Tailings remediation projects;
- ! Voluntary Cleanup and Redevelopment Program, and;
- ! Federal facility remediation projects, including DSMOA sites, Rocky Flats and the Rocky Mountain Arsenal.

Emphasis has been placed on developing soil remediation objectives (Tiers 1, 2, and 3) for the cleanup of relatively small and simple sites, although general procedures have also been included (Tier 4) that are better suited to large, complex facilities. Use of the Tier 1 methodology or the Tier 2 table values contained within this policy may be especially beneficial to those parties with smaller more easily remediated sites that do not warrant the cost, in both time and money, of collecting and evaluating additional data in order to establish site-specific cleanup standards.

Use of this policy to develop soil remediation objectives would normally be initiated with a proposal made by the implementing party to the Division. The Division's implementation of this policy would occur as part of the normal review and oversight of established programs or by self funded means, to the extent allowed by State or Federal law and regulations. The program under which remediation is being performed, and its statutory and regulatory requirements, will ultimately decide on a case-by-case basis the acceptability of any proposal made under this policy, including: whether or not the proposed soil objectives are appropriate for the site based on its hydrogeologic setting; use of the proposed soil objectives in the remedial action decision process; the minimum level of data collection; the protocols for comparing the site data to the objectives selected; statistical parameters that specify the magnitude and frequency of deviation from the soil remediation objectives that is acceptable; adequacy of the site investigation program and evaluation of the resulting data; remedy selection; post remediation monitoring requirements; land use and the mechanism by which it is controlled, and; use of alternate input parameters, models, and risk assessment methods to calculate soil remediation objectives. These differences in program requirements preclude the Division from, at this time, defining all requirements that proponents must meet in order to consider use of the risk-based approach and the application of all elements of this policy at their site.

The implementing party is responsible for proposing and selecting the soil remediation objectives it wishes to apply to the site, including the tier or combination of tiers most applicable to their site conditions. The Division would then concur, modify or disapprove the facility's proposed soil remediation objectives in accordance with the requirements of the program under which the site is being addressed.

This policy will also be used by the Division to screen sites with soil contamination for potential regulatory action. Contamination exceeding the soil standards calculated as a result of the policy indicates a potential threat to human health or the environment which may require further study and/or remedial action. The availability of State-approved threshold soil objectives that are toxicologically based will provide the regulated community and the Division with a consistent baseline from which to assess the need for additional action at specific sites.

The procedures in this policy may not be used if its application will delay response actions when timeliness is critical to address imminent and substantial threats to human health and the environment. This policy may only be used after actions to address such threats have been completed.

It should be noted that soil remediation objectives contained within or calculated using this policy do not pre-empt any existing statutory or regulatory soil standards or performance objectives that may currently be utilized by programs within the Division. Nor will they be regarded as applicable or relevant state standards for purposes of any site for which a Record of Decision has already been issued under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or for which a corrective action decision, closure plan approval or similar decision has already been made or issued under the Colorado Hazardous Waste Management Act, including any decision made in connection with any five-year review under Section 121(c) of CERCLA, 42 U.S.C. § 9621(c). Nor is there any requirement to change any soil standards, corrective action plans, closure plans, or other decisions which have already been negotiated, approved or issued by any and all programs within the Division following the effective date of this policy.

Section 5.0 Information Requirements

In order to determine the appropriate application of soil remediation objectives developed under this policy, the implementing party must submit to the Division information characterizing the release into the environment and the actual and potential threats this release poses to human health and the environment. Although the data collection and evaluation requirements of such a characterization program are outside the scope of this policy, the Division believes that basic information is needed prior to or along with any proposal to remediate a site using soil remediation objectives the implementing party selects. The following information requirements are necessary to ensure that all risks posed by the contamination are identified and an appropriate corrective action program chosen. It should be recognized that the detail required in each of the

following elements will vary depending on the facility, its complexity, the desired remediation goal, and the requirements of the program under which site remediation is being addressed.

The implementing party should:

1. Identify all hazardous substances that may have been released into the environment as a result of site activities.
2. Locate the source(s) of the release(s) of contaminants.
3. Characterize the nature and vertical and horizontal extent of contamination, that is both within the facility boundary and that may have migrated beyond the facility boundary. This would include, but not be limited to: identification of all hazardous substances that may be present, and their concentration; defining the pathways and methods of migration of the hazardous substances or constituents; the media affected; the full lateral and vertical extent; direction and speed of contaminant migration; complicating factors influencing contaminant movement; concentration profiles; the properties of the contaminant(s), and; the methodology and results of any investigation conducted to determine background concentrations of hazardous substances.
4. Characterize the physical characteristics of the site, including, but not limited to: a description of past uses of the property; a description of the current uses and zoning of the site; distance to surface water; proximity to a flood plain; terrain slope; vegetative cover; the hydrogeology of the site and its surroundings; soil characteristics; surface soil permeability and erodibility; surface water and run-off flow patterns; potential for flooding; potential for contaminated soil movement by wind or erosion actions; depth to groundwater; materials and properties of the underlying aquifer; hydrological connections between groundwater and surface water, and; distance to sensitive environments.
5. Identify areas and populations threatened by releases from the facility.
6. Determine actual and potential threats of releases from the facility to human health and/or the environment in both the short and long term.

The Division understands that there are limits to the degree a site and associated releases may be characterized. Implementation of a remedy, such as excavation, may reveal that earlier characterization data were inaccurate. Depending on the circumstances, it may not be necessary to delay use of the soil remediation objectives and implementation of a remedy while attempting to learn everything about the release.

The level of site characterization detail needed to evaluate the appropriateness of a selected tier depends upon, among other factors, the application of the soil remediation objectives and the remediation process employed at the site. It may not always be necessary to fully define each of the six elements listed above before soil remediation objectives are calculated using this policy

and applied to the site. For example, soil remediation objectives may be used to remediate areas of limited contamination or "hot spots" through an interim measure while a facility investigation is underway. Or they may be used to screen data as it is being collected to determine whether there is a potential for concern based on soil concentrations. When used for these or other purposes, the acceptability of the soil remediation objectives chosen must be reviewed following completion of the site characterization program in light of the remediation goal.

At the outset, the site should be evaluated to determine whether conditions exist that warrant an immediate response. These include: 1) conditions that pose an imminent threat to the environment or public health and therefore require emergency action, and 2) conditions that warrant action because such action will prevent or reduce the significant spread of contaminants, reduce public exposure, or avoid or minimize the need for a later more complex costly action. If such conditions exist, appropriate immediate action should be taken at the earliest possible time and should not be delayed pending completion of a site investigation or development of soil remediation objectives under this policy.

Certain soil remediation objectives which are either selected from the Tier 2 table or calculated under Tier 3 of this policy do not include consideration of ecological receptors, sensitive environments, the migration of contaminants onto adjacent properties, or protection of surface water. Sites with such environmental protection concerns will require additional evaluation to ensure that protective soil remediation objectives are calculated with these concerns specifically in mind. To determine the eligibility of a site for cleanup under this policy, the implementing party must demonstrate that the contamination will not adversely affect surface water or nearby sensitive environments. The acceptable distance to either of these environmental concerns is dependent upon site-specific characteristics. At a minimum, the implementing party should identify any surface water or sensitive environments within one-half mile of the site.

The implementing party may also be required to submit additional data to support the use of Tier 3 and Tier 4 methodologies in the calculation of site-specific soil remediation objectives. In Tier 3, the implementing party may modify the direct exposure and soil-to-groundwater Tier 2 table values by using site-specific data rather than the default values used by the Division. Similarly, under Tier 4 the implementing party may: modify the input parameters used in the risk algorithms and groundwater models used; use models different from those used in Tier 2 and Tier 3; may use additional site data to improve or confirm predictions of exposed receptors to contaminants of concern; may analyze site-specific risks using alternate risk assessment, probabilistic data analysis, and sophisticated fate and transport models; eliminate incomplete human exposure pathway(s) not excluded under lower tiers; use toxicological-specific information not available from alternate sources, or; develop soil objectives based on alternate land uses. Data supporting these site-specific adjustments or use of alternate methodologies must also be provided to the Division for review and approval to ensure that the resulting soil remediation objectives are protective and that specified risks to human health and the environment have been minimized.

The characterization of both the facility and any hazardous substances that may have been released should be conducted in a manner acceptable to the Division. The more complete and reliable the presented information is, the more quickly the Division staff will be able to evaluate and approve the implementing party's soil remediation objectives generated using this policy. The level of Division staff oversight during the characterization of the site will be determined largely by the program under which site remediation is being addressed, but may also be influenced by factors such as the level of data available/presented and the nature of the contamination at the site.

Section 6.0 Selection of Soil Remediation Objectives

Section 6.1 Overview of the Tiered Approach

Sites with soil contamination vary greatly in terms of complexity, physical and chemical characteristics, and in the risk that they may pose to human health and the environment. The soil remediation objectives selection methodology presented in this section recognizes this site-specific diversity and utilizes a tiered approach to the development of soil standards. Within these tiers, several land use settings can be considered.

After evaluating the nature, magnitude and full extent of soil contamination associated with a site, the implementing party may select soil remediation objectives for their facility based on one or a combination of four tiers of risk-based standards:

- ! Background/Method Detection Limit Objectives (Tier 1);
- ! Table Value Objectives (Tier 2);
- ! Limited Site-Specific Modifications to Table Value Objectives (Tier 3); or
- ! Site-Specific Risk Based Cleanup Objectives (Tier 4).

At most sites, use of one or more of the standards noted above would facilitate the selection of a remedy for the contaminated area that is protective of human health and the environment, including groundwater. However, site-specific conditions may preclude the routine application of these objectives (particularly Tier 2 and Tier 3 objectives) where surface water, sensitive environments, or other limiting conditions are present. Such sites may require additional evaluation and potentially more stringent standards to ensure adequate protection.

Section 6.2 Selection of a Soil Remediation Tier

The implementing party remediating a site has the option of choosing which tier or combination of tiers shall be used to develop remediation objectives. The decision will usually depend on site-specific conditions and specific remediation goals for the particular site. It is not a prerequisite

to evaluate a site under a lower tier before selecting a higher tier to establish soil remediation objectives.

Use of each successive tier generally requires a certain level of data collection, analysis, or evaluation as conservative assumptions of the initial tiers are replaced with site-specific data. The implementing party decides which tier to apply to its facility and whether it is cost effective to collect additional information to develop alternate soil remediation objectives based on site-specific risk estimates. The consequence of selecting a higher tier over a lower tier will generally be an increase in the cost associated with additional work, increased use of Division and facility resources, a need for increased user sophistication, and increased data requirements, all of which should result in a decrease in uncertainty and conservatism, which in turn should result in the calculation of more appropriate site-specific soil remediation objectives. The implementing party decides whether the expenditure of additional resources to perform a more site-specific analysis will be cost effective and benefit the site's corrective action program. In deciding which tier to apply to its site, the implementing party should consider the following factors:

- ! Are the assumptions used to derive the Tier 1 and Tier 2 soil remediation objectives appropriate for conditions at this site?
- ! What is the cost of corrective action to achieve the Tier 1 and Tier 2 soil remediation objectives?
- ! What is the cost of a higher tier's analyses and implementation (data collection, analysis, review, monitoring requirements, etc.)?
- ! Is it likely, that in moving to a higher tier, the more site-specific remediation objectives and corrective action goals will differ significantly from those of lower tiers?
- ! How much will be saved in remediation costs by performing additional work and implementing corrective actions based on a higher tier soil remediation objectives?

Section 6.3 Land Use Setting

Tier 2 allows for consideration of three different land use settings for the direct soil exposure pathway, thus providing the implementing party with the greatest flexibility in selecting reasonable soil remediation objectives while ensuring that human health and the environment are protected. The land use settings are: residential, commercial and industrial. The direct soil exposure values are based on equal levels of human health protection for the three land use settings. Under Tier 2 and 3, the soil remediation objective selected for a site must be protective of groundwater regardless of the land use setting chosen for the facility.

The most conservative land use setting, residential, is applicable to a site unless sufficient information is presented to justify the use of a commercial or industrial land use setting. If the

implementing party proposes to use a land use setting other than residential, they must meet all of the following criteria:

- a) The facility is currently zoned for non-residential use; and
- b) The facility is expected to be zoned for non-residential use into the foreseeable future; and
- c) Appropriate and maintainable institutional controls (e.g. deed restrictions, restrictive covenants, ordinances adopted and administered by a unit of local government) will be in force; and
- d) Uses of the facility and uses and zoning of properties within 100 meters of the contaminated area are industrial, commercial or other uses where the Division concurs that the exposure is limited and thus does not warrant application of the residential standard.

The implementing party should submit all supporting documentation justifying the application of a non-residential land use setting to the Division for review and approval. The implementing party is advised to seek Division input and guidance on the use of alternate land use settings, particularly if there is a question as to whether or not a proposed land use is appropriate and applicable for a specific situation.

The goal of corrective action is to remediate a site to levels that do not pose a risk to human health, using a residential exposure scenario, and the environment, thus allowing unrestricted use of the property both now and in the future (i.e., clean closure). Achieving this goal would allow the facility owner/operator to "walk away" from the site following closure and would provide the greatest amount of protection to all prospective users or residents. For example, soil that has been remediated so that all constituent concentrations are equal to or less than the Tier 2 residential table values, including the groundwater protection values, would be viewed as being protective of human health and the environment. No land use restrictions would be placed on a facility that is cleaned-up to this standard. In such cases, the overseeing regulatory program will generally not require long-term monitoring and the site would be considered clean closed (with regard to soil only). On the other hand, institutional controls may be required for those sites that do not allow for unrestricted use of the property as a result of soil contamination being left behind at concentrations in excess of the residential land use values.

Soil contamination that has migrated beyond the facility should be remediated using conservative remediation objectives that result in clean closure and unrestricted use of the impacted property. The implementing party may not impose restrictions on the future use of properties it does not own, unless that property owner agrees to 1) the implementing party's remediation proposal, 2) the selection of the soil remediation objectives, and 3) the imposition and maintenance of institutional controls to limit future land use or development if something other than clean closure is proposed.

The Division's preference is for the implementing party to defer use of institutional controls until after a demonstration that remedial technologies either cannot or cannot reasonably (usually the basis of cost) achieve the desired permanent cleanup remedy. However, we do realize that sometimes institutional controls will be the only practicable way to afford an adequate level of protection to a site by, for instance, eliminating pathways for public exposure to contaminants. In such cases, institutional controls provide the mechanism for assuring long term protection of human health and the environment by imposing restrictions on land use that are particular to the circumstances of remediation at any given site. For instance, a person who develops remediation objectives based on industrial or commercial property may be required to place an appropriate institutional control on that property so that some future landowner does not then try to use the property for residential purposes without first being placed on notice that there is a restriction on land use which, if disregarded, could threaten human health or the environment and void any agreement made with regard to the use of these soil remediation objectives.

Both the commercial and industrial land use settings assume that public access is short-term and intermittent compared to daily exposure to the worker population. As such, land uses such as daycare facilities, educational facilities, health care facilities or playgrounds, where a more sensitive population such as young children or the elderly would be present on a regular basis, would not be consistent with the definition of a commercial or industrial land use setting, and would instead require use of more stringent soil remediation objectives (residential/unrestricted land use setting). In order to qualify for a non-residential land use setting, the implementing party must demonstrate to the Division's satisfaction that exposure assumptions discussed above have been met. Since non-residential land use settings do not constitute unrestricted use of the property, the program overseeing the cleanup may require the implementing party to impose future use restrictions. Future use restrictions may include, but not be limited to 1) institutional controls such as deed restrictions and covenants, 2) site management controls, and/or 3) enforcement mechanisms such as consent orders, contracts, post-closure permits. As part of accepting the use of this policy, the implementing party must commit to reevaluate the remedy if the land use or zoning changes from the originally selected designation. Future changes in land use may necessitate taking additional investigative and/or remedial actions to ensure the continued protectiveness of the remedy.

Since the vast majority of sites the Division deals with fall into one of three land use settings noted above, Tier 2 table values have only been calculated for those three categories. The Division understands that there are other land use designations as well, some of which may be more appropriate for the implementing party's facility. In cases where the facility has a designated land use other than residential, commercial, or industrial, the implementing party may either 1) propose to use soil remediation objectives from the Tier 2 table that are equally protective or 2) calculate site-specific soil remediation objectives based on the designated land use using the Tier 4 process.

The previous discussions regarding land use and the application of institutional controls is limited to matters involving soil contamination alone, and do not address other technical and regulatory concerns associated with impacts to other environmental media, such as groundwater and/or

surface water. That subject is outside the scope of this policy. The implementing party is advised to contact the applicable program within the Division in order to evaluate and determine the appropriate use of institutional controls to limit or eliminate public exposure to contaminants via these other pathways.

Section 6.4 Tier 1 - Background/Method Detection Limit Objectives

This tier utilizes background concentrations and analytical laboratory limitations to establish soil remediation objectives. If a constituent concentration in soil is equal to or below the background concentration, or below the laboratory method detection limit, that constituent meets the Background/Method Detection Limit Objectives and no further action with regard to that constituent in soil would be required. The implementing party has the option of remediating a facility to a more stringent standard than the one established under this tier if it so desires, a decision based perhaps on the impact of naturally occurring background concentrations on a proposed future land use.

Generally, Tier 1 can be applied to facilities where naturally occurring background concentrations can be easily determined or where laboratory method detection limits have been established for the constituents of concern. A valid background study will be required to establish appropriate background concentrations for each constituent, the results of which must be reported to the Division for review and concurrence. Although there are some national databases (e.g., USGS studies) which can provide a sense of the likely background ranges of element concentrations in soils unaffected by most man-made activities, there is enough local variation and analytical method differences to require site-specific sample data collection. Alternatively, the facility may either assume that background is non-detect or demonstrate that constituent concentrations are below the method detection limits, thus eliminating the expense of having to perform a background study. Guidelines for determining background concentrations are contained in Attachment 4 of this policy.

The Division's preference will always be that naturally occurring background be used for comparison purposes under this tier. However, the Division recognizes that constituent concentrations measured in soil at some sites will have been impacted by off-site, regional anthropogenic activities. Implementing parties that are able to demonstrate, to the Division's satisfaction, that anthropogenic contaminants are present in the region-wide background with site-specific measurements may not be required to remediate the soil below anthropogenic background values. The decision to allow the use of anthropogenic influenced background in determining site-specific soil remediation objectives will be made on a case-by-case basis requiring approval by the program responsible for reviewing and approving the implementing party's proposal.

Under this tier, the analytical method detection limit may be used as a soil remediation objective. Such objectives may be established for all substances where appropriate analytical methods that are sufficiently sensitive are available and the data is of known precision and accuracy. If the soil concentrations for all constituents of concern are below the appropriate

method detection limit, the Tier 1 standard has been achieved and that soil would not be classified as being contaminated based on this policy.

Institutional controls and long-term monitoring are not required for sites that meet the Tier 1 standard. However, a requirement for such controls at a site could be based on permits held by the facility or as a result of contamination of another media, such as groundwater.

Section 6.5 Tier 2 - Table Value Objectives

This tier utilizes a conservative risk-based methodology to calculate generic soil remediation objectives that are deemed to be protective of human health and groundwater quality. Conservative assumptions were used in order to ensure that the soil objectives could be applied to those sites that are relatively small and simple without the need for site-specific risk assessments. The risk-based soil levels developed under this tier were calculated for human exposures via each of the following pathways: dermal contact, soil ingestion, volatile inhalation, particulate inhalation, and leaching to groundwater. The combined health effects of each exposure pathway were considered in the calculation of a cumulative carcinogenic and non-carcinogenic soil concentration for each hazardous substance listed. The lowest of these two soil concentrations is listed in Table 1 for each land use setting. Soil concentrations calculated for each exposure pathway and the two sets of cumulative health effects values are all contained within Attachment 2.

As discussed in the subsections below, soil remediation objectives have been established that the Division believes will protect groundwater. Due to the nature of contaminant migration, it is unlikely that any soil cleanup level above "zero" would actually prevent all contaminants from reaching the groundwater in a conservative model. Therefore, it was considered reasonable to acknowledge the likelihood of some contaminants reaching groundwater, and to try to establish soil levels that would minimize the impact. The Division agreed that a "safe" contaminant level in groundwater would be one that does not exceed a health-based safe drinking water level for that contaminant.

Using a one-in-a-million excess cancer risk or a hazard quotient of one as acceptable levels of risk for carcinogens and noncarcinogens respectively, the contaminant concentration in soil which resulted in the applicable risk level was calculated for each contaminant assuming a cumulative exposure to each of the four direct exposure pathways. Furthermore, direct soil exposure pathway concentrations were calculated for three different land use settings. For the expected land use of a site, the lowest (most conservative) of either the direct exposure value or groundwater protection value listed in Table 1 would be selected as the applicable soil remediation objective. This is a level which will be protective of all of the pathways that were considered.

If all of the concentrations of constituents in soil do not exceed any of the table values for the land use being considered, no further action or assessment would be required for the soil, unless multiple constituents are being considered (see section 6.5.2, "Multiple Contaminant Additivity of Risk"). Institutional controls and long-term monitoring would not normally be required at sites

where residual soil concentrations are all below these objectives. Examples of where additional monitoring and/or maintenance activities could be required include: how the Tier 2 objectives are used in the development of a site remedy (e.g., capping an area of contamination versus excavation and off-site disposal); characteristics of the site differ significantly from the parameters used to calculate the Tier 2 objectives; proximity of the site to features requiring additional protection (e.g., downgradient municipal water supply well, private well, or sensitive environment); impacts to other media requiring continued monitoring (e.g., groundwater contamination), and; existing permits, orders, or agreements may require continued monitoring and post-closure maintenance activities.

There may be instances where a risk-based soil remediation objective contained within Table 1, or calculated using the Tier 3 or Tier 4 methodology, is lower than current analytical detection limits, i.e., the method detection limit. In such cases, this policy requires that reliable and available analytical methods demonstrating the lowest effective method detection limit, which most closely approaches the definable risk-based value, be used as the soil remediation objective.

If soil constituent concentrations exceed the Tier 2 table values, the implementing party may propose an appropriate remedial response, or proceed with further site-specific assessment under Tier 3 or Tier 4 procedures. Implementing parties that are able to demonstrate with site-specific data that background levels are greater than the Tier 2 standard may also consider using the Tier 1 approach for establishing soil remediation objectives.

The Tier 2 table values are not appropriate for all sites. Potential impacts to surface water (which may be subject to more stringent water quality standards than the values used in this tier), adjacent properties (over which the implementing party may have no control), sensitive environments (ecological receptors may require the use of more stringent cleanup objectives), or other limiting conditions were not taken into account when calculating the Tier 2 soil remediation objectives. Use of the Tier 2 table values at sites with such environmental concerns may require additional evaluation before the objectives can be applied and must obtain concurrence from the regulating authority. Or the implementing party may calculate more stringent remediation levels to address the environmental concern using either the Tier 3 or Tier 4 approach. Developing soil remediation objectives at sites with sensitive conditions is a complex subject that is outside the scope of this policy and should be discussed with the program responsible for overseeing the environmental work performed at the facility.

Similarly, the Tier 2 table values are not appropriate for areas of contamination that are greater than 100 square meters. The sensitivity analysis for the contaminant transport models used to calculate soil remediation objectives protective of groundwater showed that the resulting soil concentration is highly sensitive to the areal extent of contamination. The larger the areal extent, the lower the remedial objective for cleanup. Therefore the Tier 2 table values protective of groundwater apply to areas of contamination that are approximately 100 square meters in size. If the areal extent of contamination at a site exceeds 100 square meters, the soil remediation objectives protective of groundwater listed in Table 1 do not apply and the implementing party should calculate site-specific objectives using the Tier 3 or Tier 4 process. The Division retains

the option of approving the use of the Tier 2 table values by an implementing party for areas of contamination greater than 100 square meters if an evaluation of the data suggests that the increased size will have minimal potential for impacting groundwater quality.

Although the soil remediation objectives developed under this tier are deemed to be protective of human health and groundwater, it is assumed that the calculated concentrations will not exhibit the hazardous waste characteristic of ignitability, corrosivity, reactivity, or toxicity as defined in the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, Part 261, Subpart C. The implementing party will need to demonstrate, with site-specific sampling results if the situation warrants it, that the use of proposed soil objectives will not result in soil concentrations being left in place that continue to exhibit the characteristic of a hazardous waste. This demonstration must be made for soil remediation objectives calculated using Tier 2 through Tier 4 methods, regardless of the proposed land use for the site. Exceptions to this requirement include: the constituent concentrations are naturally occurring; the facility receives a permit or license from the Division to leave behind hazardous waste levels of soil contamination, and/or; the Division approves a plan to leave significant levels of contamination behind, a plan which utilizes institutional and engineering controls to minimize or eliminate exposure to the contaminants or future releases into the environment.

Unless they are incorporated into an enforcement action, the Tier 2 table values are not enforceable standards, but rather are used by the Division and the implementing party as a guide in setting appropriate site-specific remediation goals.

Section 6.5.1 Direct Exposure Table Values

The risk from direct exposure to soil must consider all potential soil exposure pathways, including soil ingestion, dermal exposure, and inhalation of vapors or particulates. Table 1 lists concentrations of individual chemicals that were developed by back-calculating a soil concentration equivalent to a 1×10^{-6} cumulative cancer risk or a hazard quotient of one. The algorithms used to calculate the Table values, their input parameters, and the toxicological data relied upon in the calculation of these values are contained within Attachment 2 of this policy, as well as soil concentrations calculated for the combined pathways. The risk standards for the residential land use setting includes consideration of children as a sensitive sub-population by calculating a time-weighted average cancer risk for an individual from age 0 to 30 years, and calculating non-carcinogenic risk for a young child, ages 0 to 6 years.

It should be noted that assessment of exposure via consumption of garden fruits and vegetables that may be grown in residential soils and consumed from home gardens is not evaluated under this policy. For many chemicals, particularly organic chemicals, reliable data on plant uptake from soil are lacking. Plant uptake factors have been derived for uptake of some metals from soil into plants, based primarily on two major compilations of empirical data (Baes, 1984 and EPA, 1992 822/R-93-001a). However, as these study results show, uptake is highly variable and the relationship between soil concentration and plant uptake can vary by up to several orders of magnitude due to differences in soil type, pH, type of produce grown, metal concentration in soil,

Colorado Department of Public Health and Environment, Hazardous Materials and Waste Management Division

Table 1 Soil Cleanup Table Value Standards [mg/kg]

Chemical	CAS	Residential/ Unrestricted Landuse		Commercial Landuse		Industrial Landuse		Soil Concentration Protective of Ground water		Leachate Reference Concentration	
		[mg/kg]	Notes	[mg/kg]	Notes	[mg/kg]	Notes	[mg/kg]	Notes	[mg/l]	Notes
Volatile Organic Compounds											
Benzene	71-43-2	0.60	c	3.59	c	2.42	c	0.17		NA	
Carbon Tetrachloride	56-23-25	0.23	c	1.34	c	0.93	c	0.925		NA	
1,1-Dichloroethane	75-34-3	546.80	nc	1,000	5,nc	1,000	5,nc	16.5		NA	
1,1-Dichloroethylene	75-35-4	0.05	c	0.27	c	0.19	c	12.0		NA	
Ethylbenzene	100-41-4	1,000	5,nc	1,000	5,nc	1,000	5,nc	104.3		NA	
Pentachlorophenol	87-86-5	0.51	c	1.95	c	1.87	c	0.045		NA	
Tetrachloroethylene	127-18-4	2.02	c	8.97	c	7.68	c	1.875		NA	
Toluene	108-88-3	667.85	nc	1,000	5,nc	1,000	5,nc	85		NA	
1,1,1-Trichloroethane	71-55-6	797.19	nc	1,000	5,nc	1,000	5,nc	62.5		NA	
Trichloroethylene	79-01-6	2.99	c	16.84	c	11.96	c	0.675		NA	
Vinyl chloride	75-01-4	0.02	c	0.10	c	0.07	c	7.0		NA	
Semi-Volatile Organic Compounds											
Naphthalene	91-20-3	289.1	nc	1,000	5,nc	1,000	5,nc	51.4		NA	
Phenol	108-95-2	1,000	5,nc	1,000	5,nc	1,000	5,nc	23.675		NA	
Xylene (total)	1330-20-7	1,000	5,nc	1,000	5,nc	1,000	5,nc	1,000	5	NA	

Colorado Department of Public Health and Environment, Hazardous Materials and Waste Management Division

Table 1 Soil Cleanup Table Value Standards [mg/kg]

Chemical	CAS	Residential/ Unrestricted Landuse		Commercial Landuse		Industrial Landuse		Soil Concentration Protective of Ground water		Leachate Reference Concentration	
		[mg/kg]	Notes	[mg/kg]	Notes	[mg/kg]	Notes	[mg/kg]	Notes	[mg/l]	Notes
Pesticides / PCBs											
DDT	50-29-3	0.58	c	2.53	c	2.20	c	1,000	5	NA	
Dieldrin	60-57-1	0.01	c	0.04	c	0.03	c	1,000	5	NA	
PCBs	1336-36-3	0.07	c	0.30	c	0.27	c	1,000	5	NA	
- Aroclor 1016	126-74-112	2.99	nc	19.69	nc	17.31	nc	1,000	5	NA	
- Aroclor 1254	110-97-691	0.63	nc	3.39	nc	3.13	nc	1,000	5	NA	
Metals and Inorganic Compounds											
Arsenic	7440-38-2	0.21	c	1.04	c	0.82	c	NA		1.1	
Cadmium and compounds	7440-43-9	99.5	nc	1052.46	nc	694.46	nc	NA		0.11	
Chromium (VI)	7440-47-3	53.94	nc	212.92	nc	208.57	nc	NA		2.2	1
Copper and compounds	7440-50-8	2,570	nc	41,522	nc	27,537	nc	NA		22	
Lead	7439-92-1	400	nc,3	2,920	nc,4	1,460	nc,4	NA		1.1	
Mercury (inorganic)	7439-97-6	17.66	nc	176.53	nc	137.07	nc	NA		0.044	

NOTES:

c - Standard based on carcinogenic risk.

nc - Standard based on noncarcinogenic risk.

NA - Not Applicable: use of this table to select soil remediation objectives under Tier 2 does not allow for the calculation of a soil concentration under this column.

1. For total chromium

2. Not to exceed the RCRA Characteristic of Toxicity regulatory limit.

3. EPA, July 14, 1994 "Revised Interim Soil Lead Guidance for CERCLA Site and RCRA Corrective Action Facilities," OSWER Directive 9355.4-12.

4. Attachment 3

5. Upper Concentration Limit

etc. Therefore, application of plant uptake values derived from these empirical studies are best applied on a site-by-site basis and are not considered reliable for generic table values.

For most of the chemicals listed in the Tier 2 table, plant uptake is not expected to be a significant contributor to total exposure from the soil pathway. However, cadmium presents a unique health concern because of its ability to bioaccumulate at relatively high concentrations in plants under some circumstances. In order to provide a margin of safety to account for plant uptake, a safety factor of 2 has been applied to the Tier 2 table value for cadmium.

Due to the unique toxicological properties of lead, table values for this chemical have been derived using a different approach than for most other chemicals. Table values for lead are based upon predictive uptake-biokinetic and pharmacokinetic models which have been developed to evaluate lead risk in children and adults. These models identify a target blood lead level at the upper end of the exposure distribution, rather than using a reference dose (RfD) approach.

The population most at risk of lead toxicity is young children who may be repeatedly exposed to lead in a residential setting. The table value adopted for the residential/unrestricted land use scenario (400 ppm) is based on the U.S. EPA Integrated Exposure Uptake Biokinetic (IEUBK) model, adopting default exposure and intake values to calculate acceptable blood lead levels in children.

Because of significant differences between young children and adults in behavior and pharmacokinetics, a different model must be used to evaluate lead exposure in adults in a commercial or industrial land use setting. A model developed by Bowers et. al (1994), which was recently endorsed by EPA's Technical Review Workgroup for Lead in Soil (EPA 1996), was used to calculate table values of 1460 mg/kg and 2920 mg/kg for the industrial and commercial exposure scenarios. Details on the methodology used to calculate this value are provided in Attachment 3.

Based on the collective experience of Superfund, RCRA Corrective Action, and TSCA Section 403 programs, the Division believes that a lead concentration of 400 mg/kg in soil is generally protective of human health and the environment. However, in some special situations, further study may be warranted at concentrations below this level. For example, agricultural areas, wetlands, areas of ecological risk, and areas of higher than expected human exposure are all situations that could require further study. Although lead is generally not mobile and will not pose significant risk to groundwater, there are situations where, because of the form of lead, hydrogeology, or the presence of other contaminants at the site, lead may be leachable and therefore pose a threat to groundwater resources.

The table values are calculated using current reasonable maximum exposure and toxicological parameters recommended by EPA, as reported in their 1996 *Exposure Factors Handbook*, the 1997 Integrated Risk Information System (IRIS), and the 1995 Health Effects Assessment Summary Table (HEAST). The parameters cited in these publications are continually being updated as both new information becomes available and the science of assessing risk evolves.

As a result, the Tier 2 direct exposure risk based concentrations are viewed as being interim values that are subject to change as more current information becomes available. Therefore, we urge the implementing party to verify that the parameters relied upon in the development of the table values are still in effect. The Division hopes to periodically review these exposure and toxicological parameters to ensure that the Tier 2 table values remain current.

Section 6.5.2 Multiple Contaminant Additivity of Risk

The soil remediation objectives listed in Table 1 were developed to be protective of public health and the environment considering both direct contact pathways and potential migration to groundwater. Each table value is based on either a 1×10^{-6} excess lifetime cancer risk or a target for non-cancer effects which corresponds to a hazard quotient of one (i.e., setting an allowable chronic daily intake that is equal to the reference dose).

Risks are presumed to be additive for all carcinogens, and for non-carcinogens with similar critical endpoints or which affect the same target organ. The soil remediation objectives listed in Table 1, or objectives calculated using any of the methods described in this policy (with the exception of Tier 1), must be adjusted downward when multiple hazardous substances with similar critical endpoints occur at a site, so that the total site risk remains below the prescribed levels.

For table values based on non-cancer risk, the Table 1 values must be adjusted if multiple chemicals are detected which exhibit the same critical effect or mechanism of action, as shown in Table 2. The Table 1 value for each chemical detected should be divided by the total number of chemicals present with the same critical endpoint. Each of the contaminant concentrations at the site is then compared to the soil remediation objectives that have been adjusted to account for this potential additivity. For example, if cadmium, toluene and barium are detected, an adjusted table value for cadmium and toluene must be derived by dividing the original table value for those chemicals by two, while the table value for barium remains unchanged.

For table values based on the risk of cancer, individual constituent concentrations may not exceed the table value based on a 1×10^{-6} excess lifetime cancer risk. The cumulative excess cancer risk posed by a site with multiple carcinogens must not exceed a 1×10^{-5} risk. When there is only one contaminant at a site, the soil remediation objectives cannot be adjusted to result in a risk above the 1×10^{-6} level, unless the background level is higher or the method detection limit is higher. If there are more than ten carcinogens or more than one carcinogen with similar critical endpoints at a site, the soil remediation objectives will need to be prorated or reduced.

When chlorinated solvents are present, such as tetrachloroethylene or trichloroethylene, consideration should be given to the potential that they may degrade to vinyl chloride, a more toxic compound. Because vinyl chloride is more mobile and toxic than its parent compounds, the soil remediation objective concentrations for the tetrachloroethylene family of compounds may need to be reduced below the levels provided in this policy. The Division may consider the mass of the contaminants remaining and the consequent mass of any potential degradation products and

Table 2. Chemicals with Noncarcinogenic Effects on Specific Target Organ/System¹

Target Organ/System	Effect
<u>Kidney</u>	
Acetone	Increased kidney weight; nephrotoxicity
1,1-Dichloroethane	Kidney damage
Cadmium	Significant proteinuria
Chlorobenzene	Kidney effects
Di-n-octyl phthalate	Kidney effects
Endosulfan	Glomerulonephrosis
Ethylbenzene	Kidney toxicity
Fluoranthene	Nephropathy
4 Methyl-2-pentanone (isopropylacetone)	Kidney effects ²
Nitrobenzene	Renal and adrenal lesions
Pyrene	Kidney effects
Toluene	Changes in kidney weights
2,4,5-Trichlorophenol	Pathology
Vinyl acetate	Altered kidney weight
<u>Liver</u>	
Acenaphthene	Hepatotoxicity
Acetone	Increased weight
Butyl benzyl phthalate	Increased liver to body weight and liver to brain weight ratios
Chlorobenzene	Histopathology
Di-n-octyl phthalate	Increased weight; increased SGOT & SGPT activity
Endrin	Mild histological lesions in liver
Flouranthene	Increased liver weight
4-Methyl-2-pentanone (isopropylacetone)	Liver effects ²
Nitrobenzene	Lesions
PCBs	Liver lesions, increased weight ²
Styrene	Liver effects
Toluene	Changes in liver weights
1,1,1-Trichloroethane	Liver effects ²
2,4,5-Trichlorophenol	Pathology
<u>Immune System</u>	
2,4-Dichlorophenol	Altered immune function
<i>p</i> -Chloroaniline	Nonneoplastic lesions of splenic capsule
<u>Central Nervous System</u>	
Butanol	Hypoactivity and ataxia
Cyanide (amenable)	Weight loss, myelin degeneration
2,4 Dimethylphenol	Prostration and ataxia
Endrin	Occasional convulsions
2-Methylphenol	Neurotoxicity
Mercury	Hand tremor, memory disturbances
Styrene	Neurotoxicity
Xylenes	Hyperactivity
<u>Adrenal Gland</u>	
Nitrobenzene	Adrenal lesions
1,2,4-Trichlorobenzene	Increased adrenal weights; vacuolization in cortex

Table 2: (continued)

Target Organ/System

Effect

Circulatory System

Antimony	Altered blood chemistry & myocardial effects
Barium	Increased blood pressure
<i>trans</i> -1,2 Dichloroethene	Increased alkaline phosphatase level
<i>cis</i> -1,2 Dichloroethylene	Decreased hematocrit and hemoglobin
2,4-Dimethylphenol	Altered blood chemistry
Fluoranthene	Hematologic changes
Fluorene	Decreased RBC and hemoglobin
Nitrobenzene	Hematologic changes
Styrene	Red blood cell effects
Zinc	Decrease in erythrocyte superoxide dismutase (ESOD)

Reproductive System

Barium	Fetotoxicity
Carbon disulfide	Fetal toxicity and malformations
2-Chlorophenol	Reproductive effects
Methoxychlor	Excessive loss of litters
Phenol	Reduced fetal body weight in rats

Respiratory System

1,2-Dichloropropane	Hyperplasia of the nasal mucosa
Hexachlorocyclopentadiene	Squamous metaplasia
Methyl bromide	Lesions on the olfactory epithelium of the nasal cavity
Vinyl acetate	Nasal epithelial lesions

Gastrointestinal System

Copper	Gastrointestinal irritation ²
Hexachlorocyclopentadiene	Stomach lesions
Methyl bromide	Epithelial hyperplasia of the forestomach

General Toxic Effects

Napthalene	Decreased body weight ²
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1. Source: EPA, 1996 (Soil Screening Guidance, Table 2)
Except as noted in footnote 2
2. Source: IRIS, 1996

the resulting potential for groundwater contamination in determining the need to reduce the cleanup levels or to require and/or lengthen the monitoring program in these circumstances.

Under Tiers 2 and 3, any proposal submitted by the implementing party to remediate a site where multiple hazardous substances are present must include a demonstration that the soil remediation objectives selected meet the cumulative risk requirements of this policy.

Section 6.5.3 Groundwater Protection Table Values: Organic Constituents

The Tier 2 table includes soil remediation objectives that are back-calculated to be protective of groundwater quality in the aquifer underlying the site. As was discussed previously, a safe soil concentration based on the leaching of constituents from soil-to-groundwater must prevent constituent levels in the groundwater from exceeding health-based drinking water standards. The standards used to calculate soil concentrations protective of groundwater were based on the Department's Water Quality Control Division groundwater standards or EPA's Maximum Contaminant Levels; when established health-based standards are not available, a risk based drinking water value must be calculated and used. The methodology used to calculate MCL-equivalent drinking water concentrations is contained within Attachment 2.

These groundwater protection table values were calculated using commercially available mathematical fate and transport models capable of simulating the vertical movement of contaminants from unsaturated soils down to the water table, as well as the mixing of the contaminants with the groundwater in the immediate vicinity of the source area. The models chosen are also capable of simulating the fate and transport of contaminants having diverse physical and chemical properties. These models were run using input parameters based on a reasonably conservative Colorado site along the Front Range corridor to ensure that soil objectives generated using this method could be applied to a wide range of sites.

Because of the diversity of site conditions and contaminants that may be simulated, more than one model was needed for this policy. The following were chosen:

 SESOIL (US-EPA, 1987a) which models the transport and fate of contaminants through the unsaturated zone down to the water table, and

 AT123D (US-EPA, 1985) which simulates the mixing of contaminants in the groundwater and transport within the saturated zone.

These models were chosen because, in addition to having been developed for situations very similar to the Division's intended use, they are readily available, well-documented, and written to work together so that the output from the SESOIL model can be used as the input for the AT123D model. The Department's use of these models does not constitute endorsement nor imply that they are the best for all situations.

SESOIL and AT123D were used to model the transport of organic contaminants and estimate safe levels of soil contamination for this group of compounds. The most important properties affecting organic contaminant transport are solubility, vapor pressure, compound partition coefficients such as the Henry's constant and the organic-carbon partition coefficient (K_{oc}), and the amount of organic carbon in the soil. Transport of inorganic contaminants, however, are heavily influenced by soil properties such as pH, redox potential and clay content. These significant behavioral differences necessitated the use of different procedures to estimate soil remediation objectives for the two groups of compounds. Due to the complexity of the subject, biological attenuation processes were not incorporated into the models used to calculate the Tier 2 objectives. The implementing party has the option of factoring in this attenuation process under Tier 4 of this policy.

The selection, evaluation, and operation of these two models to generate the soil remediation objectives are described in detail in the attached technical background document (Attachment 1).

Section 6.5.4 Groundwater Protection: Inorganic Constituents

As was discussed above, the fate of inorganic contaminants is extremely sensitive to changing site conditions, particularly to pH, redox potential and clay content of the soil. As a result of this sensitivity, use of a single model or combination of models was deemed to be inappropriate for a generic site, as was used for the organic constituents, in that it would likely result in the establishment of soil remediation objectives that are unsuitable for a wide range of real sites. It was therefore decided to require sites cleaning up inorganic contaminants under this policy to perform site-specific tests to estimate the concentration of inorganics that are likely to leach from the site soil.

In developing this policy, the Division conducted a review of potential leaching tests and utilized five objectives for selecting the recommended test procedure(s). The leaching test must: 1) accurately predict leaching potential, 2) be available at a sufficient number of regional labs, 3) not be prohibitively costly, 4) be fully developed, implementable, precision tested, and 5) have reproducible results. Based upon these objectives, the Division recommends the use of the Toxicity Characteristic Leaching Procedure (TCLP) or the Synthetic Precipitation Leach Test (SPLT).

The TCLP (EPA Method 1311) was originally developed by EPA to simulate the leaching potential of a wide variety of waste types in a municipal landfill environment. The TCLP is used to define RCRA wastes, determine whether a waste is subject to the land disposal ban, and determine cleanup levels at RCRA sites. The SPLT (EPA Method 1312) was originally designed to simulate the leaching potential of contaminated soils in a monofill under acid rain conditions. The procedures are virtually identical, the difference being the extraction fluids used. The Division determined that the acidity of the extraction fluids would not significantly affect the results of the tests and that the implementing party could select the method most appropriate to the site in question. Both methods have been precision tested and the results from each are reproducible. Though the SPLT is not widely used in regional labs, the procedure and equipment

are such that any lab that currently performs the TCLP can perform the SPLT at comparable cost. For details on both the TCLP and SPLT methods, see SW-846 Test Methods for Evaluating Solid Waste, Volume 1C:Laboratory Manual Physical/Chemical Methods, Third Edition. For additional details on the TCLP method, refer to CFR 261 Appendix 11, or Federal Register, Volume 55, No. 61, Thursday, March 29, 1990, pp. 1179-11877.

Rather than compare the leaching test result to a drinking water standard, the test result is compared to a water quality standard multiplied by a dilution factor resulting from application of the AT123D model to the generic site conditions used for the Tier 2 organic soil remediation objectives. To determine the AT123D dilution factor, the SESOIL/AT123D models were run under steady-state conditions. This resulted in a steady concentration of contaminant entering the groundwater (the SESOIL output, which is also the AT123D input) and a steady concentration of contaminant at the down gradient well (the AT123D output). Comparison of the AT123D input concentration to the AT123D output concentration under these conditions shows how much "dilution" is predicted by the AT123D model. This test resulted in a dilution factor of 22 for the conservative Colorado site. See Attachment 1 for a discussion on the calculation of this dilution factor.

The Leachate Reference Concentration was developed as a test to assure that once soils were cleaned to a point where they no longer posed a significant threat to human health via direct contact, the residual contamination would not leach to groundwater and pose a risk by this exposure pathway. The Leachate Reference Concentration, a benchmark against which results of a leaching test are compared, is calculated by multiplying the above mentioned dilution factor (22) by an constituent-specific drinking water standard (Colorado groundwater standards, EPA's Maximum Contaminant Levels) or an equivalent health-based standard for those constituents with no established standard (MCL-equivalent methodology: see Attachment 2 for examples). The results of the leaching tests performed on soil obtained from the area of concern at the facility are compared to the Leachate Reference Concentration. If the leach test results are equal to or below the Leachate Reference Concentration, it is assumed that the soil will pose little to no threat to local groundwater quality. On the other hand, if the leach test results exceed the Leachate Reference Concentration, it is assumed that the soil, if allowed to remain in place, will leach hazardous substances to groundwater and potentially degrade the quality of that resource in excess of the allowable standard. The purpose of this exercise is to show that the post-cleanup residues will not release hazardous substances into the underlying aquifer at concentrations that will negatively impact groundwater quality. Under both Tier 2 and Tier 3, the "Leachate Reference Concentration" must not exceed the RCRA Characteristic of Toxicity regulatory limit.

This policy specifies that the TCLP or SPLT procedures be used to determine the leaching potential of the soils from the site. Use of alternate leaching tests may be proposed under Tier 4 of this policy. If the implementing party elects to use a leaching test other than the TCLP or the SPLT, it is the implementing party's responsibility to provide the Division with sufficient documentation and literature on its performance to enable the Division to evaluate the application of the leaching test.

Section 6.5.5 Upper Concentration Limits

The Division has accepted the fact that chronic risk modeling has limitations and is not always a guarantee of "safe" human or environmental exposure levels. Modeling efforts that evaluate chronic risks look at relatively low individual dosages over long periods of time. For example, in the direct soil ingestion scenario, only 100 to 200 mg of soil are assumed to be ingested daily. This sets a physical limit (200 mg of pure compound per day) on what exposure inputs can be made to this model. A child might only ingest 200 mg of pure compound and be safe under these assumptions. However, one-time exposures to many hazardous substances at high concentrations via mouth, skin, and eyes can cause immediate and severe acute effects, including death. To take the most obvious example, chronic soil ingestion at higher concentrations approaching pure compound, one could follow the traditional 200 mg/day of soil ingestion rate and be safe in the long-run, but be taken ill by direct skin absorption by placing one's hand in the same soil. An accidental splashing in the eye or rubbing with one's hand could cause burns or blindness. The unwritten assumption that the allowable medium levels based on chronic risk calculations are conservative and would protect against acute exposures may be true for carcinogenic compounds, which have chronic health impacts at much lower concentration levels, but not necessarily for non-carcinogens. It is the chronic risk model itself which can be called into question with high concentrations.

The fundamental problem is that the chronic risk modeling approach can result in the calculation of soil concentrations that are very high in an absolute sense. Soil concentrations back calculated using this approach can vary between zero and pure compound. Some back calculation medium concentrations may actually exceed the limits of a pure compound. A similar problem was encountered when attempting to generate Tier 2 soil remediation objectives that are protective of groundwater quality using computer models. In a few instances, the presence of free-phase contaminant in soil is required before the modeling would predict an exceedence of standards in groundwater immediately downgradient of the source area (e.g., xylene). Some test of reasonableness of these numbers is essential before they can be used.

The problem is that pure constituent concentration in a medium is not a safe or reasonable limit from an environmental protection standpoint. At some point on an absolute increasing concentration scale, exposures to these hazardous constituent concentrations become more severe on shorter time-scales. What happens is that the chronic exposure scenarios are over shadowed by others of shorter duration and greater immediate effect.

The acute health impacts can be very severe for certain compounds. At high concentrations a number are capable of causing death through inhalation, skin contact, or direct ingestion. For example parathion is particularly lethal, with even a single drop in the eye capable of causing death. Certain compounds can cause severe, even if temporary, effects of nausea, sickness, organ damage, skin and eye irritation. OSHA and industrial toxicological manuals clearly identify these more acute and transitory exposures, in the same concentration ranges as those found in some chronic risk assessment outputs in this policy.

At very high concentrations, the physical-chemical forms of compounds become important. Above certain concentrations (soil saturation limit), pure liquid-phase contaminant is expected in the soil. A fluid compound like xylene would act as a liquid. As such it could move through and change soil structures, act as a solvent and change the mobility and transport characteristics of other more toxic compounds, and display much greater volatility. At high enough concentrations, compounds with high vapor pressures could become explosive or flammable. The more volatile, acidic, basic, or reactive compounds might fail one or more of the RCRA characteristic tests. In confined situations, vapors could cause immediate breathing problems. Liquids in the free (unabsorbed) state could be much more dangerous via skin absorption. Chemicals in the free state might be more prone to further reaction with other compounds. At high concentrations, certain compounds can affect the integrity of both synthetic and clay liners, as well as natural confining layers which may inhibit the vertical migration of contaminants through the subsurface. Some soil concentrations calculated using the methods presented in this policy are the normal levels of industrial chemical compounds which are regulated under the U- and P- listings of RCRA, let alone the F- and K- lists.

For all these reasons, the Division believes that it is necessary to "cap" the chronic risk scenario and soil-to-groundwater modeling concentration outputs at some maximum level. Therefore under both Tier 2 and Tier 3, an upper concentration limit of 1000 mg/kg has been established as a soil remediation objective for certain organic hazardous substances. The Tier 2 direct exposure table values being replaced with the upper concentration limit may be found in Attachment 2 tables. The implementing party always has the option of calculating alternate upper concentration limits (e.g., soil saturation limits) under Tier 4 of this policy. The need for calculating soil remediation objectives that are protective of groundwater under both these tiers will undoubtedly reduce the prospects of actually allowing such individual high limits. Similarly, tests for RCRA characteristics will also catch some of higher concentrations that may be calculated.

Section 6.5.6 Format of the Tier 2 Table

Table 1 provides soil remediation objectives for a limited number of organic and inorganic compounds which can be compared to measured total contaminant concentrations in the soil at the site. Leachate concentrations are measured by performing a leaching test on representative soil samples from the site. The actual soil remediation objectives applied to a site would be the lowest concentration from amongst the direct exposure and soil-to-groundwater columns for each constituent, unless the method detection limit is higher, in which case the method detection limit may be used as the soil remediation objective (Tier 1 approach). For inorganic compounds, Table 1 provides acceptable leachate concentrations for each contaminant. If the leachate level results in a lower total concentration than any of the other pathways, then this method must be used to develop soil remediation objectives for that particular inorganic compound.

Section 6.6 Tier 3 - Site-Specific Adjustments to the Table Value Objectives

Tier 3 allows for consideration of site-specific information to modify the Tier 2 method of calculating soil remediation objectives or to calculate soil remediation objectives for hazardous substances not listed in Table 1. Allowing limited site-specific adjustments to the standardized parameters is intended to maximize the usefulness and flexibility of the soil remediation objectives selection process while maintaining a consistent methodology that ensures the protectiveness of remedial actions.

Attachment 2 of this policy contains all the intake equations and default exposure parameters that were used to calculate the Tier 2 table values. Similarly, Attachment 1 contains the SESOIL and AT123D model input parameters and chemical specific properties used to develop the Table 1 soil remediation objectives. Using the Division's Tier 2 methodology, the implementing party may either calculate alternate site-specific soil remediation objectives for constituents listed in the Tier 2 table, or it may calculate new soil objectives for constituents not listed in the table. The equations and basic methodology specified for calculating the Tier 2 table values may not be modified under Tier 3, although site-specific modifications can be made to both under Tier 4, if proposed by the implementing party and approved by the Division. Under Tier 4, the implementing party has the option of calculating soil remediation objectives for alternate land use scenarios using the same equations (but with different exposure assumptions) and methodology specified for calculating the Tier 2 table values.

The development of Tier 3 soil remediation objectives shall be based upon information which is scientifically justified and completely documented with site data collected from the facility. Any proposed changes to Tier 2 parameters shall be submitted to the program under which remediation is being performed for review and approval. At a minimum, Tier 3 soil remediation objectives development shall be documented with sufficient information to allow the reviewer to evaluate the following factors:

- a) The justification for the modification;
- b) The appropriateness and validity of any chemical-specific and/or site-specific input parameters used;
- c) The technical and mathematical basis for the modification, and;
- d) Whether the calculations were correctly performed and/or the site-specific data were properly collected.

As with the Tier 2 table values, Tier 3 soil remediation objectives do not include consideration of sensitive environments or protection of surface water. Objectives developed under this policy are only based on protection of human health from direct soil contact and soil-to-ground water pathways. Sites with special environmental protection concerns require additional evaluation to

ensure protectiveness and should be discussed with the program responsible for overseeing the environmental work performed at the facility.

Section 6.6.1 Exposure Table Value Adjustments

Tier 3 allows input of site-specific data into the standard risk equations where values other than default input parameters are appropriate. Contained within Attachment 2 of this policy are all the equations used to develop the direct exposure soil remediation objectives for each land use setting, along with the standard default risk and exposure assumptions made in calculating these values. As was discussed in the previous subsection, any changes made to the default input parameters must be justified and supported with documented site-specific information, all of which must be submitted to the Division for review and approval. The risk equations may not be modified or substituted under this tier.

The objectives for an acceptable risk level remains consistent with Tier 2 standards, i.e., total risk of 1×10^{-6} for carcinogens and a hazard quotient of one for non-carcinogens. However, due to site-specific conditions, the Tier 3 soil remediation objectives will likely be a higher concentration than the Tier 2 table value, which were developed using conservative generic default values. As with the Tier 2 soil remediation objectives, if multiple contaminant additivity or cumulative risk is a potential concern at a site, the impact of additivity and cumulative risk must be evaluated in accordance with the procedures contained within Section 6.5.2, and the soil standards potentially modified to ensure the protectiveness of the remedial action. Similarly, the upper concentration limit of 1000 mg/kg applies to chronic risk scenario and soil-to-groundwater modeling concentration outputs calculated for organic hazardous substances under this tier.

Section 6.6.2 Soil-to-Groundwater Protection Standard Adjustments

Under Tier 3, the implementing party may elect to modify the input parameters to the fate and transport models used, SESOIL and AT123D, to calculate soil remediation objectives that more accurately model conditions at their facility. By using site-specific data (permeability, porosity, soil organic carbon, hydraulic conductivity, bulk density, etc.), the implementing party may be able to demonstrate that an alternate soil remediation objective will be equally protective of groundwater quality. Similarly, the implementing party may also input an alternate water quality standard into the model, but only if groundwater underlying the facility has been classified by the State of Colorado as something other than domestic use quality or if natural ambient conditions warrant the use of an alternate site-specific standard. A complete list of model input parameters that may be modified under this tier is contained within Table 3 of Attachment 1.

Changing certain parameters, such as porosity, permeability, conductivity, and the soil disconnectedness index, may result in significant changes to the water balance in the model. As a consequence, the implementing party will be required to submit a justification and defend with site-specific data each adjustment to the standardized default parameters to the Division for review and approval. Division staff will review the proposed adjustments to determine whether the facility's model parameters are still valid.

Similar to Tier 2, use of the contaminant fate and transport models are expected to yield soil remediation objectives that should be protective of groundwater quality. Limited to no groundwater monitoring would be required for sites that have been remediated to the degree that residual constituent concentrations in soil are equal to or below the concentrations calculated using the Tier 3 approach, unless required to do so for other reasons (groundwater contamination, remedy evaluation, permit condition, etc.). Depending on site conditions and assumptions made in developing the alternate input parameters, the Division may require the implementing party to implement a groundwater program to verify that soil remediation objectives proposed under this tier are truly protective of groundwater quality following remedy implementation.

Section 6.7 Tier 4 - Site-Specific Risk Based Soil Remediation Objectives

Tier 4 sets forth a flexible framework to develop remediation objectives by allowing the implementing party to conduct a more detailed evaluation of site information in an effort to calculate safe, protective soil objectives unique to that site. A more sophisticated analysis may be performed that includes the use of complex chemical fate-and-transport models and probabilistic evaluations of possible exposures and risk. This assessment is comparable to those conducted at Superfund sites, complex sites where an implementing party believes that an alternate soil standard, calculated using site-specific data and a different methodology, may be equally protective of human health and the environment. Many other factors, besides threats to human health and groundwater quality, may be considered or may limit the application of soil remediation objectives calculated using this tier. It is anticipated this approach may be favored at sites where alternate standards allow a more cost effective remedy than simple application of Tier 1 through Tier 3 soil remediation objectives.

Situations that can be considered for a Tier 4 evaluation include, but are not limited to:

- 1) Modification of parameters not allowed under Tier 3 (e.g., a cumulative cancer risk other than 1×10^{-6} or a target hazard quotient greater than 1 is requested);
- 2) Use of models different from those used in Tier 2 and Tier 3;
- 3) Use of additional site data to improve or confirm predictions of exposed receptors to contaminants of concern;
- 4) Analysis of site-specific risks using formal risk assessment, probabilistic data analysis, and sophisticated fate and transport models;
- 5) Requests for site-specific remediation objectives because a "common sense" assessment indicates further remediation is not practical (e.g., the remaining contamination is under a structure such as a permanent building);
- 6) Incomplete human exposure pathway(s) not excluded under Tiers 1 and 2;

- 7) Use of toxicological-specific information not available from sources relied upon by the Division in the development of this policy;
- 8) Land uses which are substantially different from the assumed residential, industrial or commercial property uses of a site (e.g., a site will be used for recreation in the future, a land use scenario not addressed in Tiers 1 or 2).
- 9) Calculating soil remediation objectives that are protective of surface water and sensitive environments.
- 10) Incorporation of biological attenuation processes on chemical mass, mobility, and toxicity over time to calculate groundwater protection values.

The Tier 4 evaluation is potentially complex and will likely also include a more detailed site assessment. A Tier 4 risk assessment may include a wide range of modeling approaches, such as sophisticated chemical fate and transport models, and probabilistic evaluations of risk. The implementing party may propose the use of other models they can validate as being appropriate. A justification for the alternate model selected must be submitted to the Division for review and approval, prior to its use (see Attachment 5 for acceptance guidelines for alternate models). Tier 4 may require additional investigative efforts beyond those described in the lower tiers to define the physical characteristics of the site. However, in situations where remedial efforts have simply reached a physical obstruction (e.g., a building), additional investigation may not always be necessary for a Tier 4 submittal.

Tier 4 allows flexibility in the risk algorithms adopted and allows use of site-specific parameters to assess risk. Tier 4 risk assessments should be based on standard EPA risk assessment methodology, as described in the "Risk Assessment Guidance for Superfund, Volume 1, Human Health Manual" (EPA/540/1-89/002, December 1989). Departures from standard reasonable maximum exposure assumptions must be discussed and justified in the risk assessment. Total site-wide risk must be quantified by the user and presented to the Division in a standard risk summary.

Proposed soil remediation objectives developed under this tier may consider the use of institutional and engineering controls (deed restrictions, restrictive zoning, fencing, capping, other barriers or containment systems) to achieve risk reduction.

As is required under Tier 3, soil remediation objectives developed using the Tier 4 approach shall be based upon information which is scientifically justified, completely supported with site data collected from the facility, and supported with appropriate documentation. At a minimum, Tier 4 soil remediation objectives development shall be documented with sufficient information to allow the Division reviewer to evaluate the following factors:

- a) The justification for the modification or new approach taken;

- b) The appropriateness and validity of any chemical-specific and/or site-specific input parameters used;
- c) The technical and mathematical basis for the modification or new approach taken, and;
- d) Whether the calculations were correctly performed and/or the site-specific data were properly collected.

The proposed Tier 4 soil remediation objectives and all supporting documentation shall be submitted to the program under which remediation is being performed for review and approval. When reviewing a submittal under Tier 4, the Division shall consider whether the interpretations and conclusions reached are supported by the information gathered. The Division shall approve a Tier 4 evaluation if the implementing party submits the necessary supporting documentation and establishes through such information that public health is protected and that specified risks to human health and the environment have been minimized or eliminated. In the event that an alternate risk assessment and/or contaminant fate and transport model is chosen, the implementing party will have to agree to a longer review time and pay for its review by outside consultants if the Division does not have the expertise in the proposed model.

Section 7.0 References

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ATTACHMENT 1

THE DEVELOPMENT OF SOIL REMEDIAL OBJECTIVES PROTECTIVE OF GROUNDWATER QUALITY

ORGANIC REMEDIAL OBJECTIVES

Introduction

Soil remedial objectives protective of groundwater can be generated using many different methods, each with its own advantages and disadvantages. These approaches range from fairly simple methods, such as a dilution-attenuation factor, to a mathematical approach, requiring a significant amount of site-specific data. The State of Colorado has endeavored to use a method somewhere between the simplistic and complex approaches in order to derive remedial objectives protective of groundwater resources in the state that are not overly conservative. The approach chosen to derive remedial objectives for organic constituents closely approximates real interactions between soil, water and vapor phases by using a computer-based model. This attachment discusses the technical basis for the soil remedial objectives derived to protect groundwater resources.

Environmental contaminants have widely varying physical and chemical properties. They can be divided into two broad categories, organics and inorganics (which include metals). Transport of organic contaminants in the environment is controlled by:

- solubility in water,
- vapor pressure,
- sorption to soil materials,
- biodegradation, and
- other possible site specific chemical interactions.

Soil properties which influence organic contaminant transport are:

- moisture content and
- organic carbon content.

The transport of inorganics is dependent upon the complex interaction of:

- pH,
- redox potential,
- cation exchange capacity and
- natural background concentration in soil.

The model or model combinations chosen for this exercise needed to simulate the vertical movement of contaminants from unsaturated soils to the water table, as well as transport of the contaminants through groundwater. The chemical behaviors modeled include partitioning between air, water and soil phases, volatilization and diffusion. Biodegradation and decay rates vary and tend to be site-specific, therefore, biodegradation and decay were not used. The

remedial objectives determined to be protective of groundwater were derived assuming that the organic contaminant was partitioned between air, water and soil phases, and that no separate phase or free phase organics were present. Therefore, the remedial objectives for organic contamination are only applicable if no separate phase organics are present.

Several computer models were initially evaluated for use, including: MULTIMED, Summers, SESOIL/AT123D, VLEACH, CHEMFLOW, PRZM and PESTAN. After a preliminary review of the models and their different computational algorithms, the combination of SESOIL and AT123D was chosen for further analysis. A review of the methods employed by other states to produce similar standards was also conducted. Several states have used the SESOIL model, including Oregon, Rhode Island, Wisconsin and Massachusetts. The approach chosen for use in Colorado closely follows that used by Oregon.

The process used in Colorado involved the derivation of a conceptual model based on a hypothetical "Typical Colorado Site" that was then used to simulate the transport of contaminants through the vadose zone to the water table, and then through a typical aquifer. The model was used to determine an initial soil concentration above which the applicable groundwater standard would be exceeded. This approach is proposed for use at sites that are relatively small, in a fairly simple hydrogeologic setting. Characteristics for this hypothetical site represent the most common characteristics encountered at sites in Colorado where groundwater contamination is likely to occur, i.e., sites with fairly shallow depth to groundwater, groundwater occurring in an unconsolidated formation, and relatively homogeneous soils. The conceptual model is a combination of the site-specific characteristics for this hypothetical site and the physical setting of the site (physical setting includes: distance to a down-gradient point-of-compliance well, size/shape of the contaminated soil mass, depth of the contaminant etc.) The derivation of the conceptual model and the soil and aquifer characteristics for the hypothetical site are discussed in this attachment.

SESOIL/AT123D Models

SESOIL is an acronym for Seasonal Soil Compartment Model. The model is a one-dimensional vertical transport code for the unsaturated zone. The model is designed to simultaneously model water transport, sediment transport, and pollutant fate. The model was developed for EPA's Office of Water and the Office of Toxic Substances in 1981 by Arthur D. Little, Inc. The model was subsequently modified and has since been incorporated into the RISKPRO package which includes a link to the groundwater flow and transport code AT123D.

SESOIL was developed as a screening-level model, utilizing less soil, chemical and meteorological data than other more complex models, which makes it particularly well-suited for application to a hypothetical site. The model uses actual climate data from Denver, Colorado in the hydrological cycle predictions, rather than a constant infiltration rate which is common in other similar models. The model output includes time-varying contaminant concentrations at different soil depths and removal of the contaminant from the soil column by surface runoff, percolation to groundwater, volatilization and degradation. The soil remedial objectives developed herein are anticipated for use on sites that no longer have a continuous contaminant

source. Although the SESOIL model has 3 different methods to simulate the application of contaminant to the soil column, use of an initial soil concentration was determined to be the most appropriate approach for this exercise.

The concentration in leachate, derived from the SESOIL model, was used as input to the saturated zone model to compute a resulting concentration in groundwater beneath the site. The model AT123D (Analytical Transient 1-,2-, 3-dimensional) was used to predict resulting groundwater concentrations. AT123D is an analytical groundwater transport model that computes the spatial-temporal concentration distribution of a contaminant in the aquifer and predicts the transient spread of a contaminant plume through an aquifer, using advection, dispersion, adsorption and decay. Due to uncertainty in decay constants, only advection, dispersion and adsorption were utilized. As shown in Figure 1, the "Point of Compliance" for the modeling simulations was chosen to be 10 meters downgradient from the edge of the contaminated soil.

Model Input Parameters for "Typical Colorado Site"

The SESOIL/AT123D models require input for various soil characteristics, including: the depth to the water table (or thickness of the unsaturated zone), the bulk density of the soil, effective porosity, soil organic carbon content, hydraulic conductivity of both the vadose and saturated zones, hydraulic gradient of the saturated zone and 3-dimensional dispersivity.

The model input parameters for the "Typical Colorado Site" were selected by reviewing available data for 9 sites located along the Colorado Front Range. Sites were chosen based on the availability of applicable data and their hydrogeologic setting. In general, sites were chosen which focused on unconsolidated deposits, as these sites are more vulnerable to groundwater contamination than those with groundwater and/or contamination occurring in bedrock formations. The sites chosen for evaluation were:

- Rocky Flats,
- Rocky Mountain Arsenal,
- Lowry Air Force Base,
- AAD Disposal,
- Koppers Industries, Inc.,
- Colorado Crystal (Loveland),
- Colorado Department of Transportation Headquarters,
- Chemical Sales Company, and
- Conoco/Total Refineries.

All pertinent data from unconsolidated deposits at each site were compiled and the quality/reliability of the data were evaluated. A statistical analysis was conducted and a representative value for each soil characteristics was selected. The data and analysis are contained in the separate document titled "Evaluation of Soil Characteristics Along Colorado's Front Range For Use in Developing Cleanup Standards Protective of Groundwater". The document is available for public review in the CDPHE records center. The recommended values for the Typical Colorado Site are given in Table 1.

Table 1
Model Input Parameters for the "Typical Colorado Site"

Property	Value
Soil Type	Sandy Clay Loam
Intrinsic Permeability (unsaturated zone)	$4 \times 10^{-9} \text{ cm}^2$
Soil Disconnectedness Index (C)	7.5
Bulk Density	1.58 g/cm^3
Effective Porosity	0.25
Fraction Organic Content	0.0014
Volatilization Factor	0.15
Moisture Content	0.10
Depth to top of Contamination	1 meter
Thickness of Contamination	1 meter
Distance Between Bottom of Contamination and Top of Water Table	1 meter
Areal Extent of Contamination	$10 \times 10 \text{ meters} = 100 \text{ meters}^2$
Aquifer Thickness	2.1 meters
Aquifer Hydraulic Conductivity	$3.6 \times 10^{-3} \text{ cm/sec}$
Aquifer Hydraulic Gradient	0.008
Longitudinal Dispersivity	12 meters
Lateral and Vertical Dispersivity	2 meters
Distance from Edge of Waste to Monitoring Well, "Point of Compliance"	10 meters

Conceptual Model

As mentioned previously, the Conceptual Model is really a combination of the characteristics of the "Typical Colorado Site" and the physical setting of the site. Given the determination of the parameters for the Typical Colorado Site, the conceptual model shown in Figure 1 was developed. Several aspects of the Conceptual Model were further investigated during the Sensitivity Analysis which is discussed later in this document.

Chemical Properties

Chemical properties are cited in numerous literature publications, however, the values vary over a large range. Due to the wide variation of these parameters in the literature, the values recommended by EPA in the final Soil Screening Guidance (EPA, 1996), as shown in Table 2 were chosen. Biodegradation and decay were not used, as these rates vary and tend to be site-specific.

Table 2
Chemical-Specific Properties used to Develop Soil Standards

Compound	Organic Carbon Partition Coefficient (K _{oc}) (L/kg)	Diffusion Coefficient in Air (D _{i,a}) (cm ² /sec)	Water Solubility (mg/l)	Henry's Law Constant @ 25• C (H') (dimensionless)	Henry's Law Constant @ 25• C (H) (atm-M ³ /mol)
Benzene	59	0.0880	1,750	0.2280	0.00556
Carbon Tetrachloride	174	0.0780	793	1.2500	0.0305
1,1-Dichloroethane	31.6	0.0742	5,060	0.2300	0.00561
1,1-Dichloroethylene	59	0.0900	2,250	1.0700	0.0261
Dieldrin	21,400	0.0125	0.195	0.000619	0.0000151
DDT	2,630,000	0.0137	0.025	0.000332	0.0000081
Ethylbenzene	363	0.0750	169	0.3230	0.00788
Naphthalene	2,000	0.0590	31	0.0198	0.000483
Pentachlorophenol	592	0.0560	1,950	0.000001	0.000000244
Phenol	28.8	0.0820	82,800	0.0000163	0.000000398
Tetrachloroethylene	155	0.0720	200	0.7540	0.0184
1,1,1-Trichloroethane	110	0.0780	1,330	0.7050	0.0172
Trichloroethylene	166	0.0790	1,100	0.4220	0.0103
Toluene	182	0.0870	526	0.2720	0.0066
Vinyl Chloride	19	0.1060	2,760	1.1100	0.0271
Xylene	368	0.0800	175	0.2760	0.00673

(U.S. EPA, 1996)

Model Calibration

The most important step in using the SESOIL model is to calibrate the model using an appropriate water balance for the site. The model requires the user to input a value for intrinsic permeability, k , soil disconnectedness index, C , and effective porosity, n_e . The model was calibrated by varying the values of k , C and n_e , until a realistic water balance was achieved, and the moisture content of the "Typical Colorado Site" of approximately 10% was matched. Intrinsic permeability can be determined by multiplying hydraulic conductivity in cm/sec times a conversion factor of 10^{-5} cm-sec. Using an initial, estimated hydraulic conductivity for the unsaturated zone of 4×10^{-3} cm/sec, the resulting intrinsic permeability is 4×10^{-8} cm².

The SESOIL manual suggests n_e in the range of 0.24 to 0.30 for a sandy clay loam. The a stable water balance was achieved using::

$$k = 4 \times 10^{-9} \text{ cm}^2$$

$$C = 7.5$$

$$n_e = 0.25.$$

These values closely correspond to the recommendations in the SESOIL manual, and produce a valid water balance for the "Typical Colorado Site".

SESOIL/AT123D Sensitivity Analysis

After the water balance was calibrated, the next phase of the project was to conduct a sensitivity analysis in order to help guide decisions regarding the conceptual model for the final determination of soil standards protective of groundwater. The following parts of the conceptual model were investigated during this phase:

- Location of the contaminant in the vertical profile
- Size of the contaminated soil zone
- Volatilization factor

Location of the contaminant in the vertical profile

The sensitivity analysis evaluated differences in results if contaminated soil was placed in the upper, middle or lower soil zones. Each zone was assumed to be 1 meter thick. Placing the contaminant lower in the soil profile resulted in higher concentrations of contaminants reaching the water table, as volatilization decreased and the distance to the water table was also decreased. The largest difference occurred between the upper and middle layers, while less of a difference was found between the middle and lower layers. It was determined that placing the contaminant lower in the profile, more closely represents the majority of sites that will be using the soil standards for guidance. However, in an effort to avoid being overly conservative, the soil standards were derived using modeling scenarios where the contamination is located in the middle of the soil profile, beneath a layer of clean soil, with a 1-meter thick layer of initially clean soil between the contaminant and the water table.

Size of the contaminated soil zone

Because SESOIL is a compartmental model, it is not sensitive to changes in the areal extent of the contaminated soil zone. However, when the results are input into AT123D, the larger the areal extent of contamination, the higher the resulting groundwater concentrations. A sensitivity analysis was conducted using several different areal extents of contamination. The sensitivity analysis showed that the resulting soil remedial objective is highly sensitive to the areal extent of contamination. The larger the areal extent, the lower the remedial objective for cleanup. Since the guidance is to apply to small, simple sites, it was determined that an area of contamination approximately 10 meters on a side or 100 square meters would fairly represent the type of site expected to use the guidance document. If the areal extent of contamination at a site exceeds 100 square meters, site specific standards should be determined, and the guidance document values do not apply.

Volatilization Factor

Volatilization increases in drier soils. Given Colorado's semi-arid climate, the SESOIL model is extremely sensitive to changes in the input parameters relating to volatilization. The model allows volatilization from the top soil layer, and diffusion upwards from the lower layers, at differing rates from 0 to 1, with 0 corresponding to no volatilization, and 1 corresponding to 100% volatilization. Since it was decided that volatilization should be accounted for in the model, a value of 0 was not used. Since the model assumes a constant moisture content profile for each month, it does not account for natural variations in moisture content with depth and over time. The State of Oregon used a volatilization factor of 0.2 in all layers. This was based on a comparison of the Oregon SESOIL results against the results of another model (Anderson, 1992).

There is some disagreement among soil scientists as to the proper exponent to use on the Millington equation, which is the equation governing volatilization in the model. In SESOIL, an exponent of $10/3$ is used, while some other models, for example, VLEACH, uses an exponent of $7/3$. The net result is a higher predicted mass lost to volatilization from the SESOIL model.

In order to more accurately determine how much difference occurs between the computations using different algorithms calibrated for a Colorado site, the SESOIL results were compared against VLEACH. Using the same input parameters for each model, it was found that for compounds with a Henry's Law constant greater than 0.36, (the more volatile compounds) SESOIL over predicts volatilization when compared to VLEACH. In order to match the VLEACH results, the value for the volatilization fraction in SESOIL was set at 0.15 for these more volatile compounds. For compounds with Henry's Law Constants less than 0.36, the value used for the volatilization fraction in SESOIL does not significantly impact results. Developing a specific volatilization fraction for each compound with a different Henry's Law Constant was unreasonable, as it was solely dependent upon the site-specific parameters being used in the two models, and the model algorithms themselves. Therefore, a value of 0.15 or 15% volatilization for all chemicals was used as it lead to fairly good agreement between the two models, only impacted the more volatile compounds, and was supported by the State of Oregon's similar methodology.

Model Execution

The actual model runs determining the soil remedial objectives protective of groundwater were conducted for each chemical using the input parameters shown in Tables 1 and 2, and the conceptual model shown in Figure 1. Specific examples of SESOIL and AT123D input and output files are included in Appendix A. For each contaminant, the model was run for a sufficient period of time to ensure that the maximum concentration at the monitoring well occurred. The maximum concentration at the monitoring well was compared to the groundwater standard, and the initial soil concentration was adjusted until the model prediction at the monitoring well matched the groundwater standard.

Comparison of Colorado Standards to Other States

Once soil concentrations that would be protective of groundwater for a typical Colorado site were determined, those standards were compared against the values derived by the States of Oregon and Rhode Island. Differences in the standards were expected based on the differing climates, soil characteristics and chemical properties used by those states. However, wide variations were not expected between the values, as essentially the same conceptual model and overall methodologies were applied by all three states. This comparison revealed that for 1,1-Dichloroethylene, Pentachlorophenol and 1,1,1-Trichloroethane the difference was attributed to the use of substantially different chemical properties. The other remaining chemicals for which wide variations occurred in the standards were Carbon Tetrachloride, Tetrachloroethylene, Trichloroethane and Vinyl Chloride -- the most volatile compounds for which standards were derived. An investigation was conducted which determined that these differences were largely due to the different climates and not the different soil properties used in the simulations. Both Oregon and Rhode Island receive substantially more precipitation than Colorado, consequently, the amount of leaching that is predicted by SESOIL is much greater. Since leaching was minimal in the Colorado model due to lack of moisture, more contaminant mass was available for volatilization. Thus, the SESOIL model predicts a much higher loss to volatilization in Colorado than Oregon or Rhode Island, which in turn results in less mass transport to groundwater and consequently, higher soil standards for a site in Colorado.

Deriving Site Specific Remedial Objectives for Organic Constituents

The remedial objectives for organic constituents protective of groundwater quality were derived based upon modeling which used the input parameters for a "Typical Colorado Site", Table 1, and the chemical specific properties in Table 2. A facility may desire to develop remedial objectives based upon model input parameters which are more specific to their site. In this case, the Division will evaluate site specific SESOIL/AT123D modeling and remedial objectives but a limited number of the "Typical Colorado Site" input parameters may be altered. The following table lists the input parameters which can be changed in the SESOIL/AT123D modeling to develop site specific remedial objectives for organic constituents which are protective of groundwater. Sufficient documentation must be submitted to the Division to justify changing the input parameters. A Facility can not simply choose to alter a few of the parameters in Table 3. If the input parameters are to be changed from the Typical Colorado Site, all of the parameters in Table 3 must be evaluated and changed accordingly on a site specific basis. None of the chemical properties listed in Table 2 may be altered. For chemicals not listed in Table 2, a facility may propose chemical properties to the Division for review and approval.

Table 3
Model Input Parameters for the "Typical Colorado Site" Which Can be Altered to Develop Site
Specific Remedial Objectives Protective of Groundwater

Model Input Parameters
Fraction Organic Content
Depth to Top of Contamination (Must be 1 meter or more)
Thickness of Contamination
Distance Between Bottom of Contamination and Top of Water Table
Areal Extent of Contamination
Aquifer Thickness
Aquifer Hydraulic Conductivity
Aquifer Hydraulic Gradient
Distance from Edge of Waste to Monitoring Well, "Point of Compliance" (Must be 10 meters or less)

INORGANIC REMEDIAL OBJECTIVES

Introduction

Following the development of soil remedial objectives for organic constituents, the Division began to evaluate the development of objectives for inorganic constituents. The fate and transport of inorganic constituents in the environment is controlled by complex chemical interactions, both in the soil column and the underlying aquifer. These complex interactions make modeling the fate and transport of inorganic constituents highly site specific, relative to modeling the fate and transport of organic constituents.

It was decided that the inorganic remedial objectives would be developed using the same modeling software (SESOIL/AT123D) and site conceptual model (Figure 1) that were used to develop organic remedial objectives. In order to develop remedial objectives that would be protective of all types of inorganically contaminated environments, a conservative approach had to be taken in that the adsorption and transformation of inorganic constituents were not considered during the modeling. By negating the effects of adsorption and transformation, SESOIL and AT123D simply simulate the flushing and dilution of an "inert constituent", through the vadose zone, to the monitoring well. It was decided that the contaminant concentration in the leachate at the bottom of the vadose zone would be divided by the contaminant concentration at the monitoring well, resulting in a "dilution factor" that could be used to calculate inorganic soil remedial objectives.

Conceptual Model

The conceptual model of the contaminated soil column and adjacent monitoring well used for the organic modeling, was identical to that used for the inorganic modeling (Figure 1) with the exception of how the contaminant was input. In the organic conceptual model, the contaminant was present in the middle layer of the vadose zone at an initial concentration. In the inorganic conceptual model, the vadose zone was continuously loaded in the middle layer with contaminant to evaluate the flushing and dilution from the vadose zone to the monitoring well.

Chemical Properties

In the inorganic modeling, the only chemical property inputs used were solubility and molecular weight. By setting all other chemical properties to zero, the model would not allow the constituent to adsorb to soil or diffuse to soil air. Therefore all of the contaminant mass input to the column was partitioned to the water phase.

Model Execution

Several modeling runs were made to evaluate the sensitivity of the model using the inorganic modeling parameters. As expected, varying the amount of contaminant continuously input to the vadose zone, did not change the modeled dilution factor. But it was discovered that the leachate concentration at the bottom of the vadose zone depended heavily upon the amount of precipitation passing through the vadose zone.

When the rate of contaminant mass input to the vadose zone was held constant, and the amount of precipitation was increased, the concentration of the leachate at the bottom of the vadose zone decreased due to dilution. Increasing the amount of precipitation did not have any effect on the contaminant concentration at the monitoring well, because the same amount of mass was being loaded to the aquifer, regardless of the amount of precipitation. This relationship between precipitation and leachate concentration, caused variation in the dilution factor. Therefore, the amount of precipitation and all other climatic input parameters were modeled, fixed at the wettest month of the year for the Denver metro area which is May. By fixing the precipitation at its maximum, the ratio of leachate/monitoring well concentrations was minimized at 22. Therefore, the inorganic remedial objectives were calculated by multiplying the groundwater standard for an inorganic constituent by 22 to obtain the remedial objective for that constituent in soil.

Deriving Site Specific Remedial Objectives for Inorganic Constituents

Due to the complex nature of the fate and transport of inorganic constituents in the environment, the Division could not develop a simple approach to altering the inorganic remedial objectives on a site specific basis. If a facility does not agree with using the dilution factor of 22 to obtain remedial objectives for inorganics, other proposals will have to be reviewed by the Division on a site specific basis.

References

Anderson, Michael R., Oregon Department of Environmental Quality, Development of Generic Soil Cleanup Levels Based on Analysis of the Leachate Pathway, May 12, 1992.

U.S. Environmental Protection Agency, Soil Screening Guidance User's Guide, Office of Solid Waste and Emergency Response, EPA/540/R-96/018, April, 1996.

ATTACHMENT 2

DIRECT EXPOSURE RISK ASSESSMENT METHODOLOGY

Human Health Tier II Look Up Table

Note: The Tier II look up table is not applicable if the following exposure pathways are affected by soil contamination:

1. ingestion of surface water
2. ingestion of groundwater
3. ingestion of sediments
4. ingestion via the food chain
5. sensitive environments or other ecological concerns

If any of the above pertain to a given site, another tier must be considered to attain remediation objectives.

This look up table should only be used if all of the following exposure pathways are complete:

1. direct ingestion of soil
2. inhalation of either particulates or volatile organic compounds from subsoil or groundwater
3. dermal contact with soil

If these pathways are not complete at a given site, this look up table will provide an overly conservative soil clean-up value. Therefore, when all three pathways are not complete, this look up table may not be appropriate and should not be referenced. If the site is covered at least partially by cement, blacktop, or vegetation, this table may also not be appropriate.

Below is a description of physical constants and values used, exposure factors used, and equations used for risk based concentrations (RBCs) protective of human health. Colorado-specific numbers that differ from standard EPA default values are italicized. Physical constants and chemical properties were found in the Soil Screening Guidance: User's Guide (EPA/540/R-96/018) unless otherwise noted.

The RBCs are compared with the groundwater modeling values of the same constituent. The most conservative value is considered the Soil Remediation Objective (SRO).

Physical Constants

Chemical Name

CAS No.

Henry's Law constant (unitless) - chemical specific

Henry's Law constant (atm m³/mole) - chemical specific

Molecular weight (g/mole) - chemical specific

Volatile or Particulate - determined by the following guideline: if Henry's Law > 10⁻⁵ atm m³/mole and the molecular weight < 200 g/mole, the contaminant is considered "volatile"

Koc (L/kg) - chemical specific soil organic carbon - water partition coefficient

Diffusivity in air (cm²/sec @ 25° C) - chemical specific

Diffusivity in water (cm²/sec @ 25° C) - chemical specific

Da (cm²/s) - apparent diffusivity needed to calculate volatilization factor

$$Da = \frac{[(\bullet_a^{10/3} Di H' + \bullet_w^{10/3} Dw)]}{\bullet_b K_d + \bullet_w + \bullet_a H'}$$

where:

\bullet_a (L_{air}/L_{soil}) - air filled soil porosity ($n \bullet_w$)

n (L_{pore}/L_{soil}) - total soil porosity ($1 - \bullet_b / \bullet_s$)

\bullet_w (L_{pore}/L_{soil}) - water filled porosity (default 0.15)

\bullet_s (g/cm³) - soil particle density (default 2.65)

Di (cm²/sec) - diffusivity in air

H' (unitless) - Henry's Law constant

Dw (cm²/sec) - diffusivity in water

Kd (cm³/g) - soil-water partition coefficient = (Koc)(foc)

Koc (cm³/g) - soil organic carbon partition coefficient

foc - fraction organic carbon in soil (default 0.006 g/g)

All default values were those used in the EPA Soil Screening Guidance document (1996).

VF (m³/kg) - a volatilization factor which defines the relationship between the concentration of the contaminant in soil and the flux of the volatilized contaminant to air (Soil Screening Guidance: User's Guide, EPA/540/R-96/018). This is a chemical-specific factor calculated only for those chemicals which meet the definition of a VOC (i.e., molecular weight < 200 g/mole and Henry's Law constant > 10⁻⁵ atm m³/mole).

$$VF = \frac{Q/C \times (3.14 \times Da \times T)^{1/2} \times 10^{-4} \text{ (m}^2/\text{cm}^2)}{(2 \times Da \times \bullet_b)}$$

where:

Q/C ($\text{g/m}^2\text{-s}$ per kg/m^3) - inverse of the mean concentration at the center of a .5 acre square source.
Colorado default is $75.59 \text{ g/m}^2\text{-s per kg/m}^3$. This value differs from national EPA default values.

Da (cm^2/sec) - apparent diffusivity

T (sec) - exposure interval (default 9.5×10^8)

ρ_b (g/cm^3) - dry soil bulk density (default 1.5)

PEF(m^3/kg) - a particulate emission factor which relates the concentration of contaminant in soil to the concentration of dust particles in air. It represents an annual average emission rate based on wind erosion that should be compared with chronic health criteria. **The Denver default is $1.10 \times 10^9 \text{ m}^3/\text{kg}$** which differs from the national EPA default and is based on the PEF calculation (equation 5) in the EPA Soil Screening Guidance: User's Guide, (EPA/540/R-96/018) using Denver-specific Q/C in Exhibit 11 of that document (**Colorado-specific Q/C = 75.59**).

Toxicity Factors

SFo (Risk/mg/ kg day) - chemical specific cancer slope factors (oral)

SFi (Risk /mg/ kg day) - chemical specific cancer slope factors (inhalation)

oral RfD (mg/kg day) - chemical specific oral reference dose

oral dermal absorption factor (unitless) - chemical specific lower and upper bounds

adj oral RfD for dermal (mg/kg day) - dermal reference dose calculated from the oral reference dose

adj oral RfD for dermal = (oral RfD) X (upper bound oral-dermal absorption factor)

adj oral SFd (Risk/mg/kg day) - dermal cancer slope factor calculated from the oral cancer slope factor

adj oral SFd = (SFo) X (upper bound oral-dermal absorption factor)

inh. RfC (mg/m^3) - inhalation reference concentration - chemical specific

adjusted inh. RfC (mg/kg day) - converts inhalation RfC, which is expressed as an air concentration (mg/m^3) in EPA's IRIS, into a dose

(inh RfC) X (Inhalation Rate_{adult}) / (Body Weight_{adult})

Note: No route to route extrapolation was done if oral but not inhalation toxicity values for specific chemicals were available.

General Equations for Calculating Cumulative Risk Based Concentrations (RBC cum)

Noncarcinogenic

assumes complete pathways: soil ingestion, inhalation of particulates, and dermal contact

$$RBC_{cum}] \cdot \frac{THI \times AT \times BW}{\left[(EF \times ED \times \frac{1}{RfDo} \times cf \times INR) \cdot (EF \times ED \times \frac{1}{RfDd} \times cf \times ABS \times SA \times ADF) \cdot (EF \times ED \times \frac{1}{RfDi} \times IR \times \frac{1}{PEF} \times ET) \right]}$$

assumes complete pathways: soil ingestion, inhalation of volatiles, and dermal contact

$$RBC_{cum}] \cdot \frac{THI \times AT \times BW}{\left[(EF \times ED \times \frac{1}{RfDo} \times cf \times INR) \cdot (EF \times ED \times \frac{1}{RfDd} \times cf \times ABS \times SA \times ADF) \cdot (EF \times ED \times \frac{1}{RfDi} \times IR \times \frac{1}{VF} \times ET) \right]}$$

Carcinogenic

assumes complete pathways: soil ingestion, inhalation of particulates, and dermal contact

$$RBC_{cum}] \cdot \frac{TR \times AT \times BW}{\left[(EF \times ED \times SFo \times cf \times INR) \cdot (EF \times ED \times SFd \times cf \times ABS \times SA \times ADF) \cdot (EF \times ED \times SFi \times IR \times \frac{1}{PEF} \times ET) \right]}$$

assumes complete pathways: soil ingestion, inhalation of volatiles, and dermal contact

$$[RBC_{cum}] \cdot \frac{TR \times AT \times BW}{\left[(EF \times ED \times SFo \times cf \times INR) \cdot (EF \times ED \times SFd \times cf \times ABS \times SA \times ADF) \cdot (EF \times ED \times SFi \times IR \times \frac{1}{VF} \times ET) \right]}$$

where:

THI	= target hazard index (unitless)
TR	= target risk (unitless)
AT	= averaging time (days)
BW	= body weight (kilograms)
EF	= exposure frequency (days/year)

ED	= exposure duration (years)
RfDo	= oral reference dose (mg/kg-day)
RfDd	= calculated dermal reference dose (mg/kg-day)
RfDi	= inhalation reference dose (mg/kg-day)
cf	= conversion factor (10^{-6} kg/mg)
INR	= ingestion rate (mg/day)
ABS	= absorption factor (unitless)
SA	= surface area (cm ²)
ADF	= soil to skin adherence factor (mg/cm ² -day)
IR	= inhalation rate (m ³ /hr)
PEF	= particulate emission factor (m ³ /kg)
ET	= exposure time (hours/day)
VF	= volatilization factor (m ³ /kg)
SFo	= oral cancer slope factor (risk/mg/kg-day)
SFi	= inhalation cancer slope factor (risk/mg/kg-day)
SFd	= calculated dermal cancer slope factor (risk/mg/kg-day)

Residential Calculations: Children have a special sensitivity to environmental hazards: pound for pound, they ingest more food, water, and air than adults, giving them a proportionately greater dose of contaminants. They have a higher absolute exposure as a result of their behavior (playing on hands and knees, sucking on hand or thumb, etc.). They also pass through numerous critical periods of growth, during which they are especially vulnerable. Consequently, the noncarcinogenic equations were calculated by assuming a conservative child exposure scenario. Exposure factors for body weight (BW), exposure duration (ED), and contact rates that reflect child exposure were used to result in a more protective risk based RBC compared to an adult-only assumption. The child exposure scenario should be used for most noncarcinogens with the exception of those that can produce long-term toxicity such as cadmium. Chemicals which can produce long-term toxicity should be assessed using age-average exposure factors.

It should also be noted that cadmium was not calculated in the same fashion as other contaminants. The oral RfD for cadmium was derived from an absorbed dose. Therefore, no gastrointestinal absorption factor was used in the risk calculations. In the residential scenario, the cadmium calculation also reflects its known cumulative toxicity (age averaging was applied) and its rate of uptake in plants.

The residential carcinogenic equations were age averaged to assume possible lifetime exposure from a given area. This is done because of the long latency which some chemicals have in producing cancer. When assessing the age averaged cumulative carcinogenic RBCs for the residential scenarios, exposure time (ET), body weight (BW), and exposure duration (ED) are dropped from the equations as the age averaged exposure factors (ingestion, inhalation, and surface area) have already been accounted for in these variables:

Age Averaged Ingestion Factor

$$INR_{ageav} \cdot \frac{(24 \text{ years})(100 \text{ mg soil ingested})}{(70 \text{ kg})} \cdot \frac{(6 \text{ years})(200 \text{ mg soil ingested})}{(15 \text{ kg})} \cdot 114 \frac{\text{mg} \cdot \text{year}}{\text{kg} \cdot \text{day}}$$

Age Averaged Inhalation Factor

$$IR_{ageav} \cdot \frac{(24 \text{ years})(20 \text{ m}^3/\text{day air inhaled})}{(70 \text{ kg})} \cdot \frac{(6 \text{ years})(10 \text{ m}^3/\text{day air inhaled})}{(15 \text{ kg})} \cdot 10.85 \frac{\text{m}^3 \cdot \text{year}}{\text{kg} \cdot \text{day}}$$

Age Averaged Surface Area Factor (resulting from outdoor exposure)

$$SA_{ageav} \cdot \frac{(24 \text{ years})(7100 \text{ cm}^2 \text{ body area})}{(70 \text{ kg})} \cdot \frac{(6 \text{ years})(4600 \text{ cm}^2 \text{ body area})}{(15 \text{ kg})} \cdot 4274 \frac{\text{cm}^2 \cdot \text{year}}{\text{kg}}$$

* Surface Areas are based on indoor exposures. The assumption was made that indoor dust is equal to outdoor dust. Child dermal exposure includes head, hands, arms, legs, and feet. Dermal exposure for adults was assumed to include head, hands, arms, and legs (EPA Exposure Factors Handbook, 1989).

Industrial Calculations: Only adult exposure parameters were used for the industrial scenario. The dermal exposure factor includes head, hands and arms (EPA Exposure Factors Handbook, 1989). These values are meant for light industrial work only. If heavy physical labor is performed under dusty conditions, the RBCs are not appropriate. Rather, a site specific risk assessment should be performed.

Commercial Calculations: Adult exposure parameters were used for the commercial scenario. Age averaging methods were not utilized. The dermal surface area used for this scenario includes head, hands, and arms (EPA Exposure Factors Handbook, 1989).

Recommended Maximum Exposure (RME) Factors Used in the Tier II Look Up Table

Parameters	Symbol	Residential	Industrial	Commercial	units	Source
Body Weight (adult)	BWa	70	70	70	kg	OSWER 1991, 1993
Body Weight (child)	BWc	15			kg	OSWER 1991, 1993
Exposure Duration (adult)	EDa	24	25	25	y	OSWER 1991, 1993
Exposure Duration (child)	EDc	6			y	OSWER 1991, 1993
Exposure Duration (age averaged)	EDageav	30			y	OSWER 1991, 1993
Exposure Frequency	EF	350	250	250	d/y	OSWER 1991, 1993
Exposure Time	ET	24	8	8	h/d	OSWER 1991, 1993
Averaging Time (noncarcinogenic)	ATnc	10950	9125	9125	d	OSWER 1991, 1993
Averaging Time (carcinogenic)	ATcar	25550	25550	25550	d	OSWER 1991, 1993
Conversion Factor	cf	0.000001	0.000001	0.000001	kg/mg	
Target Risk	TR	1.00e-06	1.00e-06	1.00e-06		
Target Hazard Index	THI	1	1	1		
Ingestion						
Ingestion Rate (adult)	INRa	100	100	50	mg/d	OSWER 1991, 1993; Exposure Factors Handbook 1989
Ingestion Rate (child)	INRc	200			mg/d	OSWER 1991, 1993; Exposure Factors Handbook 1989
Ingestion Rate (age average)	INRageav	114.3			mg y/kg d	RAGS 1989
Fraction Ingested that is Contaminated	FI	1	1	1		
Inhalation						
Inhalation Rate (adult)	IRa	20			m ³ /d	Exposure Factors Handbook 1989
Inhalation Rate (adult)	IRa	0.83	1.3	0.83	m ³ /h	Exposure Factors Handbook 1989, 1996

Parameters	Symbol	Residential	Industrial	Commercial	units	Source
Inhalation Rate (child)	IRc	10			m ³ /day	Exposure Factors Handbook 1989
Inhalation Rate (age average)	IRageav	10.85			m ³ y/kg d	
Particulate Emission Factor	PEF	1.10e+09	1.10e+09	1.10e+09	m ³ /kg	<i>CO-specific value</i>
Dermal						
Surface Area (indoor age average)	SAageav	4274			cm ² year/kg	
Surface Area (adult outdoor)	SAao		4700	4700	cm ²	CDPHE RCRA Policy 1993
Absorption Factor (inorganic)	ABS	0.01	0.01	0.01		EPA Dermal Guidance 1992
Absorption Factor (organic)	ABS	0.1	0.1	0.1		EPA Dermal Guidance 1992
Soil to Skin Adherence Factor (90%)	ADF	1	1	1	mg/cm ² -event	EPA Dermal Guidance 1992
Soil to Skin Adherence Factor (50%)	ADF	0.2	0.2	0.2	mg/cm ² -event	EPA Dermal Guidance 1992

MCL-Equivalent Methodology

In order to evaluate soil contamination values that are protective of groundwater, a starting point in the modeling effort was needed to determine the acceptable/maximum concentration of a contaminant in groundwater. Health based drinking water standards were used as an allowable concentration of contaminant in the model. The model used the Department's Water Quality Control Division groundwater standards or the maximum contaminant levels (MCLs) promulgated by the EPA. Two chemicals (Phenol and Naphthalene) have no reported MCLs. Therefore, a MCL - equivalent had to be calculated using EPA general methodology for drinking water equivalent levels. The general equations include:

$$DWEL \text{ (mg/l)} \cdot \frac{RfD \text{ (mg/kg} \cdot \text{day)} \times 70 \text{ kg}}{2 \text{ liters/day}}$$

A 20% drinking water contribution (%DWC) was then applied to the DWEL to calculate a MCLG-equivalent:

$$MCLG \text{ (mg/l)} \cdot DWEL \times \%DWC$$

Chemical Specific MCL-Equivalents

Phenol

$$DWEL \text{ (mg/l)} \cdot \frac{0.6 \text{ (mg/kg} \cdot \text{day)} \times 70 \text{ kg}}{2 \text{ liters/day}}$$

$$DWEL \cdot 21.0 \text{ mg/l}$$

$$MCLG \text{ (mg/l)} \cdot 21.0 \text{ (mg/l)} \times 0.2$$

$$MCLG \cdot 4.2 \text{ (mg/l)}$$

Naphthalene

$$DWEL \text{ (mg/l)} \cdot \frac{0.04 \text{ (mg/kg} \cdot \text{ day)} \times 70 \text{ kg}}{2 \text{ liters/day}}$$

$$DWEL \cdot 1.4 \text{ mg/l}$$

$$MCLG \text{ (mg/l)} \cdot 1.4 \text{ (mg/l)} \times 0.2$$

$$MCLG \cdot 0.28 \text{ (mg/l)}$$

References Cited for SROs

Agency for Toxic Substances and Disease registry. 1989. Toxicology Profile for Aldrin/Dieldrin. TP-88/01. U.S. Department of Health and Human Services.

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NOTE: Insert the following three files here:

resid.pdf
comdraft.pdf
newindus.pdf
indus.pdf

ATTACHMENT 3

DERIVATION OF TIER II TABLE VALUES FOR LEAD

General Methodology for Residential Scenario - Exposure to Young Children from Lead in Soil

For the residential scenario, the table value for lead is based on current EPA guidance entitled "Revised Interim Soil Lead Guidance for CERCLA and RCRA Corrective Action Facilities", OSWER Directive 9355.4-12/Jul 94. This guidance document recommends an action level of 400 ug/g in the absence of site-specific data or information. The default value (400 ppm) is derived based on default exposure and biokinetic values and predicted blood lead levels in young children. The approach used is designed to protect the most sensitive or potentially susceptible individual (a young child 0-7 years of age) who may be exposed to lead in soil on a frequent or daily basis for several months to several years.

General Methodology for Commercial/Industrial Scenario - Adult Exposure to Lead in Soil

Derivation of the table values for lead for the commercial and industrial settings (2920 ug/g and 1460 ug/g, respectively) is based on the methodology described in a document entitled "Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil", published by the U.S. EPA Technical Review Workgroup for Lead, December 1996 (EPA 1996). The methodology described in this guidance document was specifically designed to assess lead risk to adults in nonresidential settings, such as where the place of employment is situated on lead contaminated soils.

The approach used assumes women of child-bearing age who may work at a facility are potentially the most susceptible adult in the workplace. The table values listed for the commercial and industrial settings are designed to prevent an unacceptable level of blood lead in the mother and fetus. The rationale for the algorithms and default parameter values selected for use in this adult lead model is provided in the Appendix to the above referenced report (EPA 1996). Table 1 from the EPA guidance document, a summary list of the default parameter values, is provided as an attachment.

The basic risk algorithm used to calculate the soil lead table values is as follows:

$$\text{RBC} = \frac{(\text{PbB}_{\text{adult,central,goal}} - \text{PbB}_{\text{adult,o}}) \times \text{AT}}{(\text{BKSF} \times \text{IR}_s \times \text{AF}_s \times \text{EF}_s)}$$

where:

- RBC = Risk-based concentration or target soil lead concentration (ug/g) (appropriate average concentration for individual)
- $PbB_{adult,central,goal}$ = Goal for central estimate of blood lead concentration (ug/dL) in adults (i.e., women of child-bearing age) that have site exposures. The goal is intended to ensure that $PbB_{fetal,0.95,goal}$ does not exceed 10 ug/dL.
- $PbB_{adult,0}$ = Typical blood lead concentration (ug/dL) in adult women of child-bearing age, in the absence of exposures to the site that is being assessed.
- AT = Averaging time; the total period during which soil contact may occur (365 days per year for continuing long term exposures).
- BKSF = Biokinetic slope factor relating (quasi-steady state) increase in typical adult blood lead concentration to average daily lead uptake (ug/dL blood lead increase per ug/day lead uptake).
- IR_s = Intake rate of soil, including both outdoor soil and indoor soil-derived dust (g/day).
- AF_s = Absolute gastrointestinal absorption fraction for ingested lead in soil and lead in dust derived from soil (dimensionless).
- EF_s = Exposure frequency for contact with assessed soils and/or dust derived in part from these soils (days of exposure during the averaging period).

Commercial Calculations

A risk-based value for lead in soil was derived for the commercial setting using the default model input values listed in Table 1. It was assumed that a GSD of 1.8 (more homogeneous population) and a background adult blood lead level of 1.7 ug/dL was appropriate for worker exposure at most Colorado sites. It was also assumed that a worker may ingest up to half of the total daily ingestion rate for soil and dust at the workplace.

Therefore,

$$\text{RBC}_{\text{comm}} = \frac{[(10 \times 1.8^{-1.645}) - 1.7] \times 365}{0.4 \times 0.025 \times 0.12 \times 219} = 2920 \text{ ug/g}$$

Industrial Calculations:

The risk-based value for lead in soil was derived for the industrial setting in an identical fashion to that used for the commercial setting, except that it was assumed that daily ingestion in this setting, on average, would be twice that of a commercial setting. Thus,

$$\text{RBC}_{\text{ind}} = \frac{[(10 \times 1.8^{-1.645}) - 1.71] \times 365}{0.4 \times 0.050 \times 0.12 \times 219} = 1460 \text{ ug/g}$$

Table 1. Summary of Default Parameter Values for the Risk Estimation Algorithm

Parameter	Unit	Value	Comment
$PbB_{fetal,0.95,goal}$	• g/dL	10	For estimating RBRGs based on risk to the developing fetus.
$GSD_{i,adult}$	--	1.8 2.1	Value of 1.8 is recommended for a homogeneous population while 2.1 is recommended for a more heterogeneous population.
$R_{fetal/maternal}$	--	0.9	Based on Goyer (1990) and Graziano et al. (1990).
$PbB_{adult,0}$	• g/dL	1.7-2.2	Plausible range based on NHANES III phase 1 for Mexican American and non-Hispanic black, and white women of child bearing age (Brody et al. 1994). Point estimate should be selected based on site-specific demographics.
BKSF	• g/dL per • g/day	0.4	Based on analysis of Pocock et al. (1983) and Sherlock et al. (1984) data.
IR_s	g/day	0.05	Predominantly occupational exposures to indoor soil-derived dust rather than outdoor soil; (0.05 g/day = 50 mg/day).
EF_s	day/yr	219	Based on U.S. EPA (1993) guidance for average time spent at work by both full-time and part-time workers (see Appendix for recommendations on minimum exposure frequency and duration).
AF_s	--	0.12	Based on an absorption factor for soluble lead of 0.20 and a relative bioavailability of 0.6 (soil/soluble).

ATTACHMENT 4

GUIDELINES FOR DETERMINING BACKGROUND CONCENTRATIONS

The following guidance has been prepared to assist an implementing party in determining representative site-specific background soil levels. It has been prepared especially for the implementation of the soil remediation objectives policy, but may also be appropriate for use in other Department cleanup programs. It is recommended that all background soil sampling plans be presented to and approved by the Division prior to their implementation.

The number and locations of background samples at a site will depend upon site-specific characteristics. The Division prefers that 9 samples be collected at appropriate locations and depths to evaluate background concentrations. This is generally considered the minimum number of samples required to determine whether the data are normally or log normally distributed. If less than 9 samples are collected (a minimum of 5 samples will generally be required) the data must be analyzed using non-parametric methods as described below. More samples may be required where sites cover large areas with varying soil characteristics or where constituent concentrations vary significantly with depth. Professional judgement will be used to determine the number of samples required for background characterization on a site-by-site basis.

Background concentrations of naturally-occurring constituents, such as metals, vary greatly depending upon the source of the soil matrix or depositional environment. Use of countrywide, statewide or regional background data for site specific background is therefore unacceptable. However, background data from other sites may be used provided that:

- (1) The data were collected and approved during the process of another investigation with oversight by the Division or EPA;
- (2) The data contain no outliers for contaminants of concern; and
- (3) The reference site is located within the same geologic region and the samples were collected from a unit with the same lithology and characteristics as the strata at the site under investigation.

Background samples are taken to determine the level of a particular compound that is either 1) naturally occurring in the area of a site or 2) is derived from off-site anthropogenic sources affecting a large region around the site (anthropogenic background, e.g., polynuclear aromatic hydrocarbons as incomplete combustion products from the burning of fossil fuels). Background samples should not be collected from areas where other local anthropogenic sources may have contributed the same constituents as those encountered at the site in question. Sampling conducted during a site characterization or investigation should be capable of determining whether on-site activities may have contributed to background concentrations present at the site. The analytical methods used to evaluate the background samples must be chosen based upon the site

investigation results, the type of contamination at the site, and any knowledge of historical activities in the vicinity of the site that could have caused contamination.

1. SAMPLE LOCATION OBJECTIVES

Objectives for the selection of background sample locations and collection of background soil samples are:

- (a) Samples must be taken up-wind and/or topographically up-gradient from known or suspected contaminated area(s). Generally, the background sample location will be at or beyond the site boundary. Historical files, aerial photographs, and tax records may help in determining locations that have not been affected by local anthropogenic activities, and;
- (b) Samples must be taken from geologic strata similar to that in which the samples from the contaminated area are taken. For example, if site characterization includes collection of soil sample at predefined depths (e.g., surface, 1, 3, 10, and 20 feet), then background samples are to be collected at the same depth intervals. At least one sample must be taken at each depth interval and strata medium (soil type), and;
- (c) Samples shall be collected using the same soil sampling protocols as applied in the previous site characterization or investigation.

2. DATA ANALYSIS

Two methods for evaluating background data are described below. The first method assumes that the data set is large enough that statistically valid analyses can be performed and that the data are either normally or log-normally distributed. The second method is provided for sites where a smaller number of data are collected such that evaluations of normality are not valid. This second method is intended to provide a conservative determination of the background level for small sites where collection of a large number of background samples may not be cost effective. Other statistical approaches to evaluating background data may also be used (e.g., U.S. EPA 1992). Where other methods are used, sufficient documentation must be provided demonstrating the validity of the approach for the site circumstances.

Under both methods, data that indicate non-detectable levels of the constituent of concern should be treated in the evaluation as a value equal to $\frac{1}{2}$ of the method detection limit. (Note that where more than 15% of the sample analytical results indicate compounds were not detected, the statistical approaches described in this guidance will likely not be appropriate and other methods will need to be considered.)

Method A -- This method may be used at sites where 9 or more background samples have been collected.

Naturally-occurring constituents, such as metals, are usually found in a log normal distribution in soil. Some statistical methods to calculate the mean, standard deviation, and confidence intervals are valid only when the data are normally distributed. To evaluate whether the data set for naturally occurring substances are normally distributed, an initial screening process should be performed using the following method:

(a) Calculate the mean, standard deviation, and coefficient of variation (standard deviation divided by the mean). Generally, if the coefficient of variation is less than one (1), no data transformations are necessary -- the raw data can be used without transformation. For naturally occurring constituents which have a coefficient of variation greater than one, the data must be transformed. First, calculate the natural logarithm of each concentration (e.g., $\ln(x_1)$, $\ln(x_2)$... $\ln(x_n)$). Then use these log values to calculate the mean and standard deviation of the data set. If the data do not appear to be normally distributed even when logged values are used, Method B described below may be used to calculate background. The Division should be consulted under these circumstances

(b) Calculate the upper 95% confidence limit of the transformed or raw data. The upper 95% confidence limit is equal to the mean plus the product of the "t" statistic and the standard deviation. The "t" statistic is dependent on the number of samples and can be obtained from the Table below. For log transformed data sets, take the antilog of the result (e.g., e^x where x = 95% confidence limit of log transformed data). The upper 95% confidence limit is the background cleanup level.

Wide variations in the concentration of hazardous constituents in the samples used to determine background concentrations are unacceptable. A valid statistical method contained in ASTM Standard E 178-80 (Standard Practice for Dealing with Outlying Observations) can be used to identify data points that lie outside acceptable limits and thus would have a disproportionate effect on the determination of background cleanup levels. If one (or more) of the background samples is determined to be an outlier utilizing the ASTM E 178-80 Method, the result may be rejected from the data set and background cleanup levels calculated using the remaining data. The Division may require that additional background samples be taken where outliers are identified if the background soil remediation objective is significantly above a soil remediation objective listed in Table 1 of the policy or background levels determined on other sites located in the general vicinity of the site.

“T” Statistic for 95% Confidence

Number of Samples	“t”	Number of Samples	“t”
2	6.314	12	1.796
3	2.920	13	1.782
4	2.353	14	1.771
5	2.132	15	1.761
6	2.015	16	1.753
7	1.943	17	1.746
8	1.895	18	1.740
9	1.860	19	1.734
10	1.833	20	1.729
11	1.812	infinite	1.645

Method B - This method should be used at sites where fewer than 9 background sample have been collected.

This method involves evaluating the interquartile range (IQR) of the sample set and using this value to estimate the 95% confidence level. The IRQ is determined by arranging the data in numerical order from the lowest to highest sample value. The median of the data set is calculated. Without considering the value of the data, the datum that lies halfway between the median and the highest datum is identified. This value is the upper quartile. The datum that lies halfway between the median and the lowest datum is the lower quartile. Where there are an even number of samples, the median and the upper and lower quartiles are determined by calculating an average. For example, if there are 8 samples, the median will be the average of the 4th and 5th data, the lower quartile will be the average of the 2nd and 3rd data, and the upper quartile will be the average of the 6th and 7th data. The IQR is then calculated as the difference between the upper quartile and the lower quartile.

The background value at a 95% confidence level is estimated as the median of the data plus 2 times the IQR. While outlying data should not be excluded from the determination of the IQR, it should not be used to define the background level as provided in 3(b) below. Outliers are defined by data that lies outside the interval defined by the median plus 3 times the IQR.

3. COMPARISON TO SITE DATA

Two methods that may be used to compare the results of the contaminated zone sampling and analysis to that of an acceptable background are:

- (a) Compare each hazardous constituent in a contaminated area sample to the background cleanup level as determined by statistical analysis. If it is below that level, then the background cleanup level for that constituent has been achieved.
- (b) Compare each hazardous constituent in a contaminated area sample with the maximum concentration in the background samples (assuming it is not an outlier). If it is equal to or less than the maximum background concentration, then the background soil remediation objective for that constituent has been achieved.

Additional guidance on comparing background data to the contaminated zone sample results can be found in the reference documents cited below.

Once the background concentration from a specific hazardous constituent is achieved, no further analyses for that constituent is needed. If the background concentration for a constituent is not achieved, cleanup and testing must continue for that constituent in order to meet the Tier 1 objectives. The Division may consider the acceptability of constituents concentrations which are only slightly above background levels on a case-by-case basis.

References:

EPA, 1986, *Permit Guidance Manual on Unsaturated Zone Monitoring for Hazardous Waste Land Treatment Units*, EPA/530/SW/86/040.

EPA, 1988, *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Guidance*, Office of Solid Waste, Permits and State Programs.

EPA, 1992, *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance*, Office of Solid Waste, Permits and State Programs.

ATTACHMENT 5

ALTERNATE MODEL APPROVAL

Under Tier 4 of the policy, the implementing party has the option of using other means of calculating soil remediation objectives that are protective of groundwater quality, including the use of computer models other than SESOIL and AT123D. Similar to what is required under Tiers 2 and 3, any soil remediation objectives developed using site-specific fate and transport models must be low enough so that any contaminants that may leach from the soil and enter the groundwater will not result in groundwater concentrations exceeding the State of Colorado groundwater standards, EPA's maximum contaminant levels, or a health-based drinking water standard.

After a decision has been made to use an alternate model, the implementing party should select the model to be used and determine what values will be used for each of the input parameters. This information should then be submitted to the Division with a request that the model be reviewed and approved for use of at their site. At a minimum, the request should include (1) an explanation of why the chosen model is appropriate for the site, (2) a list of the input parameters that you propose to use in the model, and (3) a summary of sensitivity tests which show how the model responds to changes in input. Each of these required elements is discussed in greater detail below.

(1) Explanation for Choice of Model:

Describe why you think that this model is appropriate for your site and submit supporting documentation. The documentation must be sufficiently detailed and include relevant technical information about the model, such as:

- the model name, version number and date,
- the names of the author(s) and company,
- the intended use of the model as described by the author/company,
- the governing mathematical equations and boundary conditions,
- the assumptions used in the development of the model, and
- comparisons of the proposed model to other established models.

If available, an example of a field application of the model should also be included. Appropriate documentation will normally consist of one or more articles published in scientific journals. The Division will not consider commercially produced literature (i.e. company advertisements for the software) to be sufficient supporting documentation, although this may be submitted along with other information.

(2) List of Input Parameters:

A table should be supplied which lists all of the input parameters that the model is capable of using along with the value of each parameter that you are proposing to use for the site. Note that the parameters will tend to fall into one of the following three categories. You must clearly identify which of your parameters fall into these categories.

- a) Site-specific data - These include parameters that were actually measured in the field or for which locally published data are available. Examples are hydraulic gradient, depth to groundwater and annual precipitation. For each datum, briefly state how the value was measured or determined and provide an estimate of its variability. For example, you may intend to use 25 feet as the depth to groundwater, but you have information showing that it varies from 25 to 35 feet at your site.
- b) Established parameters - some model parameters may not be practical to measure at your site and it may be appropriate to estimate them from data published in scientific text or journals. Examples of this include aquifer dispersivities. Each estimated parameter should include the reference where the value was found along with your rationale for selecting it and explanation of why you think that your estimate is conservative for your site.
- (c) Published physical and chemical data - This group includes compound solubilities and partition coefficients. Please include the reference where the proposed value can be found.

If appropriate, you should also include a discussion of any simplifying assumptions that will be used when the model is applied and explain why the simplifying assumption is also a conservative assumption. For example, the materials at the site may be stratified such that three different permeable zones are located in the volume being modeled. However, you may decide to model the site using a single permeability. If so, you should explain why this is conservative, i.e, why this will result in predicted concentrations more protective of groundwater than if the three different layers were used in the model.

For your reference, selected input parameters used in the SESOIL and AT123D models for development of the concentrations in the Tier 1 soil remediation objectives Table 1 are listed below.

More information can be found in Attachment 1, the technical background document for the development of the soil objectives protective of groundwater.

SESOIL and AT123D Model Input Parameters

Permeability	$4 \times 10^{-9} \text{ cm}^2$
Bulk Density	1.58 g/cm^3
Porosity	0.25
Soil Organic Carbon	0.1%
Hydraulic conductivity	$3.6 \times 10^{-3} \text{ cm/sec}$
Hydraulic Gradient	0.008
Longitudinal Dispersivity	12 m
Transverse Dispersivity	2 m
Vertical Dispersivity	2 m
Annual Precipitation	Denver data (15.3 in/yr, varies by month)
Volatilization	Vol. Fraction = 0.2
Henry's Constant	Compound Specific
K_{oc}	Compound Specific
Solubility	Compound Specific
Size of Contaminated zone	Width = 10 meters Length = 10 meters Thickness = 1 meter
Depth to Groundwater	
From surface	3 meters
From bottom of contam. zone	1 meter
Distance to nearest well	10 meters

(3) Sensitivity analysis:

Information must be provided which demonstrates how the model results change with variations in the value of the input parameters. If such information is not included in the supporting literature, you must perform your own sensitivity tests on the model and submit the results to the Department. Such tests can help determine the potential for errors that may be caused by input data that are not representative of the actual site conditions. While conducting sensitivity tests during SESOIL/AT123D modeling, for example, the Division found that the permeability and the soil organic carbon were the two most sensitive parameters. In other words, slight changes in these parameters caused relatively large changes in the resulting groundwater concentrations. For this reason, the Division used fairly conservative input values for these parameters when generating the numbers in Table 1.

If, after reviewing the submitted information, the Division still has questions about the use of the model, the implementing party must be able to make a working version of the proposed model available to the Division for further evaluation and testing. The Division reserves the right to request actual field or laboratory data from the site to verify any input parameters that may be suspect due to site-specific concerns or results of sensitivity tests.

MODEL APPLICATION

After obtaining Division approval, you can proceed with the application of the model. Since models generate a simulated contaminant plume, and concentrations in that plume will vary depending on location as well as time, it is important to define a specific location at which groundwater contaminant levels must be modeled. For purposes of this policy, that location is to be 10 meters from the downgradient edge of the contaminated zone, in the center of the plume at the surface of the aquifer, unless an alternate location is approved by the Division. A sufficient time period must be modeled to show what the maximum concentration of each contaminant will be in this location. In order for the Division to consider your proposed alternative soil remediation objectives, the model-generated maximum groundwater contaminant concentrations resulting from the proposed soil objectives may not exceed the State of Colorado groundwater standards, EPA's maximum contaminant levels, or a health-based drinking water standard.

Modeling results should be present to the Division in a report. This report should include the proposed soil remediation objectives, all models input parameters, the predicted maximum groundwater concentrations and the groundwater protection standard for each site contaminant. In addition, site-specific sensitivity test results should be included for each parameter determined to be sensitive, using a range of input values considered to be reasonable for the site.