RISC

User's Manual

Risk Assessment Software for
Soil and Groundwater Applications

RISK-INTEGRATED
RISC
SOFTWARE FOR CLEAN-UPS

Version 3.0

Developers:

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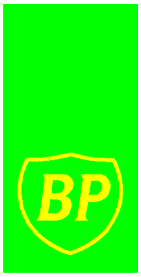
September, 1997



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September 10, 1997

To: BP RISC Recipients

From: Terry Walden

RISC Software

Thank you for your purchase of RISC. Enclosed is the RISC (Risk-Integrated Software for Cleanups) package. This includes a user's manual and 3 diskettes containing the Windows-based software.

RISC has been in development for nearly 5 years and we think it is a unique piece of software that greatly simplifies the understanding and implementation of risk-based assessments and corrective action. One of the unique features of RISC is its ability to perform both a conventional *forward* and a *backward* risk calculation. The latter refers to calculating cleanup levels for an input value of risk, following the approach adopted under the U.S. RBCA, European CONCAWE, and New Zealand and Australia Oil Industry Working Group frameworks. This requires not just a simple transposition of an equation, but rather an iterative procedure involving convergence toward a solution within a host of fate and transport models. I believe this is the only software on the market with such a capability.

A number of other features are also available. These include:

- An Excel spreadsheet based on the RBCA algorithms has been incorporated as a stand alone application to enable users to replicate the tiered RBCA process. If a site should fail this Tier 1 screen, the user can then proceed to a Tier 2 evaluation based on the fate and transport codes and Monte Carlo techniques in the main body of the RISC software.

- The ability to determine risk-based TPH (total petroleum hydrocarbon) targets has been achieved by including the TPH fractions proposed by the U.S. Air Force-led TPH Working Group. With these additional compounds, the chemical database now contains close to 90 compounds with full physical, chemical and toxicological data.

- The full original version of the Johnson and Ettinger indoor air model (which includes convective-driven vapor flow due to pressure differentials) is included for the soil vapor pathway, and a shower model is available for the groundwater pathway.

- The algorithms in RISC can distinguish between presence or absence of phase-separated product in the source zone.

- The software can accommodate additive risk due to multiple pathways and/or compounds, as well as individual risk following the RBCA philosophy. Additive risk due to multiple receptors (e.g. a resident exposed as both a child and an adult) can also be modeled.

- Monte Carlo analyses capability is available for estimating probabilistic risk due to a statistical distribution (rather than fixed value) of exposure parameters.

The code has been thoroughly tested and peer-reviewed by Prof. Paul Johnson of Arizona State University - one of the country's noted experts in subsurface risk and an original developer of the RBCA guidelines. Paul has made a detailed technical review of the models and their computational results, and provided critical commentary on the interface and user's manual. His review is included with the user's manual.

We are not finished but will continue to develop the software. Our next target is to upgrade the indoor air pathway with one or more new models that are now in development. We also intend to incorporate food chain pathways - especially one on vegetable ingestion - hopefully by late fall 1998. Inclusion of aquatic and terrestrial ecological risk pathways remains a target for 1999.

Finally, regarding help with the software. The following page provides technical support information.

Happy risk assessing….

RISC Questions and Help Desk

Technical support is provided by Lynn Spence.

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INSTALLATION NOTE FOR BP RISC

When installing RISC, the installation package will indicate that EXCEL cannot be found on your computer, even if you have Excel installed. This will not cause a problem when running RISC, it is just that the location of the Excel spreadsheet software was not found in the directories listed in your computer's PATH statement.

Excel is used by RISC to display the the Tier 1 spreadsheet. This spreadsheet is not linked to the software directly (it does not share data) and is not required in order to run RISC. If Excel is not in the path, you will not be able to click on the Excel button from the main menu of RISC and have the Tier 1 spreadsheet brought up automatically. To run the Tier 1 spreadsheet, you can either add the Excel directory to your path or just open the Tier 1 spreadsheet manually:

To load the Excel macros manually: Open Excel. Open the file named "TIER1.XLS" located in your RISC directory.

To add the Excel directory to your path: edit the autoexec.bat file and add the file directory name to the path. Save the file, exit, and reboot your computer. If this doesn't work, call technical support for detailed help or open the file manually.

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In 1993, BP made a business decision in the U.S. to develop a standardized approach for conducting soil and groundwater risk assessments across all the 'downstream' activities (service stations through refineries). The rationale was that the company needed to ensure that the latest thinking in fate and transport, exposure, statistical analyses and toxicological criteria were adopted and uniformly applied cross-business. It was also important that BP spoke with a consistent voice when approaching regulators and the community on this vital issue.

Eventually it became clear that a software package containing embedded fate and transport models with easily-executed user inputs offered the most convenient and flexible means of implementing this objective. This would enable the process to be readily standardized, communicated and transferred, while still allowing a risk application to be individually tailored to the regulatory regime of the particular business or country. By developing the code in-house, BP is also in the position of rapidly adopting evolving trends (e.g. the methodology for assessing the risk due to TPH), thus keeping the process and technical approach *evergreen*.

Versions 1.0 and 2.0 of the code were released in January, 1994 and August, 1995. These versions contained the suite of embedded fate and transport models and Monte Carlo exposure analyses, but allowed for only a *forward* risk calculation. The major change in this Version (3.0) is the ability to perform the *backward* calculation, i.e. generating soil and groundwater cleanup levels for an input value of risk while running fate and transport codes via semi-analytical (or non closed form) solutions.

BP is distributing an executable version of this software to all its U.S. and international affiliates. BP is also distributing the software and user's manual to members of the PERF (Petroleum Environmental Research Forum) 94-06 project group, with whom BP has a contractual obligation. This group includes the American Petroleum Institute, Amoco, Alcoa, the Canadian Association of Petroleum Producers, Chevron, Conoco, Dupont, Exxon, the Gas Research Institute, Shell, Texaco and Unocal. All recipients are free to freely transfer the program to their regulators and risk consultants utilizing the licensing agreement included on the software diskettes. However, these releases should be delayed till 30 days have elapsed since the mid-September distribution to the PERF 94-06 group.

Review of Risk Integrated Software for Cleanups (RISC) *v*3.0
September 6, 1997
Prepared by:

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1.0 INTRODUCTION

In recent years there has been increased acceptance of more formalized risk-based assessment and decision-making at sites where soil, groundwater, or air have been impacted by chemical releases. This in turn has stimulated the need for tools to help facilitate the decision-making process. One can now find guidance documents, spreadsheets, worksheets, and other software specifically authored for this purpose. Examples include the USEPA's Soil Screening Guidance[1], GSI's Tier 2 Toolkit[2], American Petroleum Institute Decision Support Software (DSS)[3], and the American Society for Testing and Materials (ASTM)[4] E1739-95 Guide to Risk-Based Corrective Action at Petroleum Release Sites.

This review focuses on a software tool - the Risk-Integrated Software for Cleanups (RISC *v*3.0), which has been developed for, and is distributed by British Petroleum. RISC is a point-and-click software package that currently runs under the Windows® operating system. With RISC a user can: (i) assess the potential for adverse human health impacts due to exposure to contaminated soil, water, and air, (ii) calculate target cleanup levels for these media, and (iii) estimate the cross-media transport of chemicals in the environment. RISC appears to be a tool focused towards site-specific, yet reasonably simplistic analyses. This corresponds closely to the Tier 2 analyses prescribed in the ASTM RBCA framework, and the "Simple Site-Specific" analysis proposed in the USEPA's Soil Screening Guidance.

Relative to other available software tools, RISC is unique in a number of respects. First, the software comes bundled with a stand-alone Microsoft Excel® spreadsheet that calculates initial risk-based screening levels using the ASTM E1739-95 RBCA example

[1] - USEPA Office of Solid Waste and Emergency Response Report EPA/540/R-96/018, April 1996.
[2] - Groundwater Services, Inc., 2211 Norfolk, Suite 1000, Houston TX 77098
[3] - American Petroleum Institute, 1220 L Street NW, Washington, DC 20005
[4] - American Society for the Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428

Tier 1 Table algorithms. This is by itself a valuable tool that professionals, regulators, and other environmental professionals will appreciate as many regulatory agencies are currently developing similar spreadsheets. Second, RISC encompasses a wider range of exposure scenarios and transport pathways than most conventional tools. For example, RISC allows the user to evaluate the potential for adverse impacts due to indoor vapor migration from soils and groundwater, and also includes the evaluation of exposures caused by showering with contaminated water. Third, RISC allows the user to perform both "forward" and "backward" calculations; that is to say that RISC allows the user to either: (i) assess the potential adverse impacts caused by user-specified soil, water, groundwater, and air concentrations, or (ii) estimate cleanup levels corresponding to pre-determined acceptable potentials for adverse health impacts. Fourth, RISC algorithms identify and distinguish between scenarios where immiscible phase is and is not initially present in the source zone.

Other less unique, but useful features include the ability to incorporate Monte-Carlo analyses, pre-defined sets of exposure parameters (e.g., residential adult, residential child, worker, etc.), a chemical database, site data statistical analysis tools, the ability to simultaneously conduct analyses for more than one receptor type, and the option to consider additive risk due to multiple pathways and compounds in both the "forward" and "backward" risk calculation scenarios.

In the following, RISC *v*3.0 software is described and critiqued in more detail. The review is organized as follows:

- overview of the exposure scenarios and cross-media transport models found in RISC
- RISC input requirements
- comments specific to the user interface and user's manual
- comments on the back-calculation of cleanup levels
- comments on RISC partitioning algorithms
- comparison of RISC output with independent calculations
- comparison of RISC output with other published target cleanup concentrations

2.0 OVERVIEW OF THE EXPOSURE SCENARIOS AND CROSS-MEDIA TRANSPORT MODELS FOUND IN RISC

Table 2.1 summarizes the exposure scenarios that can be assessed with RISC *v*3.0. These encompass most scenarios considered in conventional risk assessments. The only obvious omissions that users might find elsewhere are calculations involving vapor and dust emissions from surficial soils. In the case of the former, one can use the RISC subsurface vapor transport algorithms, but these are more conservative than conventional surficial soil volatilization algorithms. In addition, there is no option for assessing surficial soil particulate emission impacts; although, this is typically not a dominant pathway when soil ingestion is also considered.

It should also be noted that RISC allows the assessment of a number of pathways that have historically not been quantified, but are of increasing interest to regulatory agencies. These include vapor migration from soil and groundwater to buildings and the volatilization from water during showering.

The user can select from eight pre-defined exposure parameter sets, or the user can create their own. Pre-defined parameter sets include "RME" and "Typical" exposures for a residential adult, residential child, worker, and a trespasser. In RISC the RME scenario is similar to the USEPA's reasonable maximum exposure scenario in that near upper-bound exposure parameter values are used to produce very conservative intake estimates. RISC's Typical exposure parameter settings are more representative of the average intake for a large population. To examine the distribution of possible exposures, the degree of conservatism of the RME scenario, the representativeness of the Typical scenario, or the probabilities of other given scenarios occurring, RISC includes a Monte-Carlo intake analysis option. It allows users to specify probability distributions for source concentrations and exposure/intake parameters.

Chemical fate and migration algorithms contained in RISC are of the variety generally classified as screening-level algorithms. In other words, they are not intended for the detailed simulation of chemical migration, but they are appropriate for generating initial estimates of cross-media transfer rates, receptor-point concentrations, migration rates, and source longevity estimates. Table 2.2 briefly summarizes characteristics of the models that users can select. With the exception of the dissolved groundwater transport model, all models are one-dimensional. The vadose zone and saturated zone source models are linked with the dissolved groundwater transport model. In other cases where more than

one transport model is used, mass is not strictly conserved. However, given the intended use of RISC, this is not a significant issue of concern.

Table 2.1. Summary of exposure scenarios that can be assessed using RISC.

Source Media	Migration Pathway	Exposure Media	Exposure Routes	Receptor Characterization
outdoor air	none	outdoor air	inhalation	8 pre-defined scenarios for all pathways - (RME and Typical Exposures)* for: • adult residential • child residential • worker • trespasser plus any user-defined scenarios
indoor air	none	indoor air	inhalation	
surface water	none	surface water	ingestion and dermal adsorption during swimming	
ground water	none	ground water	ingestion, dermal adsorption	
	volatilization during showering	indoor air	inhalation	
	groundwater transport	groundwater	ingestion, dermal adsorption	
	groundwater transport followed by volatilization during showering	indoor air	inhalation	
	volatilization and vapor transport into buildings	indoor air	inhalation	
	volatilization and vapor transport to outdoor air	outdoor air	inhalation	
soil (surface and subsurface)	none	soil	ingestion and dermal adsorption	
soil (subsurface)	volatilization and vapor transport	outdoor air	inhalation	
	volatilization and vapor transport	indoor air	inhalation	
	leaching to groundwater followed by groundwater transport and then ingestion and dermal contact	groundwater	ingestion and dermal contact	
	leaching to groundwater followed by groundwater transport and then volatilization during showering	indoor air	inhalation	

* - RME - similar to the "reasonable maximum exposure scenario" commonly used by USEPA
* - Typical - reasonable exposure scenario more representative of the average exposure to the general population

All models have been borrowed from the peer-reviewed literature and should be familiar to the experienced user. The algorithms range from steady-state models with constant-strength sources to depleting source and transient transport scenarios. First-order degradation is accounted for in the dissolved groundwater and vadose zone leaching

models. Given that degradation in the vadose zone is poorly understood at this time, it is not included as an attenuation mechanism in the vapor migration models; however, layered soil systems are considered and this is a significant feature for site-specific analyses. For those not familiar with any particular model, the accompanying RISC User's Manual provides sufficient detail to be able to identify model assumptions, limitations, governing equations, and relevant literature references.

Table 2.2. Transport algorithms incorporated in RISC (see the RISC user's manual for complete literature references).

Migration Pathway	Algorithm	Steady-State (SS) or Transient (T)	Coupled to Other Models in RISC?
volatilization from water to indoor air during showering	Foster and Chrostowski (1986)	T (depends on shower duration)	Y (vadose zone and groundwater transport models)
volatilization from soils to outdoor air	Unlu et al. (1992) - modified for multiple layers above the source	T (depleting source coupled with steady-state vapor transport solution)	Y (coupled with a box outdoor air dispersion model)
volatilization from soils to indoor air	Johnson and Ettinger (1991)	SS	N
leaching to groundwater	Unlu et al. (1992) - modified for multiple layers above the source	T	Y (coupled with dissolved groundwater transport model)
loading to groundwater due to saturated sources and fluctuating water tables	Simple partitioning model, allowing for source depletion	T	Y (coupled with dissolved groundwater transport model)
dissolved groundwater transport	AT123D - Yeh (1981)	T	Y (coupled with vadose zone model leachate)
volatilization from groundwater to indoor air	Johnson and Ettinger (1991), ASTM (1995)	SS	Y

The software implies that future upgrades will also address food-chain type pathways and ecological receptor impacts.

Some models may be linked together automatically within RISC; for example, vadose zone leaching and dissolved groundwater transport may be used collectively to assess impacts due to leaching and subsequent downgradient potable use of groundwater.

3.0 RISC INPUT REQUIREMENTS

RISC's data input requirements are reasonable and consistent with the goal of providing site-specific screening-level estimates. Most of the required site-specific parameters will be familiar to the intended audience (porosity, density, thickness, etc.) and can be selected given typical site assessment data. RISC provides suggested key input values for various soil types; however, the user should review these before accepting any of the values.

Missing from RISC is a sensitivity analysis feature, so users will have to manually vary individual input parameters to identify those to which the results are most sensitive.

Many users will not be familiar with the parameters required for RISC to estimate soil moisture content from infiltration rates and will want to read that section of the user's manual that discusses these properties and their use.

Necessary chemical-specific properties for typical compounds of interest can be found in the RISC chemical database. A cursory review of some of the more commonly encountered chemicals indicates that the database values are reasonable, however, the user may wish to consult other sources as well before adopting any input value. As is often the case with chemical-specific properties, user's will find a range of properties in the literature. Generally the deviations between solubility, vapor pressure, and Henry's Law constant will be small (±20%). Variability between sorption coefficients and organic carbon partition coefficients are often large (an order of magnitude is not unusual). Variability is also typically large for most properties when considering the larger molecular weight compounds (e.g. benzo(a)pyrene).

With respect to the toxicological inputs, more experienced users will note that RISC still uses conventional inhalation slope factors and reference doses for inhalation pathway calculations, rather than the unit risk factor (URF) and reference concentration (RfC) approach now beginning to appear in USEPA documents. The user should note, however, that for all practical purposes this has little effect on the final results as chemical-specific toxicological data is generally extrapolated from a single intake route (either oral or inhalation).

4.0 COMMENTS SPECIFIC TO THE RISC USER INTERFACE AND RISC USER'S MANUAL

RISC is predominantly a point-and-click program. The user interface, through a combination of arrows and highlight colors, has been designed to guide the user through the conventional sequence of risk assessment activities (identify chemicals of concern, identify source media, etc.). The interface is fairly intuitive and easy to use, and the experienced professional will have little need for the accompanying user's manual to be able to operate the program.

For the novice user, the user's manual provides an excellent introduction to the software. Step-by-step instructions are provided along with tutorial examples to help familiarize the user with the interface and possible uses of the software. In most cases, only a few hours should be required to learn how to use the program.

While it is very easy to use the software and to generate results, the interface and output provide few clues as to what the software is actually doing. Having access only to the software, a user would be hard-pressed to discuss the inherent assumptions and limitations of the calculations and models. An on-line help system is included in RISC, but it appears to be in its infancy at this stage and is of little use for technical questions. At this time, discussions relevant to the algorithms and models being used are only contained in the user's manual. The one exception is a discussion of the shower volatilization model, which can be accessed through the on-line help system. It is strongly recommended that RISC not be used without first reading the user's manual, especially those appendices that describe the models being used.

Based upon an initial review of the user's manual and software, it appears that the software and supporting materials are targeted towards (and should only be used by) environmental professionals that have had some formal training in the fundamentals of chemical migration, exposure assessment, and risk assessment. Those not well-versed in the basics of these fields will not be familiar with the terminology and will lack the intuition necessary for properly choosing some of the input parameters.

A range of output options is available to the user. These include different summary tables, graphs, and charts that may be printed or copied and pasted into a report. The summary tables are sufficiently detailed for the user to review all inputs, outputs, and many of the intermediate calculations. Depending on the number of chemicals and migration and

exposure pathways chosen, the user may find that output tables do not always print out well in 8.5 in x 11 in portrait or landscape format.

5.0 COMMENTS ON THE BACK-CALCULATION OF CLEANUP LEVELS

As stated earlier, one of the unique features of RISC is its ability to allow the user to either: a) assess potential adverse impacts associated with some current site conditions, or b) develop site-specific target cleanup levels. While calculating cleanup levels often seems to be a straight-forward exercise, in general, it is actually very difficult. For example, in the case of multiple compounds or the case of a single compound with multiple source media, there is no unique solution. In other words, there is an infinite number of sets of cleanup numbers that satisfy the same single overall risk management target (e.g., suppose that it is desired that the total incremental cancer risk level falls below 10^{-5}).

RISC allows the user to choose between two options for calculating cleanup goals. In the first, a single total risk management goal is applied collectively to all compounds in a given source media (e.g., air, water, soil). RISC then iteratively determines cleanup goals for that source media subject to the condition that the concentrations of all chemicals are reduced proportionately. While this is the simplest approach, it very often leads to the false and impracticable conclusion that remediation is necessary for some chemicals already present at low and insignificant concentrations. In the second approach, the user specifies a single risk management goal to be met individually by each compound (e.g., suppose we wish to achieve a target hazard index of 0.2 for each compound). In many cases it is this second approach that will lead to the most rational target cleanup levels, as those compounds already present at insignificant concentrations will be found to have target cleanup levels greater than current concentrations at the site (in other words, they already satisfy their cleanup goals). If additivity of compounds is not desired, then estimation of cleanup levels individually is, of course, also possible.

Users should be made aware that the back-calculated cleanup levels are dependent on the initial media concentrations input to RISC. This is an artifact of the uniqueness problem mentioned above.

If the user prefers not to have RISC use either of these two methods for determining cleanup levels, then they can also manually iterate (input soil concentrations and then determine the estimated risk and hazard quotients) the software to develop other sets of appropriate target cleanup numbers.

Also, users should remember to consult the RBCA Tier 1 spreadsheet bundled with RISC. Assuming that the exposure inputs and risk levels are acceptable (and these can be modified by the user), these Tier 1 values can provide a quick starting point for developing site-specific risk-based cleanup numbers.

6.0 COMMENTS ON RISC SOURCE ZONE PARTITIONING ALGORITHMS

Experienced users will be familiar with most of the algorithms built into RISC. The only notable exception might be the way in which source zone partitioning is handled. Most conventional tools and algorithms assume that chemicals partition independently of each other and can always be distributed between vapor, sorbed, and dissolved phases. This assumption is reasonable for very low soil concentrations, but not for higher concentrations or petroleum fuel mixtures, where a fourth immiscible phase will form. This higher concentration regime is often modeled by looking at the partitioning from the immiscible phase to water and air.

RISC attempts to span this range of behaviors by allowing the program to decide which limiting partitioning approximation is more appropriate for the input initial soil concentration. When inputting soil concentrations for the chemicals of interest, the user can also elect to input a total hydrocarbon concentration, which is intended to represent the concentration of an immobile immiscible phase. If the input total hydrocarbon concentration is zero, RISC performs three-phase partitioning calculations much like most other conventional software tools. When the input total hydrocarbon concentration is greater than zero, RISC compares dissolved concentrations from both limiting partitioning models and chooses the one that yields the lowest concentration

7.0 COMPARISON OF RISC OUTPUT WITH INDEPENDENT CALCULATIONS

As part of this review, RISC output was compared with independent calculations using the algorithms described in the user's manual. The purpose of this exercise was to verify that RISC performs the calculations as described in the user's manual, and correctly outputs the results. While an exhaustive validation could not be performed, it is felt that the range of conditions tested covers the majority of probable applications.

7.1 Validation of Direct Exposure Pathway Calculations

Using the RISC default exposure parameters for the adult-residential-RME exposure scenario as well as the chemical-specific parameters provided in the chemical database, the potential for adverse impacts from each of the direct exposure pathways was calculated. Table 7.1 compares the RISC model output (not the spreadsheet) with independent calculations using the same inputs and the algorithms presented in the RISC user's manual. As can be seen the agreement is very good, and any deviations are within typical round-off errors for these type of calculations.

In performing this exercise it was noted that RISC is programmed to output "0.00E+00" for the calculated risk and hazard index whenever chemical-specific toxicological data is not available ("ND" entries for the chemical-specific properties). This may be incorrectly interpreted by some users to mean that those chemicals do not pose any adverse health impacts.

7.2 Calculation of Cleanup Levels for Direct Exposure Pathways

Again, using the RISC default exposure parameters for the adult-residential-RME exposure scenario as well as the chemical-specific parameters provided in the chemical database, cleanup levels were calculated for a target cumulative risk of 10^{-5}. Here the starting concentrations were similar to the input concentrations from the previous exercise. After the cleanup levels were calculated, these results were used as inputs in the forward calculation mode. This was done to see if the cleanup concentrations do indeed correspond to the target risk level. Table 7.2 presents the results of this exercise.

Table 7.1. Comparison of RISC output with independent calculations for the direct exposure pathways.

Exposure Pathway/Results*	Arsenic	Benzene	Benzo(a)pyrene	TPH Aliphatic C12-C16
Soil Ingestion				
Concentration [mg/kg-soil]	5.00	5.00	5.00	5.00
CDI (RISC) [mg/kg-d]	6.85×10^{-6}	6.85×10^{-6}	6.85×10^{-6}	6.85×10^{-6}
CDI (calculated) [mg/kg-d]	6.85×10^{-6}	6.85×10^{-6}	6.85×10^{-6}	6.85×10^{-6}
Cancer Risk (RISC)	4.40×10^{-7}	8.51×10^{-8}	2.14×10^{-5}	0.00[1]
Cancer Risk (calculated)	4.40×10^{-7}	8.53×10^{-8}	2.14×10^{-5}	ND
Hazard Index (RISC)	2.28×10^{-2}	0.00[1]	2.28×10^{-4}	6.85×10^{-5}
Hazard Index (calculated)	2.28×10^{-2}	ND	2.28×10^{-4}	6.85×10^{-5}
Dermal Contact with Soil				
Concentration [mg/kg-soil]	5.00	5.00	5.00	5.00
CDI (RISC) [mg/kg-d]	1.18×10^{-5}	1.97×10^{-4}	1.97×10^{-5}	1.97×10^{-4}
CDI (calculated) [mg/kg-d]	1.18×10^{-5}	1.97×10^{-4}	1.97×10^{-5}	1.97×10^{-4}
Cancer Risk (RISC)	7.60×10^{-6}	2.45×10^{-6}	6.16×10^{-5}	0.00[1]
Cancer Risk (calculated)	7.60×10^{-6}	2.45×10^{-6}	6.16×10^{-5}	ND
Hazard Index (RISC)	3.94×10^{-2}	0.00[1]	6.56×10^{-4}	1.97×10^{-3}
Hazard Index (calculated)	3.94×10^{-2}	ND	6.56×10^{-4}	1.97×10^{-3}
Ingestion of Groundwater				
Concentration [mg/L-H_2O]	2.00	2.00	2.00	2.00
CDI (RISC) [mg/kg-d]	5.48×10^{-2}	5.48×10^{-2}	5.48×10^{-2}	5.48×10^{-2}
CDI (calculated) [mg/kg-d]	5.48×10^{-2}	5.48×10^{-2}	5.48×10^{-2}	5.48×10^{-2}
Cancer Risk (RISC)	3.52×10^{-2}	6.81×10^{-4}	1.71×10^{-1}	0.00[1]
Cancer Risk (calculated)	3.52×10^{-2}	6.81×10^{-4}	1.71×10^{-1}	ND
Hazard Index (RISC)	1.83×10^{2}	0.00[1]	1.83×10^{0}	5.48×10^{-1}
Hazard Index (calculated)	1.83×10^{2}	ND	1.83×10^{0}	5.48×10^{-1}
Dermal Contact in Shower				
Concentration [mg/L-H_2O]	2.00	2.00	2.00	2.00
CDI (RISC) [mg/kg-d]	1.26×10^{-4}	2.65×10^{-3}	1.51×10^{-1}	1.03×10^{0}
CDI (calculated) [mg/kg-d]	1.26×10^{-4}	2.65×10^{-3}	1.51×10^{-1}	1.03×10^{0}
Cancer Risk (RISC)	8.10×10^{-5}	3.29×10^{-5}	4.73×10^{-1}	0.00[1]
Cancer Risk (calculated)	8.10×10^{-5}	3.29×10^{-5}	4.73×10^{-1}	ND
Hazard Index (RISC)	4.20×10^{-1}	0.00[1]	5.04×10^{0}	1.03×10^{1}
Hazard Index (calculated)	4.20×10^{-1}	ND	5.04×10^{0}	1.03×10^{1}
Inhalation in Shower				
Concentration [mg/L-H_2O]	2.00	2.00	2.00	2.00
CDI (RISC) [mg/kg-d]	0.00×10^{0}	6.67×10^{-2}	2.35×10^{-4}	4.84×10^{-2}
CDI (calculated) [mg/kg-d]	0.00×10^{0}	6.62×10^{-2}	2.38×10^{-4}	4.79×10^{-2}
Cancer Risk (RISC)	0.00×10^{0}	8.29×10^{-4}	7.34×10^{-4}	0.00[1]
Cancer Risk (calculated)	0.00×10^{0}	8.23×10^{-4}	7.43×10^{-4}	ND
Hazard Index (RISC)	0.00×10^{0}	0.00[1]	0.00[1]	4.84×10^{-2}
Hazard Index (calculated)	0.00×10^{0}	ND	ND	4.79×10^{-2}

* - RISC adult residential reasonable maximum exposure (RME) parameters used

[1] - RISC outputs "0.00E+00" whenever toxicological information is not available

Table 7.1. Comparison of RISC output with independent calculations for the direct exposure pathways (cont.).

Exposure Pathway/Results*	Arsenic	Benzene	Benzo(a)pyrene	TPH Aliphatic C12-C16
Inhalation of Outdoor Air				
Concentration [mg/m^3-air]	4.00	4.00	4.00	4.00
CDI (RISC) [mg/kg-d]	2.73×10^{-1}	2.73×10^{-1}	2.73×10^{-1}	2.73×10^{-1}
CDI (calculated) [mg/kg-d]	2.73×10^{-1}	2.73×10^{-1}	2.73×10^{-1}	2.73×10^{-1}
Cancer Risk (RISC)	1.75×10^{-1}	3.39×10^{-3}	8.54×10^{-1}	0.00[1]
Cancer Risk (calculated)	1.75×10^{-1}	3.36×10^{-3}	8.54×10^{-1}	ND
Hazard Index (RISC)	0.00[1]	0.00[1]	9.10×10^{0}	2.73×10^{-1}
Hazard Index (calculated)	ND	ND	9.10×10^{0}	2.73×10^{-1}
Inhalation of Indoor Air				
Concentration [mg/kg-soil]	3.00	3.00	3.00	3.00
CDI (RISC) [mg/kg-d]	4.11×10^{-1}	4.11×10^{-1}	4.11×10^{-1}	4.11×10^{-1}
CDI (calculated) [mg/kg-d]	4.10×10^{-1}	4.10×10^{-1}	4.10×10^{-1}	4.10×10^{-1}
Cancer Risk (RISC)	2.64×10^{-1}	5.11×10^{-3}	1.29×10^{0}	0.00[1]
Cancer Risk (calculated)	2.62×10^{-1}	5.07×10^{-3}	1.28×10^{0}	ND
Hazard Index (RISC)	0.00[1]	0.00[1]	1.37×10^{1}	4.14×10^{-1}
Hazard Index (calculated)	ND	ND	1.36×10^{1}	4.08×10^{-1}
Ingestion while Swimming				
Concentration [mg/L-H_2O]	6.00	6.00	6.00	6.00
CDI (RISC) [mg/kg-d]	1.10×10^{-3}	1.10×10^{-3}	1.10×10^{-3}	1.10×10^{-3}
CDI (calculated) [mg/kg-d]	1.10×10^{-3}	1.10×10^{-3}	1.10×10^{-3}	1.10×10^{-3}
Cancer Risk (RISC)	7.07×10^{-4}	1.37×10^{-5}	3.44×10^{-3}	0.00[1]
Cancer Risk (calculated)	7.07×10^{-4}	1.37×10^{-5}	3.44×10^{-3}	ND
Hazard Index (RISC)	3.66×10^{0}	0.00[1]	3.61×10^{-2}	1.10×10^{-2}
Hazard Index (calculated)	3.66×10^{0}	ND	3.66×10^{-2}	1.10×10^{-2}
Dermal - Swimming				
Concentration [mg/L-H_2O]	6.00	6.00	6.00	6.00
CDI (RISC) [mg/kg-d]	5.06×10^{-4}	1.06×10^{-2}	6.07×10^{-1}	4.15×10^{0}
CDI (calculated) [mg/kg-d]	5.06×10^{-4}	1.06×10^{-2}	6.07×10^{-1}	4.15×10^{0}
Cancer Risk (RISC)	3.25×10^{-5}	1.32×10^{-4}	1.90×10^{0}	0.00[1]
Cancer Risk (calculated)	3.25×10^{-5}	1.32×10^{-4}	1.90×10^{0}	ND
Hazard Index (RISC)	1.69×10^{0}	0.00[1]	2.02×10^{1}	4.15×10^{1}
Hazard Index (calculated)	1.69×10^{0}	ND	2.02×10^{1}	4.15×10^{1}

* - RISC adult residential reasonable maximum exposure (RME) parameters used

[1] - RISC outputs "0.00E+00" whenever toxicological information is not available

Table 7.2. Results* of Cleanup Level Calculations for a target risk of 10^{-5}.

Exposure Pathway/Results*	Arsenic	Benzene	Benzo(a)pyrene	TPH Aliphatic C12-C16
Input - Media Concentrations				
groundwater [mg/L-H_2O]	2.00	2.00	2.00	2.00
indoor air [mg/m^3-air]	3.00	3.00	3.00	3.00
outdoor air [mg/m^3-air]	4.00	4.00	4.00	4.00
soil [mg/kg]	5.00	5.00	5.00	5.00
surface water [mg/L-H_2O]	6.00	6.00	6.00	6.00
Result - Cleanup Levels (listed by pathway)				
groundwater [mg/L-H_2O]	3.0×10^{-5}	3.0×10^{-5}	3.0×10^{-5}	0.18
indoor air [mg/m^3-air]	1.9×10^{-5}	1.9×10^{-5}	1.9×10^{-5}	7.1
outdoor air [mg/m^3-air]	4.0×10^{-5}	3.9×10^{-5}	3.9×10^{-5}	15
soil [mg/kg]	0.51	0.51	0.51	2500
surface water [mg/L-H_2O]	3.2×10^{-5}	3.2×10^{-5}	3.1×10^{-5}	0.15
Cancer Risk - using the cleanup levels listed above as inputs				
groundwater [mg/L-H_2O]	5.2×10^{-7}	2.3×10^{-8}	9.4×10^{-6}	ND
indoor air [mg/m^3-air]	1.7×10^{-6}	3.3×10^{-8}	8.3×10^{-6}	ND
outdoor air [mg/m^3-air]	1.7×10^{-6}	3.3×10^{-8}	8.4×10^{-6}	ND
soil [mg/kg]	1.2×10^{-6}	2.6×10^{-7}	8.5×10^{-6}	ND
surface water [mg/L-H_2O]	5.4×10^{-9}	7.6×10^{-10}	9.9×10^{-6}	ND
Hazard Index - using the cleanup levels listed above as inputs				
groundwater [mg/L-H_2O]	2.7×10^{-3}	ND	9.9×10^{-5}	0.99
indoor air [mg/m^3-air]	0	ND	8.8×10^{-5}	0.98
outdoor air [mg/m^3-air]	0	ND	8.9×10^{-5}	0.98
soil [mg/kg]	6.3×10^{-3}	ND	9.0×10^{-5}	0.99
surface water [mg/L-H_2O]	3.0×10^{-5}	ND	1.10×10^{-4}	1.0

Cumulative Risk and Hazard Quotient by Media for the cleanup levels listed above	Risk	Hazard Index
groundwater [mg/L-H_2O]	0.99×10^{-5}	1.0
indoor air [mg/m^3-air]	1.00×10^{-5}	0.98
outdoor air [mg/m^3-air]	1.00×10^{-5}	1.0
soil [mg/kg]	1.01×10^{-5}	1.0
surface water [mg/L-H_2O]	0.99×10^{-5}	1.0

Total Risk (all pathways)	5.0×10^{-5}
HQ (all pathways)	5.0

* - For the RISC default adult residential reasonable maximum exposure (RME) parameters and a cumulative target risk of 10^{-5} and HQ=1

Conducting this analysis reveals a few subtle, but extremely important characteristics of the program. First, in this mode RISC determines cleanup levels so that the cumulative risk and hazard quotient targets are met only for each source media individually (this is not obvious from the RISC input screens). Thus, the true cumulative risk for the cleanup levels is always N times the target risk level (or hazard quotient), where N is equal to the

number of source media. For the results presented in Table 7.2 there are 5 different source media (groundwater, indoor air, outdoor air, soil and surface water).

The second and much more important characteristic of RISC is that the cleanup numbers are dependent on the initial concentrations entered. Users need to be aware of this feature. In other words, for the same four chemicals and nine exposure pathways considered, the results given in Table 7.2 will change if the initial chemical concentrations are not all equal in each source media. As stated earlier in this review, this stems from the problem that there are no unique cleanup level solutions when considering multiple chemicals and pathways.

7.3 Validation of the Monte-Carlo Calculations

The Monte-Carlo option in RISC was used to generate a probability distribution of risks for exposure to benzene in drinking water at a constant 0.005 mg/L concentration. Default adult residential RME exposure parameter distributions were used and 10,000 realizations were run. To check the accuracy of RISC, similar calculations were performed using the Crystal Ball® software package. A comparison of the output is included below in Table 7.3. As can be seen, the agreement is very good.

Table 7.3. Comparison of RISC Monte-Carlo results with independent risk calculations for groundwater ingestion of benzene at 0.005 mg/L concentration*.

Summary Statistics	Cancer Risk (RISC)	Cancer Risk (Crystal Ball®)
min	2.0×10^{-9}	5.6×10^{-9}
5%	4.0×10^{-8}	3.9×10^{-8}
50%	4.0×10^{-7}	2.3×10^{-7}
75%	4.8×10^{-7}	4.7×10^{-7}
90%	8.9×10^{-7}	8.7×10^{-7}
95%	1.3×10^{-6}	1.2×10^{-6}
max	4.8×10^{-6}	7.4×10^{-6}

* - using RISC adult residential RME default parameters and 10,000 realizations

7.4 Validation of the Groundwater to Indoor Air Transport Calculations

RISC output was compared with independent calculations for the conditions given in Table 7.4. For these conditions, both RISC and independent calculations produced indoor air concentration estimates of 2.3×10^{-3} mg/m^3.

Table 7.4. Inputs for the groundwater to indoor air transport calculations.

Soil Properties				
Parameter	Vadose Zone	Lens	Capillary Fringe	Foundation
thickness of zone [m]	1.60	0.20	0.20	0.10
total porosity [m^3/m^3]	0.35	0.35	0.35	0.25
moisture content [m^3/m^3]	0.05	0.15	0.345	0.00
soil bulk density [g/cm^3]	1.70	1.70	1.70	1.70
Building Properties				
volume [m^3]	400			
air exchange rate [changes/d]	12			
total infiltration area [m^2]	150			
fraction of area with cracks	0.001			
Chemical-Specific Parameters	default RISC Benzene values			
groundwater concentration [mg/L]	1.0			

7.5 Validation of the Groundwater to Outdoor Air Transport Calculations

RISC output was compared with independent calculations for the conditions given in Table 7.5. For these conditions, both RISC and independent calculations produced indoor air concentration estimates of 1.6×10^{-6} mg/m^3.

Table 7.5. Inputs for the groundwater to outdoor air transport calculations.

Soil Properties			
Parameter	Vadose Zone	Lens	Capillary Fringe
thickness of zone [m]	1.30	0.10	0.30
total porosity [m^3/m^3]	0.35	0.27	0.35
soil bulk density [g/cm^3]	1.70	1.70	1.70
infiltration rate [cm/y]	5.0	5.0	5.0
Van Genuchten's N	2.68	2.0	NA
saturated hydraulic conductivity [m/d]	10.0	0.10	NA
residual moisture content [m^3/m^3]	0.05	0.15	NA
moisture content [m^3/m^3]	calculated	calculated	0.34
Outdoor Air Parameters			
height of box [m]	2		
length of box [m]	10		
wind speed [m/s]	2.25		
Chemical-Specific Parameters	default RISC Benzene values		
groundwater concentration [mg/L]	1.0		

7.6 Validation of the Soil to Indoor Air Transport Calculations

RISC output was compared with independent calculations for the conditions listed in Table 7.6. Three different source zone benzene-total hydrocarbon concentration combinations were used to assess if the partitioning algorithms functioned as described in the user's manual. For these three cases RISC agree well with the independent calculations.

Table 7.6. Inputs and results for the soil to indoor air transport calculations.

Soil Properties			
Parameter	Vadose Zone	Lens	Foundation
thickness of transport zone [m]	2.80	0.20	0.15
total porosity [m^3/m^3]	0.35	0.35	0.25
moisture content [m^3/m^3]	0.05	0.15	0.00
soil bulk density [g/cm^3]	1.70	1.70	1.70
Building Properties			
volume [m^3]	400		
air exchange rate [changes/d]	12		
total infiltration area [m^2]	150		
fraction of area with cracks	0.001		
depth below ground surface [m]	3.0		
length of cracks [m]	50.0		
pressure gradient [g/cm^2-s]	5.0		
Chemical-Specific Parameters	default RISC Benzene values		
Soil Concentrations	Case A	Case B	Case C
Benzene [mg/kg]	1000	10	10
Total Hydrocarbons* [mg/kg]	0	1000	10000
Output - Indoor Concentrations			
RISC [mg/m^3]	11	0.14	0.014
independent calculation [mg/m^3]	10	0.12	0.014

* - MW=100 g/mole

7.7 Validation of the Vadose Model Calculations

RISC's vadose zone model is used to calculate vapor emissions to the atmosphere as well as leachate loading to groundwater. The vapor emission estimates are then coupled with an atmospheric box model dispersion to calculate outdoor air concentrations. Leachate loading to groundwater is used as an input to the dissolved groundwater transport model, which is used to estimate concentrations at downgradient wells.

RISC output was compared with independent calculations for the conditions listed in Table 7.7. The RISC-predicted source mass vs. time is compared with independent calculations in Figure 7.1, the RISC-predicted above ground air concentration vs. time is compared with independent calculations in Figure 7.2, and the RISC-predicted dissolved concentration just above the water table vs. time is compared with independent calculations in Figure 7.3. As can be seen, the agreement is very good in all figures.

Table 7.7. Inputs for the vadose zone model calculations.

Soil Properties			
Parameter	Vadose Zone	Lens	Source
thickness of zone [m]	4.0 m above source 2.8 m below source	0.20	3.0
total porosity [m^3/m^3]	0.35	0.35	0.35
soil bulk density [g/cm^3]	1.70	1.70	1.70
infiltration rate [cm/y]	20	20	20
Van Genuchten's N	2.68	2.0	2.68
residual moisture content [m^3/m^3]	0.05	0.15	0.05
saturated hydraulic conductivity [m/d]	10.0	1.0	10.0
moisture content [m^3/m^3]	calculated	calculated	calculated
Outdoor Air Parameters			
height of box [m]	2		
length of box [m]	10		
wind speed [m/s]	2		
Source Zone Parameters			
source length [m]	10		
source width [m]	10		
Chemical-Specific Parameters	default RISC Benzene values		
first-order decay coefficient in the source zone [1/d]	0.0		
first-order decay coefficient in the vadose zone [1/d]	0.001		
soil concentration [mg/kg]	500		
soil TPH concentration [mg/kg]	5000		
TPH molecular weight [g/mole]	100		

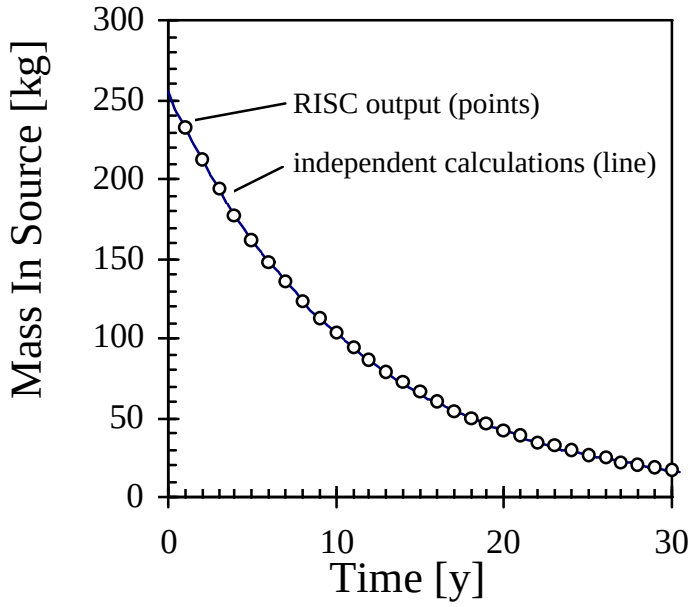


Figure 7.1. Comparison of the benzene mass remaining in the source vs. time for both RISC and independent predictions.

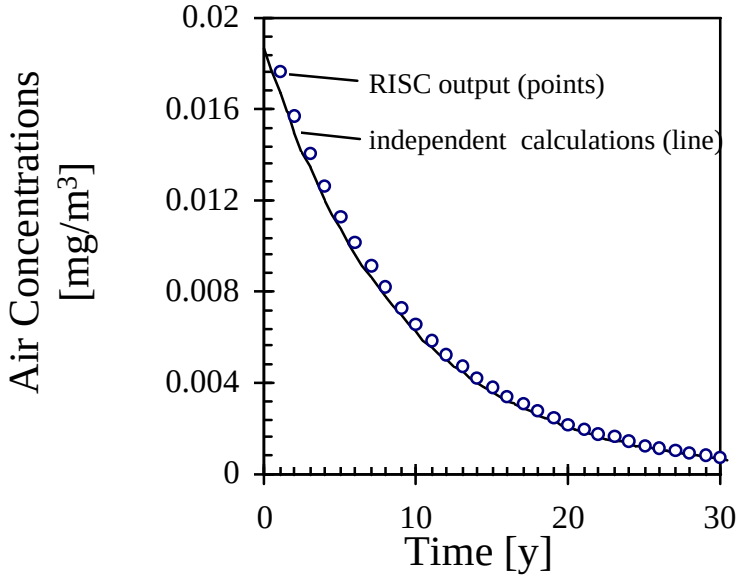


Figure 7.2. Comparison of the outdoor air benzene concentrations vs. time for both RISC and independent predictions.

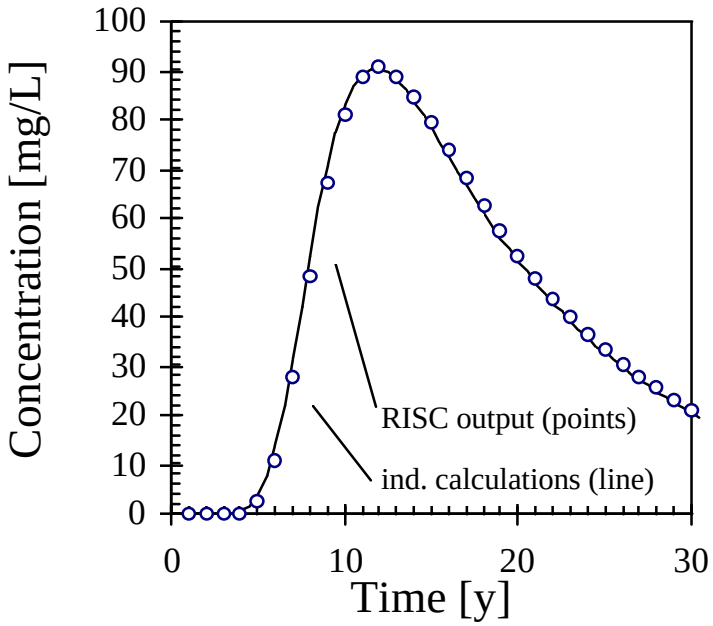


Figure 7.3. Comparison of the dissolved benzene concentration just above the water table vs. time for both RISC and independent predictions.

7.8 Validation of the Groundwater Transport Calculations

In this case a comparison was made between RISC's groundwater transport calculations and a different, but similar groundwater model - the three-dimensional analytical solution published by Domenico (1987). This was done for both simplicity, and because many other risk-based decision tools employ the Domenico algorithm, which models the transport away from a steady and infinite vertical planar source located in the saturated zone. The media is homogeneous, but may be anisotropic with respect to dispersion, and first-order decay is allowed.

To simulate this situation in RISC it is necessary to create a relatively steady source. This is accomplished by making the source zone very thick (10,000 m in this case), and also eliminating the potential for diffusive losses by either: a) placing a very thick vadose zone above the source, b) decreasing the chemical's vapor pressure, or c) increasing the moisture content of the vadose zone. Table 7.8 lists the input parameters used in these calculations. Figure 7.4 compares the steady-state dissolved groundwater concentrations vs. distance with independent calculations using the Domenico algorithm. Again, the agreement is good, and deviations close to the source are expected as both models use

different boundary conditions. Agreement should improve as one moves farther away from the source zone as is shown in Figure 7.4.

Table 7.8. Inputs for the groundwater transport calculations.

Aquifer Properties	
Parameter	Vadose Zone
effective porosity [m^3/m^3]	0.30
fraction organic carbon	0.005
hydraulic conductivity [m/d]	10
soil bulk density [g/cm^3]	1.70
hydraulic gradient [m/m]	0.001
dispersivities	code calculated
well screen interval [m]	0 - 3.0
Source Parameters	
width [m]	10
length [m]	10
thickness of source in aquifer [m]	code calculated
infiltration rate [cm/y]	20
Chemical-Specific Parameters	default RISC Benzene values
first-order degradation rate [1/d]	0.01

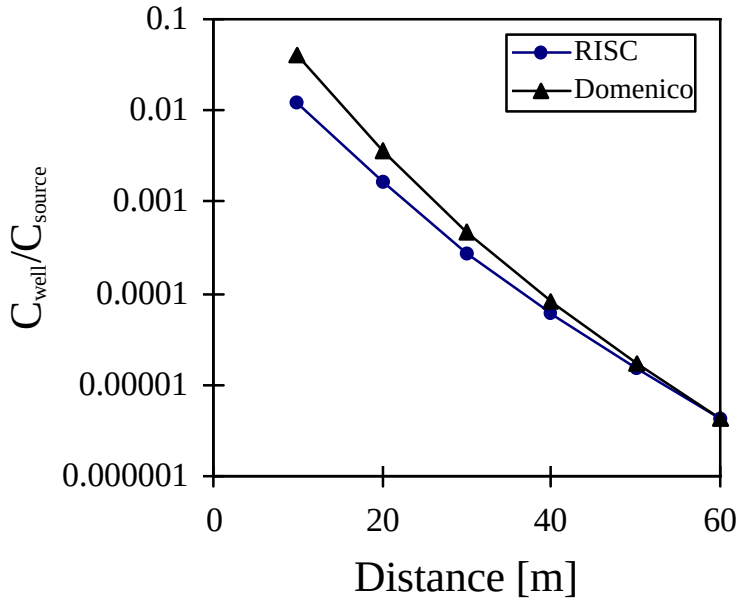


Figure 7.4. Comparison of RISC groundwater transport calculations for benzene with similar solutions using the Domenico (1987) algorithm.

8.0 COMPARISON OF RISC OUTPUT WITH OTHER PUBLISHED EXAMPLES OF SAMPLE SITE CLEANUP NUMBERS

In §7.0 it was determined that the RISC software appears to correctly use the algorithms described in the RISC user's manual. This was accomplished by comparison of RISC output with independent calculations. Those results should give the reader confidence that the software accurately conducts its calculations in accordance with the user's manual description of the algorithms used.

In addition, however, some readers will wish to know how RISC results compare with other existing approaches and published cleanup numbers. This is the focus of this section.

In the following, cleanup numbers (or target screening level values) from the following sources are compared:

a) output from the Tier 1 spreadsheet that is distributed with RISC. The user's manual indicates that the algorithms embedded in the spreadsheet are identical to those published in the *ASTM E1739-95 Standard Guide to Risk-Based Corrective Action Applied at Petroleum Release Sites.* Some of the RISC Tier 1 spreadsheet inputs, however, differ from those used in the ASTM document,

b) output from the RISC model,

c) entries from the Generic SSL Table A-1 given in the *USEPA Soil Screening Guidance: Technical Background Document* (EPA/540/R-95/128, Office of Solid Waste and Emergency Response, 1995),

d) entries from the Example Tier 1 Risk-Based Screening Level (RBSL) Look-Up Table X2.1 given in the *ASTM E1739-95 Standard Guide to Risk-Based Corrective Action Applied at Petroleum Release Sites* (ASTM, 1995) document, and

e) entries from the recently released Oil Industry Environmental Working Group (OIEWG) Guidelines for the Assessment and Management of Petroleum Hydrocarbon Contaminated Sites (Wellington, NZ).

These sources were chosen for the following reasons:

- the ASTM and USEPA Soil Screening Guidance documents form the basis for many regulatory programs and cleanup numbers, and

- the New Zealand (NZ) guidelines are an example of a comprehensive approach to development of cleanup numbers using available screening level models for a wide range of soil conditions.

Not all algorithms and inputs are common to each of the sources, so variability in the results is to be expected. To minimize this variability, inputs for the RISC-generated results were selected to insure that the scenarios modeled were representative of the scenarios upon which the ASTM, USEPA, and NZ results are based. No attempt was made to select conditions that gave a best fit between RISC output and any of the other values. In addition, not all pathways are addressed in each document. For example, the USEPA Soil Screening Guidance only addresses soil ingestion, inhalation of vapors from surficial soils, and leaching to groundwater.

In each case, relatively conservative scenarios are compared. The USEPA, ASTM, and NZ documents utilize exposure inputs considered to be "reasonable maximum exposure (RME)" parameters, so the default RISC adult residential RME values were used. Conservative transport parameters are also typically used in the development of screening level values, so soils were assumed to be sandy with properties given by the RISC default soil properties database. Where possible, other necessary inputs (distance to groundwater, distance from source to building, source size, etc.), were selected to be consistent with the values used in the ASTM E1739-95 document. Default RISC chemical-specific parameters (physical, chemical, and toxicological) were also used in the calculations.

Pathway-specific cleanup numbers were generated using RISC for a 10^{-5} target incremental cancer risk and a hazard quotient equal to one. Four chemicals were selected; two are carcinogenic and two are non-cancer causing; three are relatively volatile chemicals with a range of solubilities, and one is not volatile and relatively insoluble. All are relatively common chemicals of concern at petroleum release sites. The USEPA Soil Screening Guidance document values were generated for a 10^{-6} incremental cancer risk, and therefore needed to be adjusted for a 10^{-5} incremental cancer risk prior to entry into Table 8.1 below. ASTM E1739-95 values were similarly adjusted.

Table 8.1 presents the comparison by pathway and chemical. As can be seen, RISC results generally agree well with ASTM E1739-95, RISC Tier 1 spreadsheet, and USEPA generic soil screening level values. For the purpose of this analysis, agreement within a

factor of ten is considered good, given the slight variations in input parameters between the different approaches.

Large deviations occur, however, for the subsurface and surface soil volatilization pathways. In this case, RISC reports cleanup levels that are several orders of magnitude greater than the ASTM Tier 1 and USEPA generic soil screening values. This reflects inherent differences in the volatilization models used. The USEPA and ASTM subsurface algorithms are based on constant non-depleting sources, while the RISC algorithms account for source decay (as do the New Zealand calculations). The more realistic depleting source approach always results in larger cleanup levels than the constant source algorithms, if all other conditions are comparable.

In the case of surficial soil calculations, RISC assumes volatilization from a fixed depth equal to the source vertical midpoint, while the ASTM and USEPA algorithms allow for initial volatilization from the ground surface followed by depletion with time from an infinitely thick source. Thus, initial emissions estimates given by RISC are lower than those predicted by the USEPA and ASTM algorithms. This gives rise to the greater cleanup numbers. If the user is interested in short-time volatilization behavior, the ASTM and USEPA approaches are likely to better estimate real behavior.

All inputs being equal, it would be expected that RISC software cleanup levels would be biased towards larger cleanup values relative to ASTM example target screening levels and USEPA generic soil screening levels. This is because those other approaches assume constant strength (infinite) sources when evaluating leaching to groundwater and volatilization from subsurface soils. RISC allows for finite strength sources by accounting for the mass lost due to volatilization and leaching with time, except when considering vapor migration to indoor air from soil and groundwater.

Again, given the slight variability in inputs between the different approaches, the results presented in Table 8.1 should give the reader confidence that RISC produces reasonable conservative screening level cleanup numbers, relative to other approaches currently in practice. Thus, it is expected that RISC cleanup level output for other more site-specific conditions would also be reasonable.

Table 8.1. Comparison of conservative screening level cleanup numbers.

Pathways [and units]	Source	Benzene	Toluene	Xylenes	Benzo(a) pyrene
surficial soils - combined ingestion, dermal absorption, and inhalation of vapors					
[mg/kg]	ASTM	58	13300	>10[6]	1.3
[mg/kg]	RISC SS	39	SAT[1]	SAT[1]	1.0
surficial soils - combined ingestion and dermal absorption					
[mg/kg]	USEPA[2]	220	16000	160000	0.9
[mg/kg]	NZ[3]	190	24000	21000	7.5
[mg/kg]	RISC	20	4500	4500	0.6
volatilization to outdoor air from surficial soil					
[mg/kg]	USEPA	8	650	430	-
[mg/kg]	NZ	165	5250	4290	529
[mg/kg]	RISC	2020	>Res[4]	>Res[4]	>Res[4]
volatilization to outdoor air from subsurface soil					
[mg/kg]	ASTM	2.7	>Res[4]	>Res[4]	>Res[4]
[mg/kg]	RISC SS	3.9	SAT[1]	SAT[1]	SAT[1]
[mg/kg]	NZ	177	6940	5560	890000
[mg/kg]	RISC	565	>Res[4]	>Res[4]	>Res[4]
volatilization to indoor air from subsurface soil					
[mg/kg]	ASTM	0.054	206	>Res[4]	>Res[4]
[mg/kg]	RISC SS	0.078	SAT[1]	100	SAT[1]
[mg/kg]	NZ	2.4	210	160	>NA[5]
[mg/kg]	RISC	0.048	16	60	>Res[4]
volatilization to indoor air from groundwater					
[mg/L]	ASTM	0.74	85	>solubility	>solubility
[mg/L]	RISC SS	0.25	>solubility	60	>solubility
[mg/L]	NZ	77	>solubility	>solubility	>solubility
[mg/L]	RISC	0.37	47	88	0.0016
leaching to groundwater from subsurface soils					
[mg/kg]	ASTM	0.17	129	>Res[4]	>Res[4]
[mg/kg]	RISC SS	0.25	SAT[1]	SAT[1]	14
[mg/kg]	NZ	1.3	324	193	40
[mg/kg]	RISC	0.47	102	>Res[4]	0.47
[mg/kg]	USEPA[6]	0.03	12	200	8

SS - spreadsheet
1 - RISC spreadsheet indicates that result exceeds the concentration for which the three-phase partitioning assumption is valid.
2 - USEPA Soil Screening Guidance considers only ingestion.
3 - New Zealand guidance considers ingestion and dermal absorption separately; the value displayed in Table 7.1 is the lowest value.
4 - target cancer risk or hazard quotient cannot be exceeded even if pure phase product is present.
5 - risk-based criteria significantly higher than that likely to be encountered onsite.
6 - using a dilution attenuation factor (DAF)=20.

1.0
OVERVIEW AND GETTING STARTED

1.1 INTRODUCTION

1.1.1 Background

British Petroleum's (BP's) Risk-Integrated Software for Cleanups (RISC) has been developed to assist in the evaluation of potential human health risks from contaminated sites. RISC is a Windows• based software program that can be used to estimate the potential for adverse human health impacts (both carcinogenic and non-carcinogenic) from up to nine exposure pathways; additional pathways and other non-human health impacts may be considered in future revisions. The software contains vadose zone, saturated zone, and air fate and transport models for estimating receptor point concentrations.

The reader should note that through out this document the term “risk” will be used to refer to the estimated potential for adverse human health impacts, for both carcinogenic and non-carcinogenic compounds. For some, this is a departure from the more rigorous use of the term “risk”, where it is sometimes only used to refer to the probability of developing cancer as a result of exposure to a chemical or group of chemicals.

1.1.2 Uses of this Software

There are at least three broad applications for the RISC software. RISC can be used to (1) estimate human health risk from exposure to contaminated media, (2) estimate risk-based clean-up levels in various media, and (3) perform simple fate and transport modeling. These three different applications are discussed in the following sections.

1.1.2.1 Human Health Risk Assessment

Human health risk assessment can be defined as the characterization of the potential adverse effects on human life or health. Calculating risk is sometimes called the “forward calculation” whereas calculating clean-up levels is called the “back calculation”.
US EPA’s Risk Assessment Guidance for Superfund, or the “RAGS” manual (US EPA, 1989), characterize the risk assessment process by dividing it into four basic steps:

(1) Data Collection and Evaluation
    - Gather and analyze relevant site data
    - Identify potential chemicals of concern (CoC's)

(2) Exposure Assessment
    - Analyze contaminant releases
    - Identify exposed populations
    - Identify potential exposure pathways
    - Estimate exposure concentrations for pathways
    - Estimate contaminant intakes for pathways

(3) Toxicity Assessment
    - Collect qualitative and quantitative toxicity information
    - Determine appropriate toxicity values

(4) Risk Characterization
    - Characterize potential for adverse health effects to occur
        - Estimate cancer risks
        - Estimate noncancer hazard quotients
    - Evaluate uncertainty
    - Summarize risk information

The RISC software can be used for steps 2 through 4 of the risk assessment process. It is assumed that Step 1 has already been completed, i.e. the site has been characterized as to the chemicals present, media contaminated, etc. Usually the user will want to pare down the total list of chemicals found by evaluating the list using a concentration-toxicity screen. This process (described in detail in RAGS) identifies the chemicals that currently pose the greatest share of the risk.

The RAGS manual states that specific objectives of the risk assessment process are to:

- provide an analysis of baseline risks and help determine the need for action at sites;
- provide a basis for determining levels of chemicals that can remain onsite and still be adequately protective of public health (section 1.1.2.4);
- provide a basis for comparing potential health impacts of various remedial alternatives; and
- provide a consistent process for evaluating and documenting public health threats at sites.

The RISC software is a powerful, flexible tool that can be used for any of the above objectives. The reader is referred to the RAGS manual (US EPA, 1989) for more detailed information on each step of the risk assessment process.

1.1.2.2 Risk-Based Corrective Action

Risk-Based Corrective Action (RBCA) is a decision-making process for assessment and response to subsurface contamination, and is based on protection of human health and environmental resources. One of the steps in RBCA is to calculate clean-up levels, or concentrations of contaminants that pose an acceptable risk left in place (the back-calculation). The guidelines for RBCA are published in ASTM E1739-95, Standard Guide for Risk-based Corrective Action Applied at Petroleum Release Sites.

- The RBCA process was developed as a way to allocate limited resources (time, money, regulatory oversight, etc.) to multiple release sites in a way that allows innovative and cost-effective decision making while ensuring that human health and environmental resources are protected. In order to meet that goal, the process emphasizes the following:
- it integrates site assessment, remedial action selection and site monitoring so the approach is streamlined, targeted and consistent;
- site assessment activities are focused on collecting information needed to make risk-based corrective action decisions; and
- these corrective action decisions are based on site-specific factors and compliance points directed toward cost-effective alternatives that have a high probability of achieving an appropriate reduction in risk.

The RBCA process involves a tiered approach to data collection and evaluation. In general, Tier 1 of the RBCA process involves an initial site assessment and classification of the site based on conservative risk-based screening levels (RBSLs) that are not site specific. Tiers 2 and 3 involve evaluating the site using more site-specific information (e.g., depth to groundwater, infiltration rate, etc.) and/or evaluating alternate compliance points (locations of exposure). Tier 3 is likely to involve more complex analysis such as detailed site assessment, probabilistic evaluations, and sophisticated chemical fate and transport models.

RISC has a spreadsheet that can be used to develop Tier 1 RBSLs (or look-up tables). This spreadsheet contains all of the chemicals in the RISC software and is based on the equations presented in the ASTM E1739-95 appendix. The inputs are customizable, however, so that multiple RBSL tables can be generated (e.g., different soil types). The RISC software contains fate and transport models that may be used to develop more site-specific clean-up levels. These models are applicable to a Tier 2 analysis under RBCA. Probabilistic exposure evaluations are possible using RISC with the Monte Carlo analysis option. This would nominally fall into a Tier 3 analysis, although a user can readily implement the Monte Carlo approach using a provided default set of distributions for the exposure parameters.

The RBCA process is not limited to a particular class of compounds, even though the ASTM E1739-95 emphasizes application of the RBCA process to sites with petroleum releases. US EPA's Soil Screening guidance has been developed using a risk-based approach similar to RBCA. Many U.S. states are adopting RBCA type approaches for a wide variety of programs, not just the underground storage tank (UST) programs.

1.1.2.3 Fate and Transport Modeling

The fate and transport models in RISC are designed to be used for estimating receptor point concentrations as part of a risk assessment. The models use average annual data and are one-dimensional. These type of models are not applicable for complex engineering problems such as designing extraction wells, designing slurry walls, and the like. They can, however, be useful for evaluating several scenarios besides estimating receptor point concentrations as part of a risk assessment. Some of the questions that can be evaluated are:

- How far downgradient will a groundwater plume stabilize (reach equilibrium in terms of its length) if degradation is at rate *x*?
- Is a more sophisticated model needed? These models can serve as a "first cut" to see whether it is necessary to go to more complex codes.
- How long will it take for the contaminants to reach groundwater? What is the estimated loading rate to groundwater?
- How long until the soil source depletes?

RISC includes the following embedded chemical fate and transport models:

- Leaching from vadose zone soil source to groundwater;

- Dispersion, advection, and degradation of groundwater as it moves in an aquifer;
- Saturated soil source at the water table impacting groundwater;
- Emissions from soil to outdoor and indoor air; and
- Emissions from groundwater to indoor air.

The models listed above may be linked together as well. For example, the saturated soil source model (at the water table) can be linked with the groundwater model and then used to estimate volatile emissions to indoor air.

1.1.3 Overview of Features

1. The RISC software includes many features to assist in performing and presenting risk assessments or the results of fate and transport models. Version 4.0 of RISC allows the user to:

    - follow the ASTM tiered approach by utilizing a spreadsheet based on the ASTM algorithms for Tier 1, the embedded fate and transport models in RISC for Tier 2, and the Monte Carlo option in RISC for Tier 3;
    - choose chemicals of concern from a standard library of 86 chemicals; users may also add or delete chemicals from the library and alter the physical, chemical, and toxicological properties of each;
    - perform calculations for two different exposure scenarios (with up to thirteen exposure pathways each) simultaneously (e.g. calculations for both residential and industrial scenarios can be performed at the same time);
    - determine cumulative risks from two different exposure scenarios, as might be the case when the user wants to sum the risks for the scenario where a resident is exposed during both childhood and adulthood;
    - estimate exposure point water and air (both indoor and outdoor) concentrations using predictive chemical fate and transport models;
    - allow for additivity of pathways and compounds for either a forward calculation of risk or back calculation of cleanup levels
    - use an embedded tool to estimate average, 95th UCL, and weight-averaged concentrations for a set of parameter values; and
    - print or save tables, charts, and figures.

1.1.4 Organization and Scope of this Report

This User's Manual gives instructions on how to use RISC and discusses the technical details including the equations used to estimate risk, the fate and transport models included in the software, and the chemical database.

The organization of this User's Manual mimics the organization and flow of the RISC software; specifically:

- Section 1.2 guides the user through software installation, system requirements, and general operating instructions,
- Chapter 2 describes the RBCA Tier 1 Microsoft Excel® spreadsheet,
- Chapters 3 through 8 discuss how the software can be used to perform risk assessment calculations and determine cleanup levels,
- Chapter 9 describes various output and summary options,
- Chapter 10 provides three detailed examples to work through,
- Chapter 11 contains the chemical database, and
- the Appendices provide brief descriptions of each predictive model, the accompanying RBCA Tier 1 spreadsheet, and some input considerations.

1.2 GETTING STARTED

This section is divided into three sections: hardware and software requirements, installation instructions, and general instructions on using the software.

1.2.1 Hardware and Software Requirements

The computer hardware requirements for this software are:

- IBM 486 or compatible
- 10 MB RAM
- 8 MB hard disk space

The software requirement is:

- Microsoft Windows® 3.1, 95, 98, or NT

The following software is needed for accessing the optional RBCA Tier 1 spreadsheet:

- Microsoft Excel® 5.0 or 7.0 (for RBCA Tier 1 spreadsheet)

You will be able to run RISC without Excel, however you will not be able to view the RBCA Tier 1 table.

1.2.2 Installation Instructions

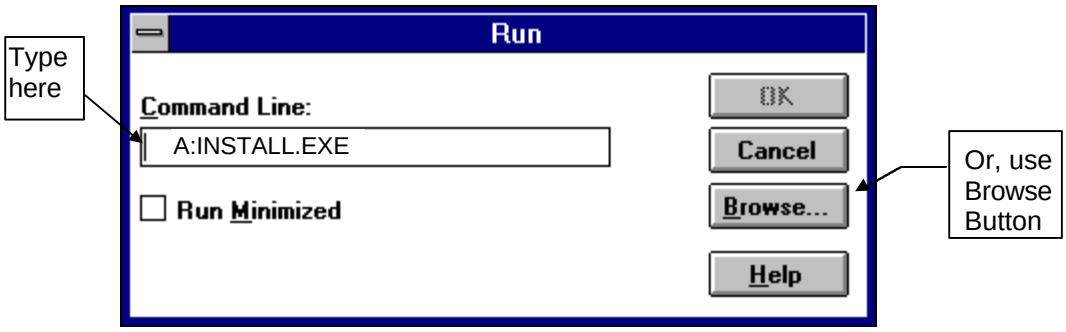
The RISC system uses the standard Windows installation procedure. If you are familiar with loading Windows programs you may just run the "INSTALL.EXE" file from Distribution Disk 1. The figures in the following instructions are for Windows 3.1, they will appear slightly different under Windows 95 and higher versions. If you are not familiar with this procedure perform the following steps to install RISC:

Step 1 Start Windows from the DOS prompt (if Windows is not running):

```
>WIN
```

Step 2 Insert Distribution Disk #1 into your computer.

Step 3 In Program Manager (Windows 3.1), (or the Start/Run buttons in Windows 95) choose **Run** from the **File** menu, then type A:INSTALL under "Command Line:" (your drive letter may be different) and click OK. Alternatively, the "Browse..." button may be used to select the install file from the disk rather than typing in the file name. The "Run" window is shown here.



Step 4 The installation package will show you several introductory screens (including one summarizing your computer system). You will be asked to select a drive where the RISC software will be installed. The installation package will let you know if you do not have enough memory to install the system.

Step 5 Next you will be prompted to enter a directory name where RISC will be installed. If the directory does not exist, the installation package will create it.

Now the files will be copied to your computer and a new Windows group called "RISC" will be created. You will be prompted to insert installation disks #2 and #3 when needed. After the files are copied and decompressed the installation package will set up a new icon and windows group for the RISC software. The installation is now complete.

1.2.3 General Instructions (How to Use RISC)

To start RISC, double-click on the “BP RISC” icon in the "BP RISC" group on your Windows desktop. This brings up the main screen of RISC. The user is encouraged to start the software and use it while reading the instructions in this chapter.

1.2.3.1 Main Screen Layout

The main screen of RISC is shown in Figure 1-1. In the main part of the screen are six steps for performing a risk assessment. Chapters 3 through 8 presents detailed instructions for completing these steps. Currently only Step 1 should be available. As you complete each step, the next step will become available. The Data and Analysis Tools (at the bottom of the screen in the white box) are not required to complete a risk assessment but can be used to for supplemental information and features. These options are described in Chapter 2.

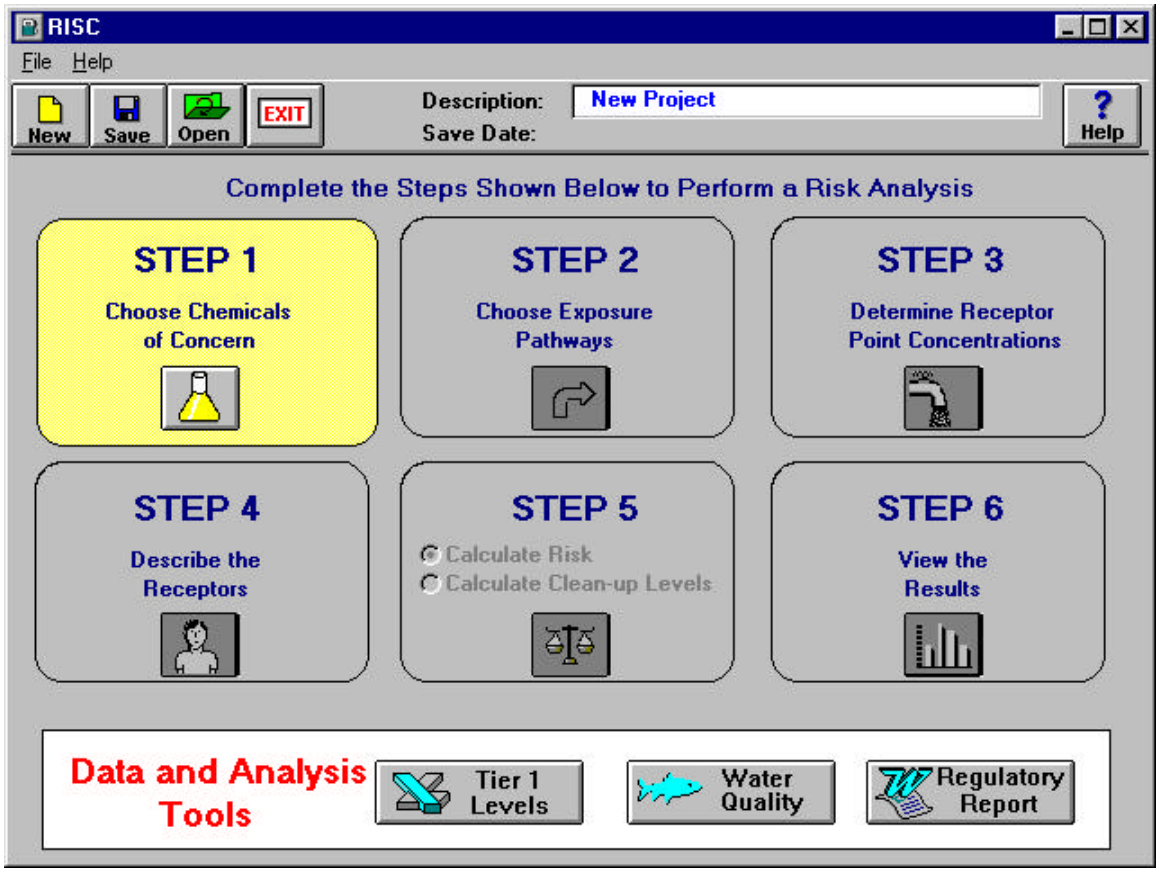


FIGURE 1-1. The Main Screen of RISC

At the top of the main window is a series of buttons (New, Save, Open, Exit and on the far right, Help). The functions of these buttons are discussed in the next sections.

1.2.3.2 New

Selecting the "New" button will clear all user-specified data (e.g. chosen exposure routes, site-specific concentrations, etc.). Suggested default inputs and chemical database entries will be retained. This should only be used when you want to start over. You will be warned and given a chance to cancel before "New" clears all current information.

1.2.3.3 Saving Projects

The "Save" and "Save As" buttons on the main button bar are used to save all the information contained in the project. "Save As" will prompt the user to enter a project file name with an extension of ".prj". It is not necessary to use this extension, but it will help identify the saved project files from other files in the directory. "Save" will save the project to the current save file without prompting for a file name (if one has been entered previously).

1.2.3.4 Loading Saved Projects

The "Open" button in the main button bar allows saved project files to be loaded into the system. The user will be prompted to choose the name of the saved file to be loaded. At this point, the user will be warned that "Open" will clear any data already entered in the system and that by continuing, this information will be lost. The user has the opportunity to "Cancel" and save current work if necessary.

1.2.3.5 Exit

The "Exit" button in the main screen closes the RISC system. You will be prompted to save your work. There are two other ways to exit the system. They are both identical to choosing the Exit button, however, these methods are available from every screen. (You don't have to return to the main screen in order to exit RISC.) The first is to chose **Exit** from the **File** pull-down menu at the top of all the windows. The second method is to

double click on the RISC system "control menu" at the top left corner of the window. (This is standard for closing any Windows software.)

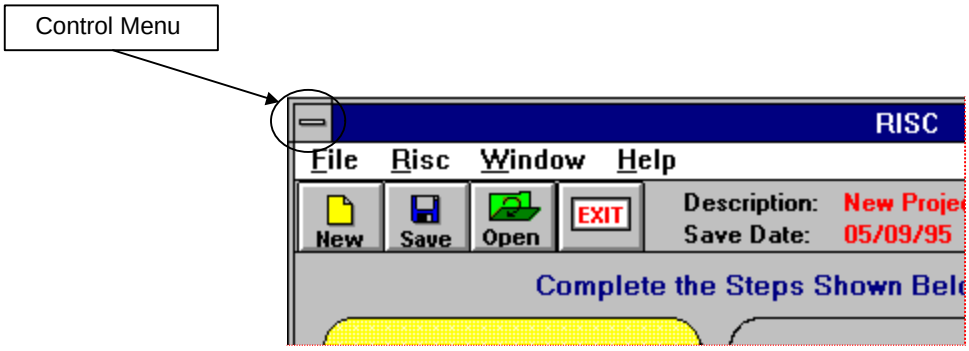


FIGURE 1-2. The Control Menu in Windows 3.1

Those using Windows 95® can also exit by clicking on the small “x” box in the upper right-hand corner of the screen.

1.2.3.6 Help System

The RISC software has on-line help that is available from every screen. This feature can be activated by choosing the HELP button. This displays the Help Window that has topic-specific information and a menu bar.

Note, some of the text displayed in the HELP window is highlighted in green. This is called HYPERTEXT and can be selected (by clicking) to view additional information on the topic. The help topics available in this version are limited and will be expanded in future versions.

1.2.3.7 Copying Text to the Windows Clipboard

Several windows (tables and charts) have a "Copy" button on their button bar allowing the text or graph in the window to be copied to the Windows Clipboard. The clipboard is a type of buffer that holds selected text or graphics. Once the text is in the clipboard, it can be copied to any other Windows application (such as Word or Excel). This may be useful for reformatting text or saving model output separately (from the project file).

Performing a Screen Dump

A screen dump takes a "snapshot" of what is currently on the screen and copies it to the Clipboard. To copy the current screen, push the "Print Screen" key from your keyboard. (If the keyboard does not have a "Print Screen" key, refer to the Windows manual to learn how to perform a screen dump.)

Once in the clipboard, the screen dump may be copied to other applications. With a screen dump the buffer contains a graphical image rather than text (note that "Copy" fills the buffer with a text file). This means that the image cannot be edited as a text file in a word processing program. The image may be modified in a drawing program such as the Windows Paintbrush, however.

This procedure will make a screen dump from any Windows application. The figures in this user's manual were generated using this procedure and then copying the image into Microsoft Excel or Word where the figure titles were added.

1.2.3.8 Printing

A "Print" button appears on several screens (specifically, tables and charts). This sends text directly to the printer. In order to use this feature, your printer must be configured in Windows and should work from other applications. The printer is configured by selecting the Windows "Control Panel" icon (usually loaded in the "Main" program group). After displaying the Control Panel, select "Printers" from the icons. The print orientation and scaling can be modified in the printer setup.

2.0
DATA AND ANALYSIS TOOLS

At the bottom of the Main RISC Screen, Figure 1-1, the user will find buttons leading to additional "Data and Analysis Tools". These provide supplemental tools, including a RBCA Tier 1 Excel worksheet and in the future, access to a surface water quality criteria look-up table. Use of the RBCA Tier 1 spreadsheet is discussed in section 2.1 It should be noted that using the Tier 1 spreadsheet is not required to perform calculations using the RISC software.

2.1 RBCA TIER 1 SPREADSHEET

This button calls upon Excel to open a spreadsheet that calculates RBCA Tier 1 Look-Up Table values for all of the chemicals initially contained in the RISC chemical database. The Look-Up Table values in this particular table are calculated using the example algorithms presented in the ASTM E1739-95 "Standard Guide to Risk-Based Corrective Action at Petroleum Release Sites" (1995). The spreadsheet is summarized in the following section and described in more detail in Appendix H.

In the RBCA approach, a Tier 1 Look-up Table is used to identify those chemicals and pathways that warrant further evaluation. It is generally understood that soil, groundwater, or air concentrations falling below Look-Up Table values are not of concern. It is envisioned that this RBCA Tier 1 spreadsheet could be used to identify those chemicals and pathways that warrant further evaluation through use of the RISC software.

Users should review the assumptions and inputs built into this table before using any of the values. Users should also note that there are differences between the algorithms used in this specific look-up table and those contained in the RISC software. In most cases, the algorithms used in the Tier 1 spreadsheet are simplifications of algorithms used in the RISC software. In some cases (e.g., inhalation exposures during showering), the RISC software includes exposure pathways and algorithms not included in the sample ASTM E1739-95 Look-Up Table (1995).

The Tier 1 spreadsheet may also be used as the first step of a Tier 2 analysis in which site-specific input values are used in conjunction with the Tier 1 algorithms to calculate Site-Specific Target Levels (SSTLs). In this mode, the receptor's point of exposure is still assumed to be at the source (same as Tier 1), however, site-specific inputs are substituted for the very conservative inputs assumed in Tier 1. Of course, the fate and transport models in RISC may also be used in an iterative fashion to calculate SSTLs for both types of exposure points, directly at the source and at a site-specific distance from the source zone. The equations used in RBCA are simpler and more conservative, in general, than the fate and transport models contained in RISC.

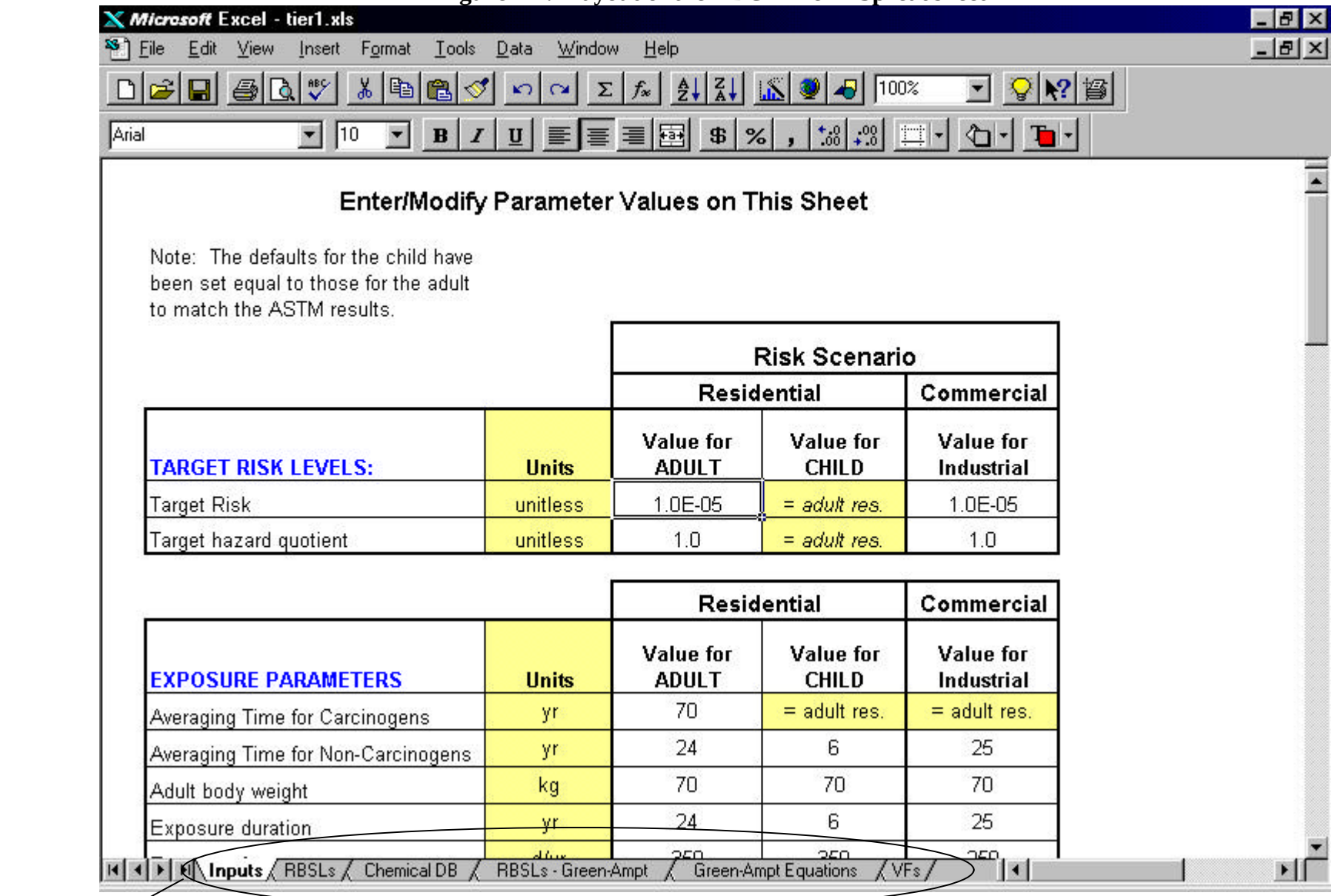
The Tier 1 spreadsheet contains several "worksheets" as shown in Figure 2-1. These different sheets can be accessed by clicking on the sheet tab on the lower left border. The input parameters are entered in the "Input Data" sheet. Note, there are input cells for both an adult and child residential scenario and an industrial scenario. For the residential carcinogenic risk calculation, a combination child and adult scenario is assumed. For hazard indices, a child receptor is assumed for residential. The residential and industrial scenarios generate different screening levels (presented in the screening level table.) The input values may be modified by the user to reflect site-specific conditions. The equations used to develop the tables are provided in Appendix H.

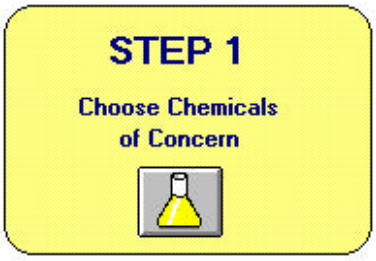
The risk-based screening levels for air, soil, groundwater, and surface water are presented on the "Look-up Table" sheet. The four media have been color-coded, with a different color for each media. The chemical database is presented on the sheet entitled "Chemical DB". The chemical database contains toxicity and physical properties for each chemical in the RISC software. These parameters may be modified by the user if more recent data is available (e.g. a new slope factor is published in IRIS). The bottom section of the "Chemical DB" sheet lists the volatilization factors, leaching factors and effective diffusion coefficients used in the screening level equations.

2.2 SURFACE WATER QUALITY CRITERIA

This button will use Excel to display a summary of the Ambient Water Quality Criteria (acceptable surface water concentrations) for all the chemicals in RISC. This feature will be available in the next version of RISC.

Figure 2-1. Layout of the RBCA Tier 1 Spreadsheet





3.0 CHOOSE CHEMICALS OF CONCERN

In this first step users identify chemicals that are of concern for their analysis. The RISC software contains a database with 86 chemicals. The chemicals of concern may be chosen from this database or new chemicals may be added to the system database and then chosen as a chemical of concern. Figure 3-1 shows the Step 1 main screen before any chemicals have been selected.

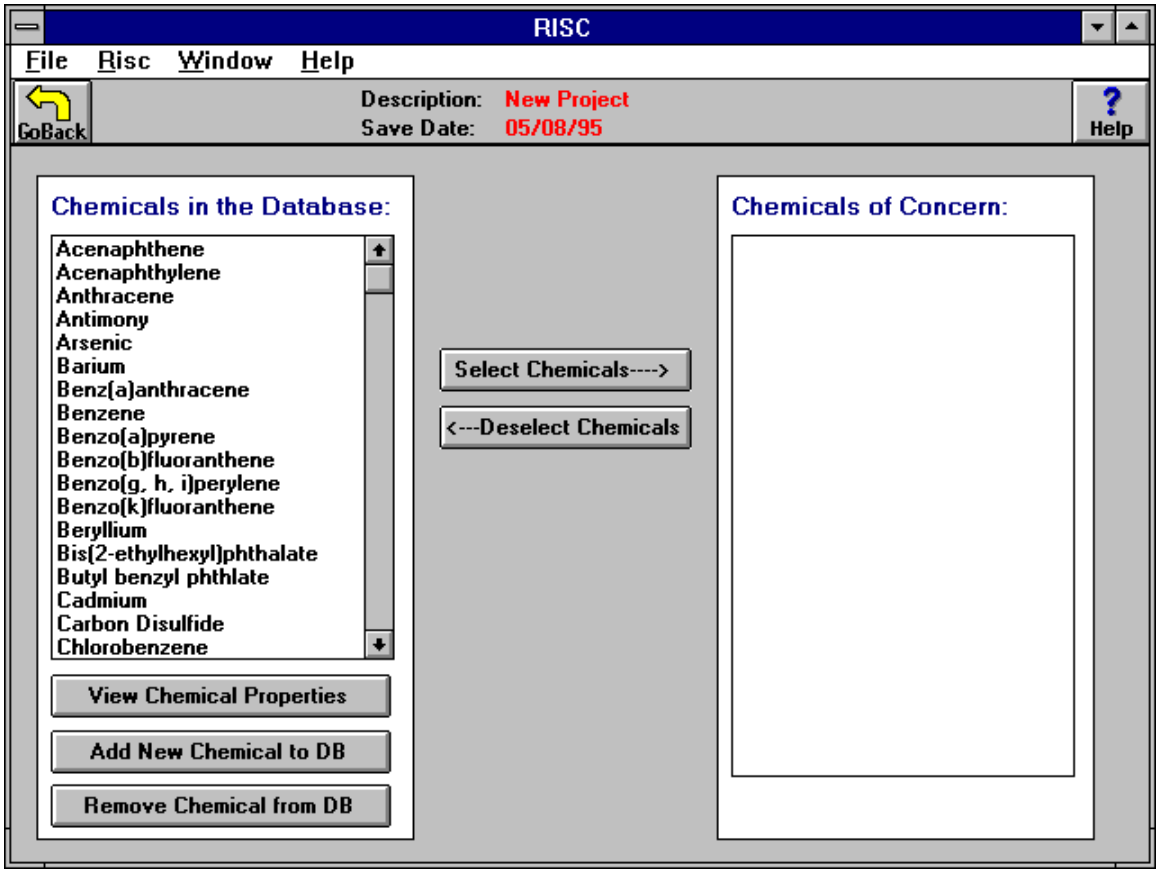


FIGURE 3-1. Chemical Selection Screen

3.1 CHOOSE CHEMICALS

The box on the left contains a list of all the chemicals currently in the system database. To select chemicals of concern, choose one or more chemicals from this list (by clicking on them with the mouse) and then choose the "Select Chemicals ---->" button. (Use the scroll bar to find chemicals not currently shown in the window.) The chemicals selected will be displayed in the box on the right. To "unselect" a chemical (or chemicals) of concern click on the chemical in the right box and choose the "<---Deselect Chemicals" button. Figure 3-2 shows the chemicals of concern screen with four chemicals of concern selected.

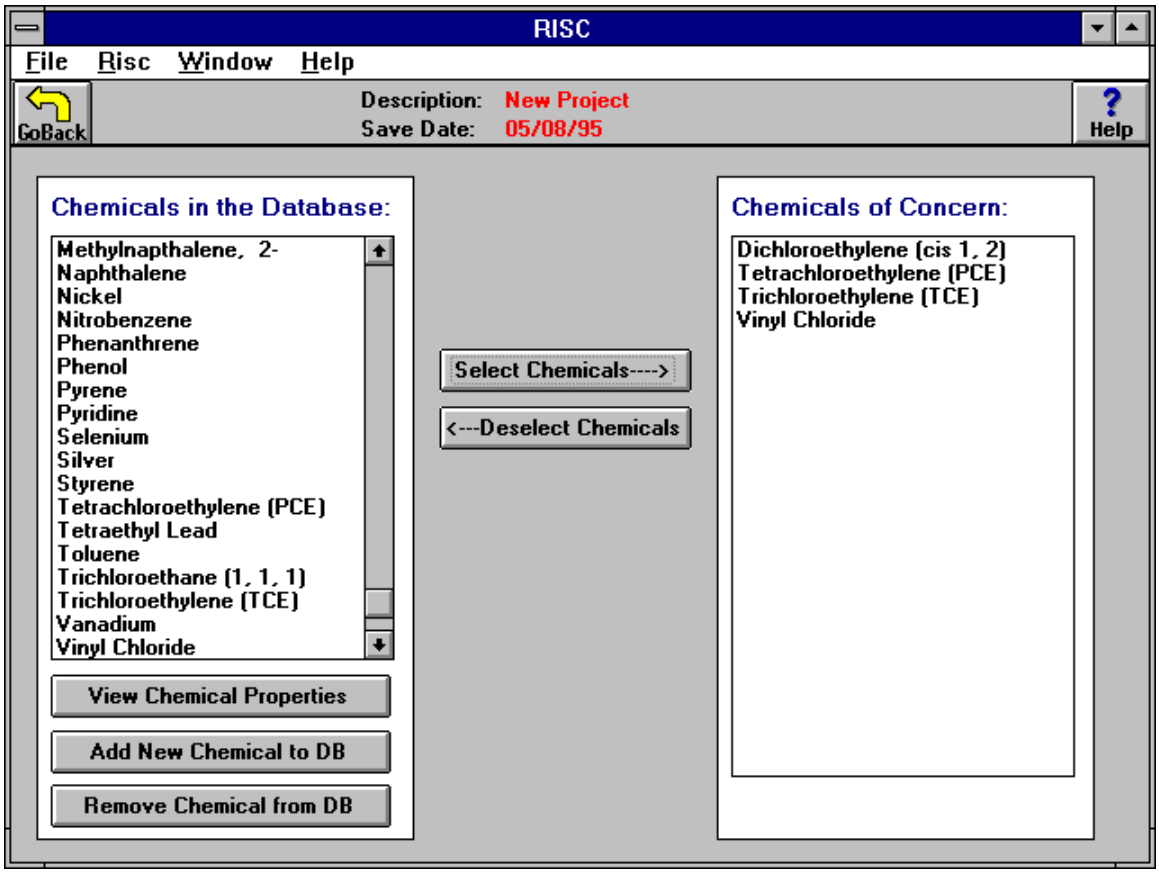


FIGURE 3-2. Chemical Selection Screen with Four Chemicals Selected

These four chemicals will now be the only chemicals considered in the current analysis. At any point the you may come back to this step and add or remove chemicals from the list of chemicals selected. Remember, however, if you have entered data or run the fate and transport models or a risk calculation with the previous suite of chemicals you may need to enter information for the new chemical(s) and rerun the models. The number of

chemicals that can be analyzed at one time is limited to 20 (due to memory limitations in the fate and transport and risk assessment computational codes).

3.2 VIEW CHEMICAL PROPERTIES

The "View Chemical Properties" allows you to view and edit the chemical properties in the system database. The physical and chemical properties were assembled from common chemical handbooks; the toxicological properties (including dose-response and absorption adjustment factors) were extracted from the an internal BP report prepared by ENSR (1995). Figure 3-3 shows the chemical properties for acenapththene. To view other chemicals, select the chemical from the list box in the top center of the screen. To edit the property values, click on the box containing the value and then enter the new value**. Any changes you make to the chemical properties will be stored in the permanent system database so be sure that the change is correct.**

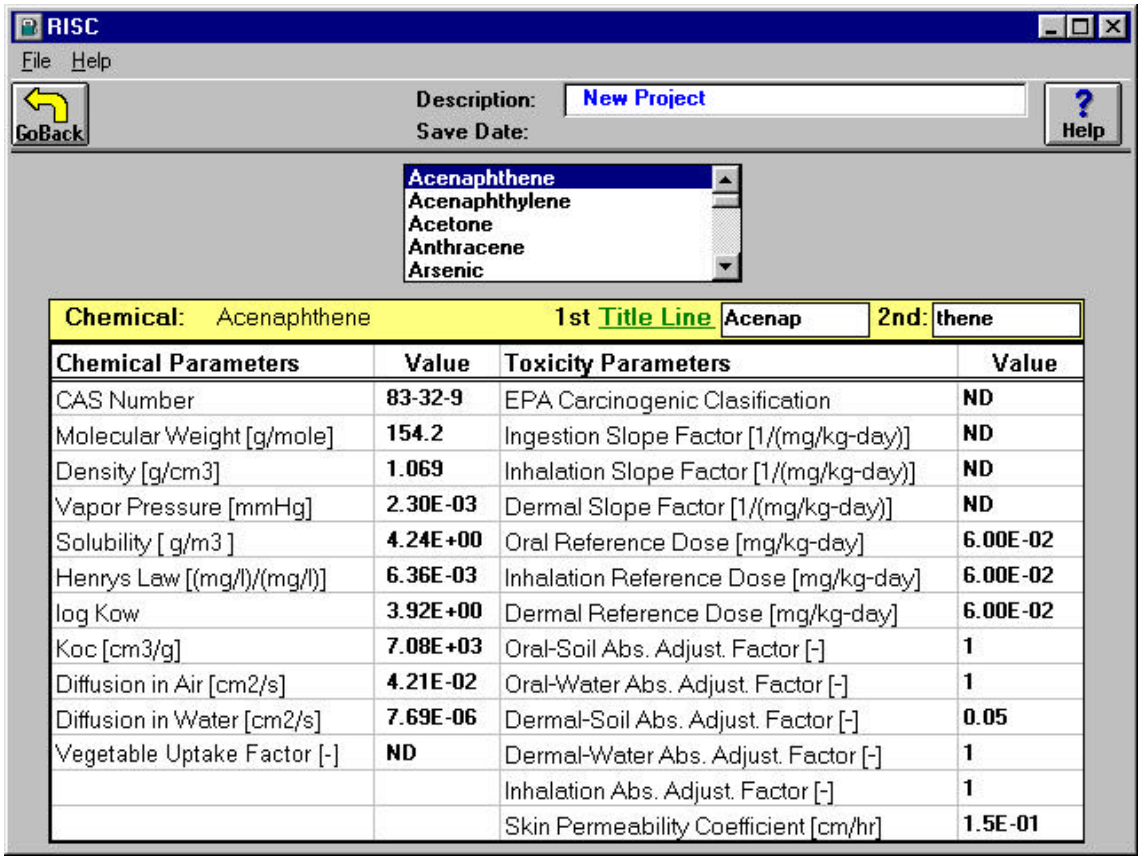


FIGURE 3-3: Chemical Properties Screen

3.3 ADD NEW CHEMICAL TO DATABASE

Selecting the "Add New Chemical to DB" button from the chemical selection screen (Figure 3-1) will allow you to add a chemical to the system database. You will be prompted to enter the chemical name.

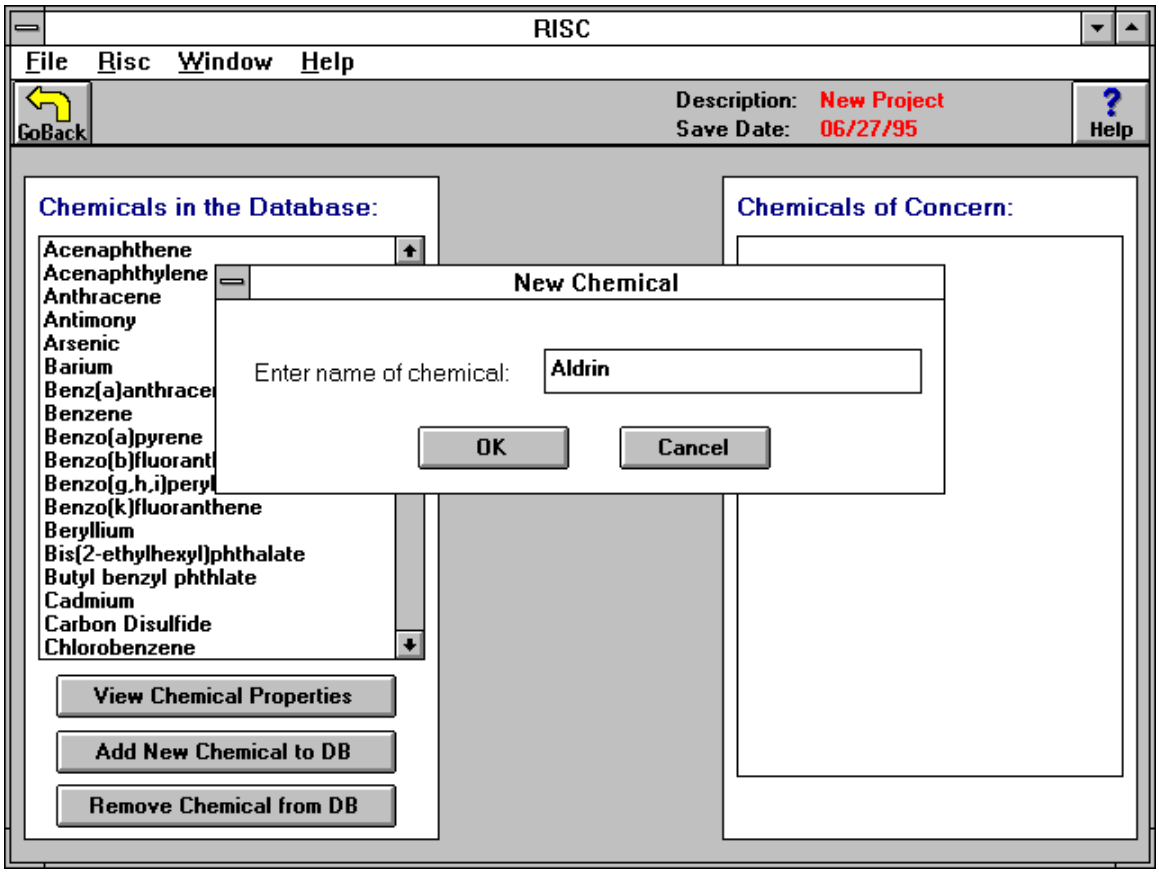


FIGURE 3-4. Adding a New Chemical

After you select the "OK" button, you will see the chemical properties screen for the new chemical (in this case, "aldrin"). Most of the chemical properties are listed as "ND" for no data (or not determined) as shown in Figure 3-5. At this point you should replace the "ND"s with the appropriate physical, chemical, and toxicological properties for the new compound.

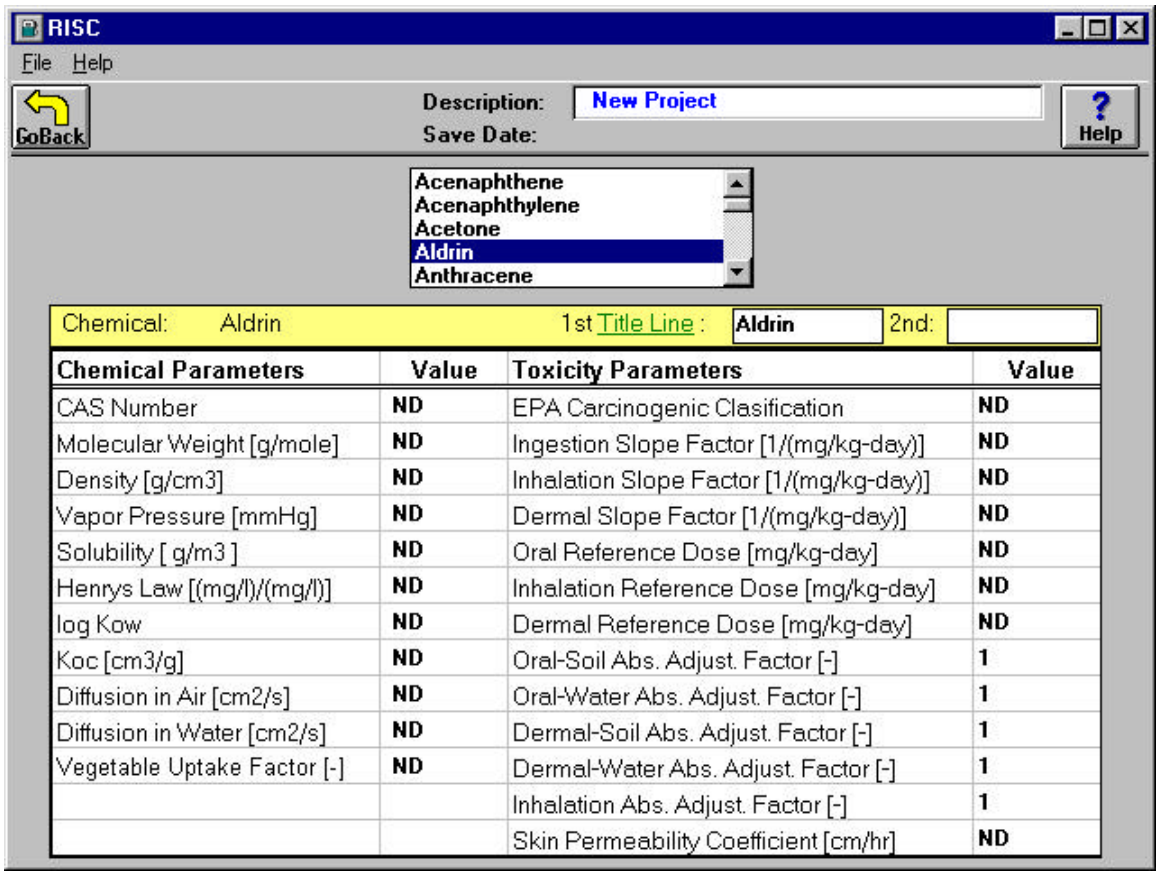


FIGURE 3-5. Default Chemical Properties for New Chemical

The empty boxes, "1st Title Line" and "2nd:" are used for long chemical names (more than 20 letters) when printing tables later in the software. For long chemical names that are printed in a column heading, the user has the opportunity to specify what to print on the first line and what to print on the second. The chemical name shown here (aldrin) is short, so nothing need be entered in these two edit boxes and the name will not be split into two title lines.

3.4 REMOVE CHEMICAL FROM DATABASE

After selecting a chemical (or multiple chemicals) from the chemical selection screen (Figure 3-1) you may remove them from the system database by clicking on the "Remove Chemical from DB" button. This action (if completed) will permanently remove the chemicals from the system database. It is recommended that you only remove chemicals that you have added yourself and leave the original chemicals in the database. One reason you may want to remove a chemical is if you added a chemical to the database and it was

misspelled. Figure 3-6 shows the warning window that appears when you choose to remove chemicals.

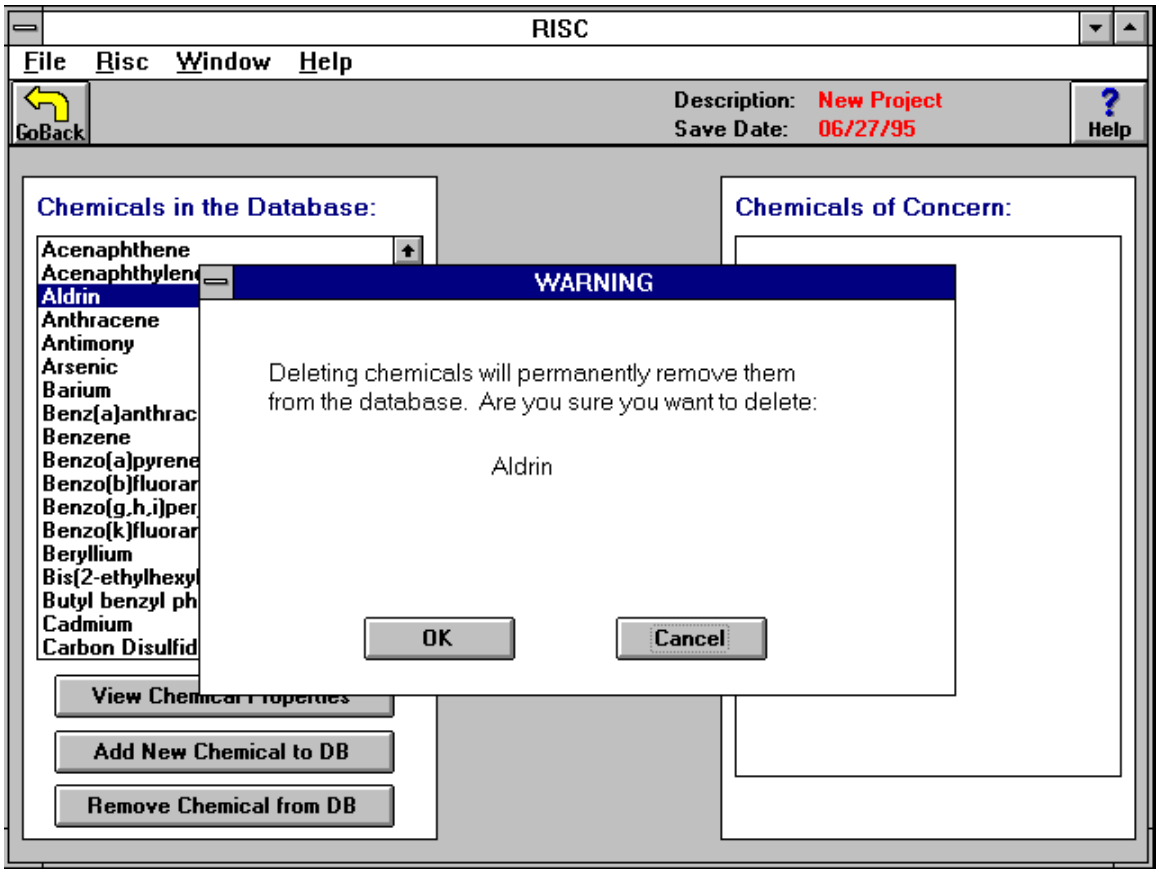
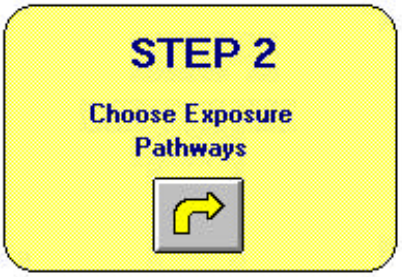


FIGURE 3-6. The Warning Window When Removing Chemicals

3.5 RESTORING THE ORIGINAL CHEMICAL DATABASE

The chemical database is contained in a binary (non-editable) file called "chemical.cdb". A duplicate file called "chemback.cdb" has been included in the RISC system directory. If you have changed the database and at some point would like to restore the original database delete the file "chemical.cdb".

Deleting "chemical.cdb" will tell RISC to use the backup file (the original database as it was shipped with RISC). However, any changes that you have made to the chemical database (additions, deletions and modifications of chemical properties) will be erased.



4.0 CHOOSE EXPOSURE PATHWAYS

This describes Step 2: Choose Exposure Pathways (main menu, see Figure 2-1). The selection of exposure pathways is a very important step in the risk assessment process. The user needs to identify those pathways that are likely to be complete, based on knowledge of the locations of impacted soil, groundwater, air, and surface water relative to the location and habits of people that might be exposed to the chemicals of concern. The US EPA's Risk Assessment Guidance for Superfund (1989) provides guidance for selecting appropriate exposure pathways for various risk assessment situations. Figure 4-1 shows the exposure pathways screen.

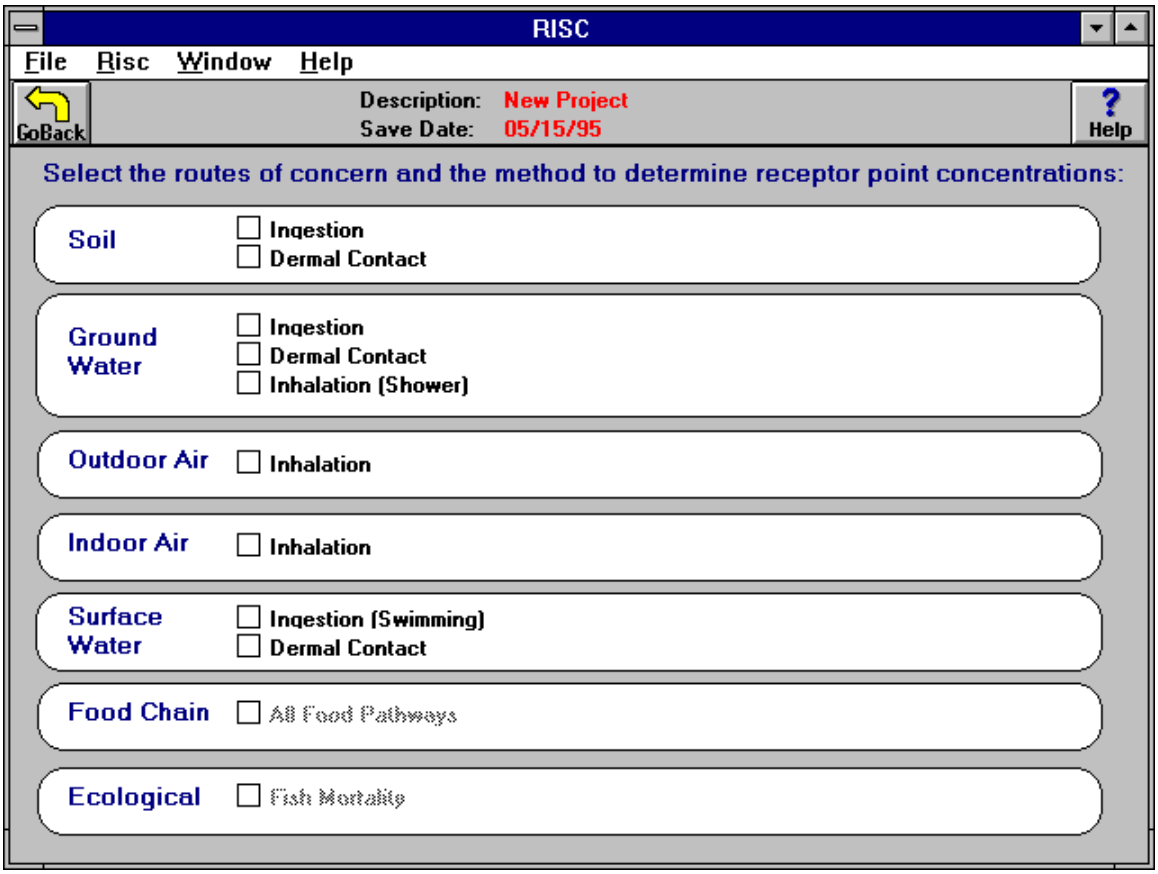


FIGURE 4-1. Choose Exposure Pathways Screen

There are nine human exposure routes available in this version of RISC. These exposure pathways are discussed in more detail in Chapter 6 (Step 4: Describe the Receptors). The equations used to estimate risk from each exposure pathway are presented in Chapter 7 (Step 5: Calculate Risk). In the next version of RISC, food chain pathways will be available along with ecological pathways. The routes of concern should be selected based on which media are contaminated (or may potentially become contaminated) **and** the likelihood that human receptors may be exposed as a result of the site contamination.

Routes are selected by clicking on the exposure route or clicking on the check box. When a groundwater, outdoor air, or indoor air exposure route is selected, the user will be asked to specify how receptor point concentrations will be estimated. For these three media, the user may specify concentrations explicitly or a fate and transport model can be used to estimate the concentrations over time. Figure 4-2 shows the options for estimating receptor point concentrations in groundwater.

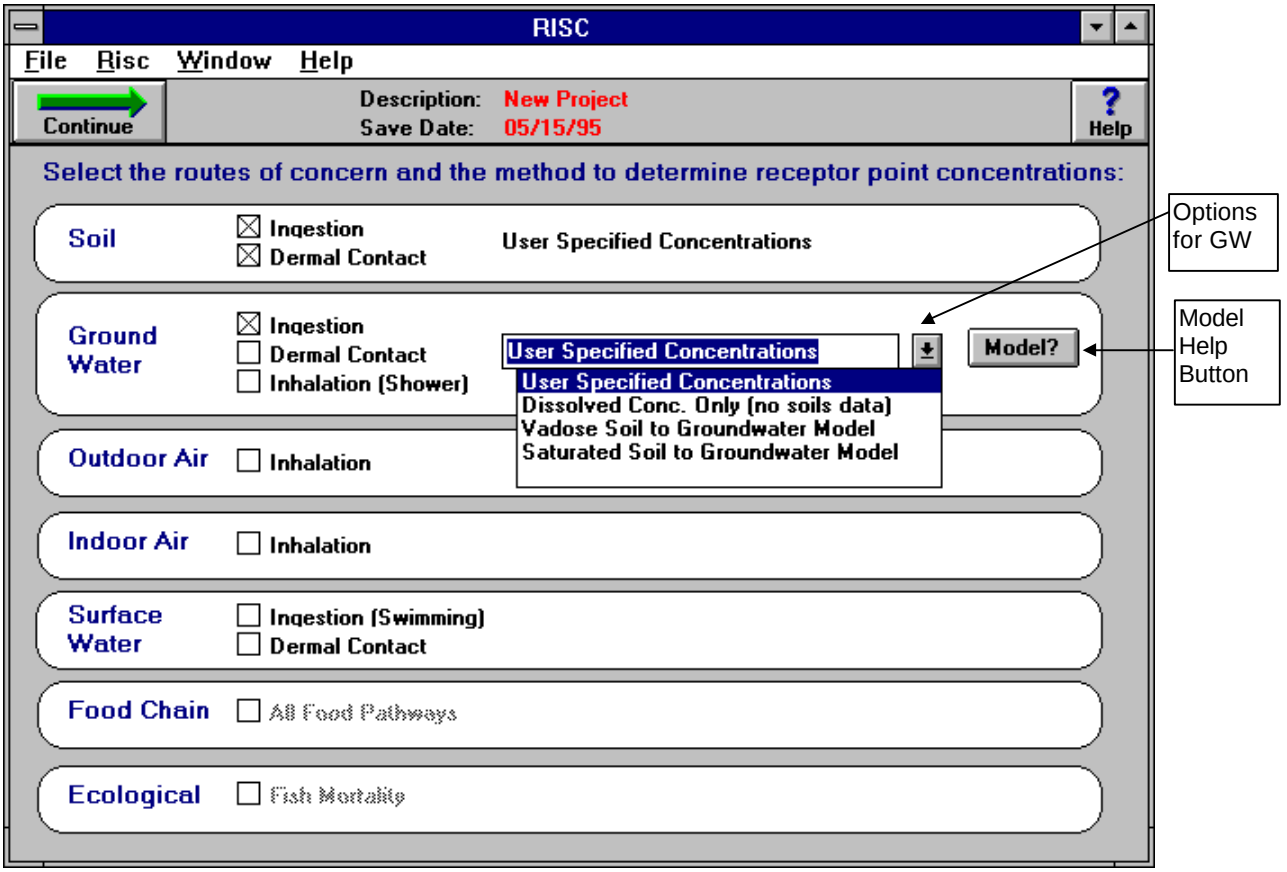


FIGURE 4-2. Options for Estimating Receptor Concentrations in Groundwater

If more than one groundwater exposure route is selected, the same method will be used for all routes in estimating the concentration. Note, the receptor point concentrations in soil and surface water cannot be estimated using a fate and transport model but must be entered explicitly by the user. Table 4-1 lists the options for specifying or estimating receptor point concentrations in each media.

TABLE 4-1. Receptor Point Concentration Options

MEDIA	OPTIONS
Soil	User Specified Concentrations
Groundwater	User Specified Concentrations Dissolved Concentrations Only (No Soils Data)* Vadose Soil to Groundwater Model* Saturated Soil to Groundwater Model*
Outdoor Air	User Specified Concentrations Vadose Soil Model*
Indoor Air	User Specified Concentrations Emissions from Soil* Emissions from Groundwater*
Surface Water	User Specified Concentrations

*** Uses a fate and transport model**

The fate and transport models are described in more detail in Chapter 5 (Step 3: Receptor Point Concentrations). There is also "on-line" help available from the 

button on the routes selection screen (Figure 4-2). There are six different fate and transport models available. Only one model may be chosen for a given media (groundwater, indoor air or outdoor air) at one time.

Fate and Transport Models For Groundwater

There are three options for estimating receptor point concentrations in groundwater: Dissolved Concentration Model, Vadose Soil to Groundwater Model, or Saturated Soil to Groundwater Model.

Both the "Dissolved Concentrations Model" and the "Saturated Soil to Groundwater Model" simulate transport of contaminants in the saturated zone only. These models differ only by the assumptions made about the source term. In the "Dissolved Concentrations Model", the dissolved phase (groundwater) concentrations in the source area must be specified. In the "Saturated Soil to Groundwater" the total soil concentrations in the source and the saturated depth of the source must be specified. In this option, the source is assumed to be in, or just above, the water table, enabling the effects of fluctuating water tables on groundwater loading to be modeled. The saturated zone model is described in Appendix B.

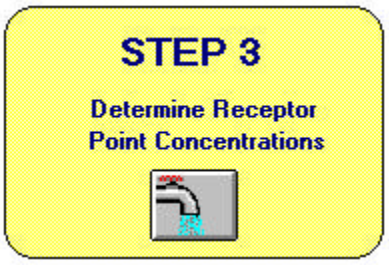
In the option, "Vadose Soil to Groundwater Model", the source is assumed to be located in the vadose zone above the water table and the transport of contaminants is modeled through the vadose zone to the groundwater. Once in the groundwater, the concentrations are transported to the receptor well. This option really consists of two fate and transport models linked together: the vadose zone model and the saturated zone model (described in Appendices A and B, respectively).

Fate and Transport Models for Indoor Air

The transport of contaminants through the vadose zone and into a building may be modeled from either a soil source or a groundwater source. These two models are quite different from each other in the assumptions that are made and are described in Appendices C and D.

Fate and Transport Model for Outdoor Air

Outdoor air concentrations may be estimated using the vadose zone model to estimate volatile emissions from contaminated soil coupled with an outdoor air "box" model to estimate concentrations in air. The outdoor air model is described in Appendix E.



5.0 DETERMINE RECEPTOR POINT CONCENTRATIONS

The third step in RISC is to determine receptor point concentrations for the various media of concern specified in Step 2: Choose Exposure Pathways. The Step 3 interface will appear differently depending on the choices made in Step 2. There are two methods for determining receptor point concentrations; the user can enter receptor point concentrations directly into RISC, or the user can enter source zone concentrations and then utilize chemical fate and transport models to estimate the receptor point concentrations. If the concentrations in one media are to be estimated with fate and transport models, and concentrations in another media entered directly, the interface will appear as in Figure 5-1. For the screen shown, a chemical fate and transport model is to be used to estimate receptor point groundwater concentrations and the receptor point concentrations in soil will be entered directly. If all the media of concern are to have concentrations entered directly, or all the media are to be modeled, the screen shown in Figure 5-1 will not appear.

This chapter will describe how to use both the direct option and the modeling options for estimating receptor point concentrations.

5.1 USER-SPECIFIED CONCENTRATIONS

Receptor point concentrations can be specified directly by the user (as opposed to using fate and transport models) for any exposure route (refer to Table 4-1). There are three different ways the concentrations may be entered directly by the user: (1) as a single value, (2) as a Monte Carlo Distribution, or (3) by building a site sample database. Figure 5-2 shows the screen with the three options as they appear for an example with soil as the media of concern.

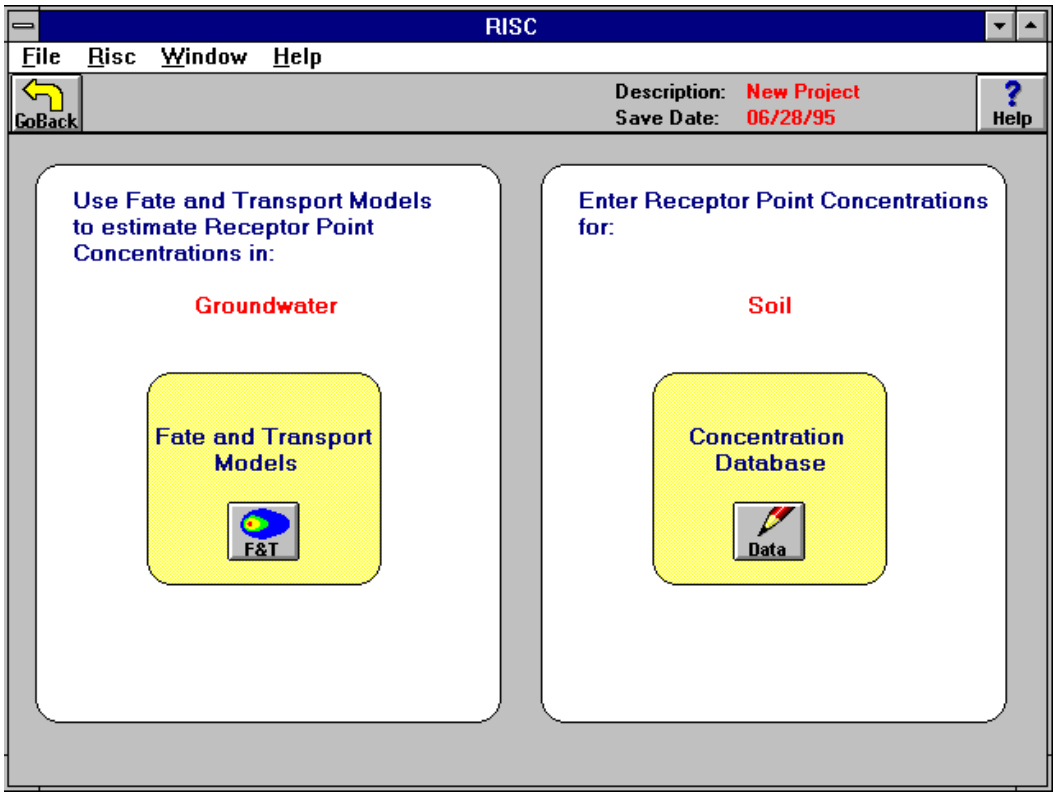


FIGURE 5-1. Main Screen for Step 3

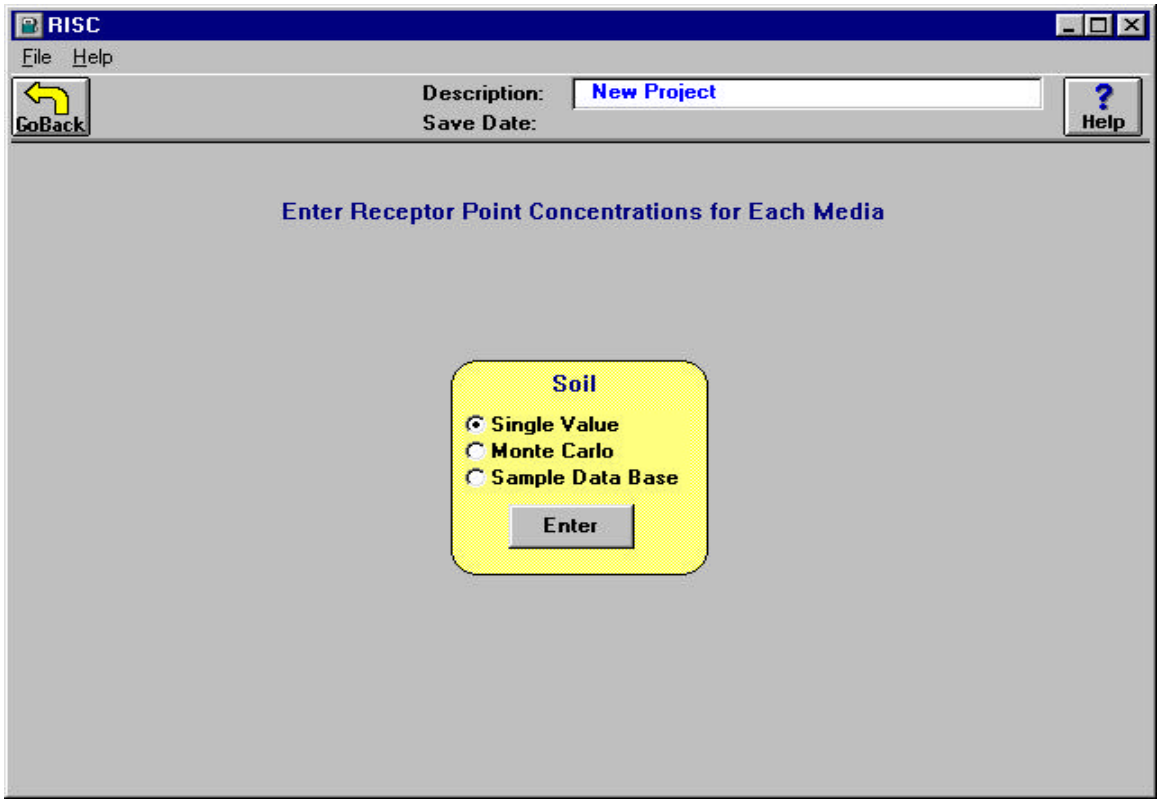


FIGURE 5-2. The Three Choices for Specifying Concentrations Directly

5.1.1 Single Value

This option is used when to specify concentrations when a point value or single deterministic value is known. In this case the user will be asked to enter one concentration value for each chemical of concern. This concentration will then be used to calculate risk in Step 5. Even if a Monte Carlo analysis for the exposure parameters is chosen in Step 4 (see next chapter), the user is still free to choose to use a single media concentration, which will then be treated as constant in the Monte Carlo analysis.

Figure 5-3 shows the input screen for entering receptor point concentrations in soil. The values entered here will only be used for ingestion of soil and dermal contact with soil - they are not the source term for any fate and transport models. The soil concentrations entered in the screen shown in Figure 5-3 should be reflective of the concentrations that receptors are likely to come in contact with - usually the top few inches of soil, or no deeper than typical excavation depths. If the user also selects any pathways involving leaching or volatilization from subsurface soils, then the user will also be required in a later step to input a second soil concentration representative of those soils containing chemicals that will leach or volatilize.

In all other cases (besides direct soil contact) the source terms are self-consistent; that is to say that the same vadose zone source soil concentrations are used to calculate leaching to groundwater and volatilization impacts. Also if one uses a chemical fate and transport model to estimate downgradient groundwater concentrations for the ingestion pathway, then the same model is used to calculate groundwater concentrations beneath a building for the volatilization pathway (the receptor locations may be different however).

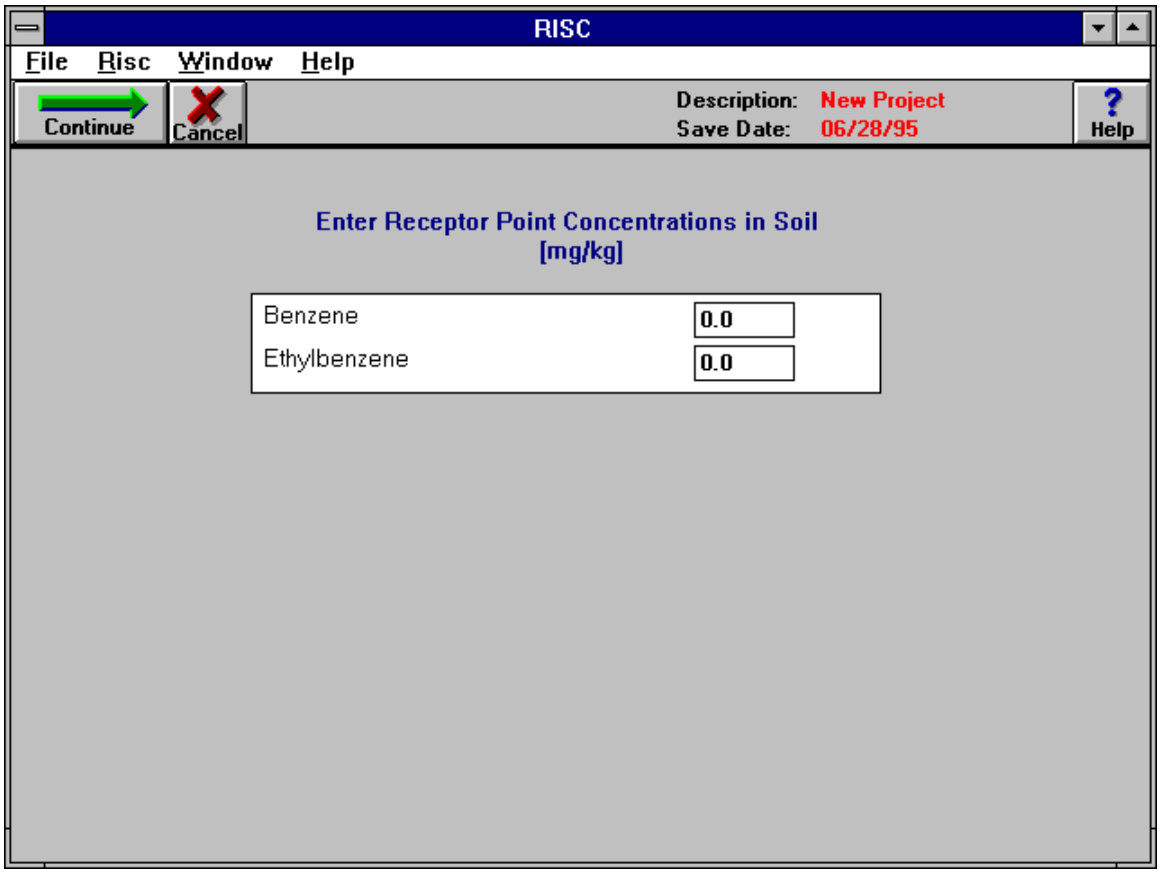


FIGURE 5-3. Entering Single Values for Receptor Point Concentrations

5.1.2 Monte Carlo Distributions

The second option for entering receptor point concentrations is to specify a "Monte Carlo Distribution" for each concentration. These distributions are used for the "Monte Carlo" option described in the next chapter. Figure 5-4 shows the input screen for specifying Monte Carlo distributions. Note the options for the statistical distributions are chosen by clicking on the "down arrow" next to the distribution description box.

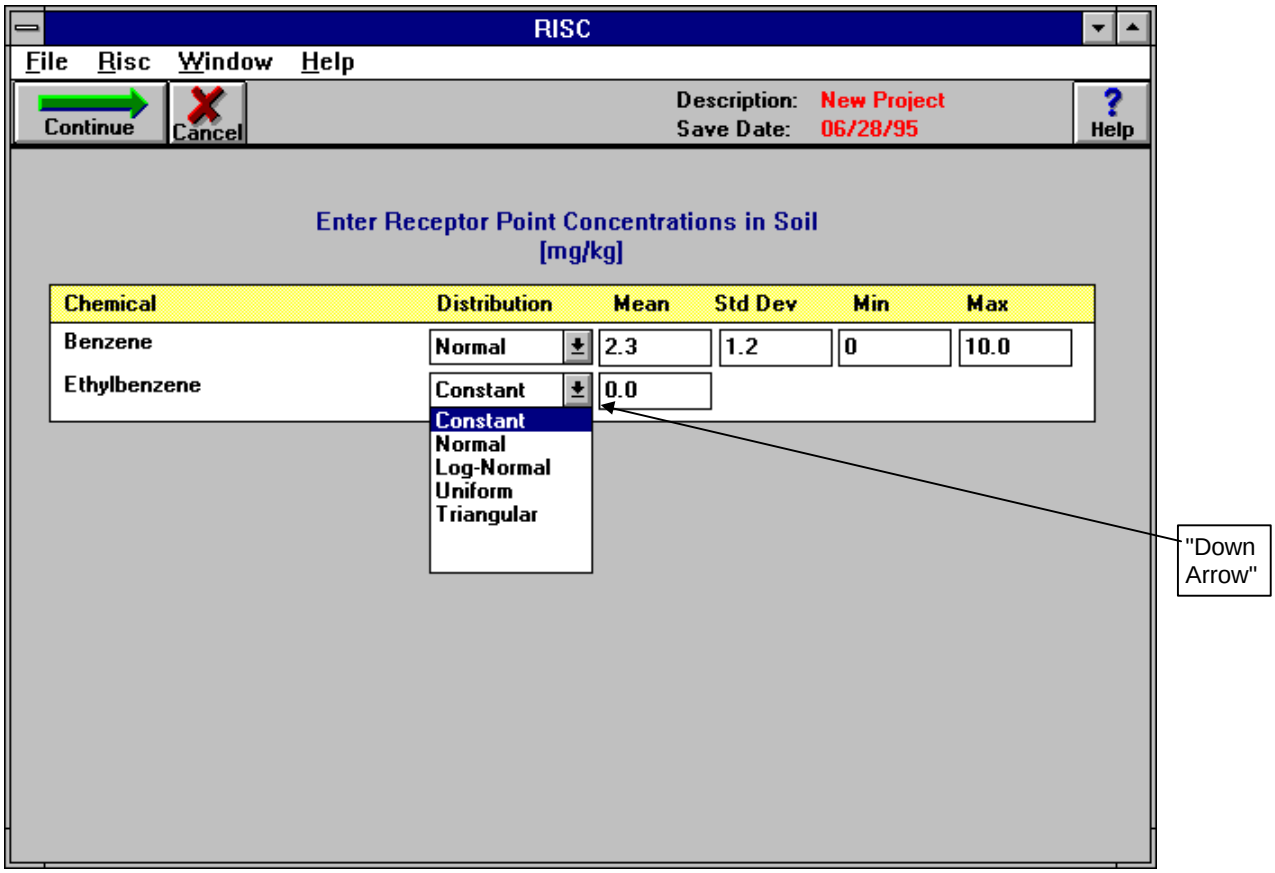


FIGURE 5-4. Entering Monte Carlo Distributions

The user may select between five distributions: Constant, Normal, Log-Normal, Uniform, or Triangular. These distributions are described in the next chapter under the Monte Carlo section. Note, when a distribution is chosen, the edit boxes required to describe the distribution appear. For example in Figure 5-4, benzene concentration in soil is described as having a normal distribution with the mean, standard deviation, minimum and maximum shown. If Monte Carlo distributions are specified, but a deterministic analysis is performed in Step 4, the mean value will be used in the risk calculation.

5.1.3 Sample Data Base

The RISC Sample Data Base is provided as a tool for users to summarize their site data, and if appropriate, to calculate means of the data to be used as inputs to the software. The sample data base can be used for both receptor point concentrations and for source concentrations that serve as inputs to fate and transport models.

The sample data base option is used when more than one (hopefully many more) measured concentrations exist for the chemicals of concern (i.e. multiple samples or analytical results). The data may consist of samples from different locations on the site, or it may consist of multiple samples taken at one location over time. In both cases, the sample data base is used to summarize the site data for purposes of estimating receptor point concentrations. Once all the samples are entered, the user must select a method for handling the "Non-Detects" and for averaging the concentration data in order to come up with a concentration that is used to calculate risk in Step 5. When the Sample Data Base option is chosen the user will be prompted to enter concentration data for each sample (Figure 5-5).

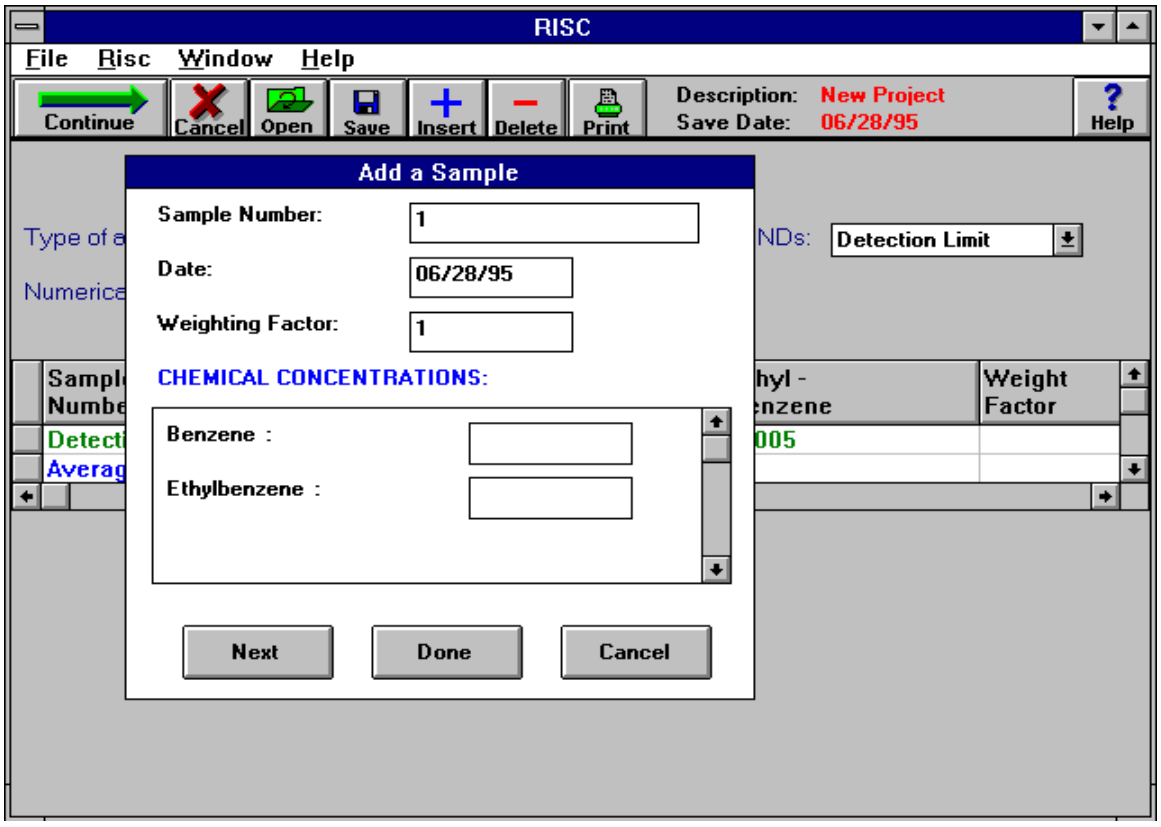


FIGURE 5-5. Sample Data Base

Default values have been provided for the Sample Name, Date, and Weighting Factor, however, the user is encouraged to change them to reflect the actual sample name and sampling date. The Weighting Factor is discussed below. Concentrations should be entered in the "Chemical Concentration" edit boxes, selecting "Next" to go onto the next sample. When all the samples have been entered, select "Done" to close the "Add a Sample" window and to view the data base. Figure 5-6 shows the Sample Data Base with four samples entered.

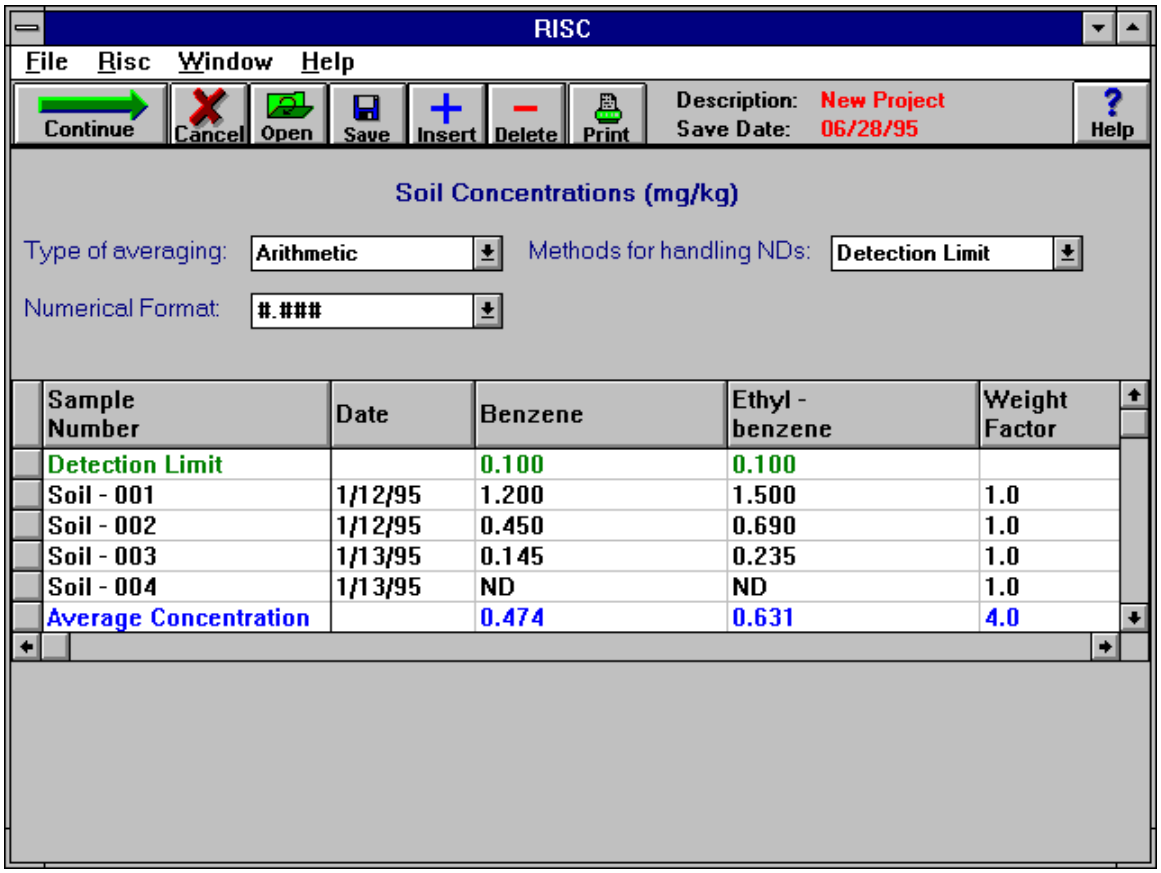


FIGURE 5-6. The Sample Data Base with Four Samples

This database shows four samples, labeled Soil-001 to Soil-004, collected on 1/12/95 and 1/13/95. The concentration averaging type used in this example is "Arithmetic" so the average concentration shown in the last line corresponds to the arithmetic mean of all the concentrations for each chemical. The average concentration line is not editable. The concentrations shown in the "Average Concentration" line are the values that will be used to calculated risk. To change the method of calculating average concentration, select from the "Type of Averaging" options in the drop down list at the top of the sample data base. All the rest of the lines in the data base are editable so the user can change values after the samples have been entered.

Method for Handling Non-Detects

For purposes of concentration averaging, the user must choose a method for handling non-detect values. There are three options. The NDs may be averaged using the detection limit, 1/2 the detection limit, or they may be considered equal to zero.

Detection Limits

The detection limit for each chemical is shown on the first line of the data base. If there are "non-detects" (NDs) entered in the data set, it is important to make sure that the detection limit is entered correctly. In this example the detection limits are 0.100 mg/kg for both benzene and ethylbenzene. The detection limits may be changed by clicking on the box containing the value and typing a new value. To proceed (and save the change) either press the "Enter" key or the "Tab" key.

Type of Averaging

The concentrations for each chemical are averaged to get a concentration to use for calculating risk. There are five different options for averaging the concentrations: arithmetic, geometric, weighting factors, 95th Upper Confidence Level (UCL) of the Mean assuming a Normal distribution, and 95th Upper Confidence Level (UCL) of the Mean assuming a Log-normal distribution.

The arithmetic mean can be used if the underlying distribution of concentrations is normal. It is calculated as follows:

$$\bar{C} = \frac{\sum_{i=1}^{n} C_i}{n}$$

where

$\bar{C}$	=	average concentration
n	=	number of samples
i	=	counter for sample number
C_i	=	concentration for sample i

The geometric mean can be used if the underlying distribution is log-normal (usually assumed to be the case for concentration data). The geometric mean is calculated from:

$$\bar{C} = \left[C_1 * C_2 * C_3 * \ldots C_n\right]^{\frac{1}{n}}$$

The geometric mean cannot be used with any zeros entered for concentrations in the data base or for the option of considering NDs as zero.

Weighting Factors

The Weighting Factor option for calculating average concentrations uses the "Weight Factor" column from the data base. This factor assigns a relative weight to each sample

entered in the data base. The weight may correspond to the area of the site (or groundwater) that is assigned the given sample concentration, or, it may correspond to the number of samples at the reported concentration. Figure 5-7 shows an example where a 100 m^2 site has been sampled extensively and found to have a hot spot of 3 m^2 and the samples taken from the rest of the site were below the detection limit.

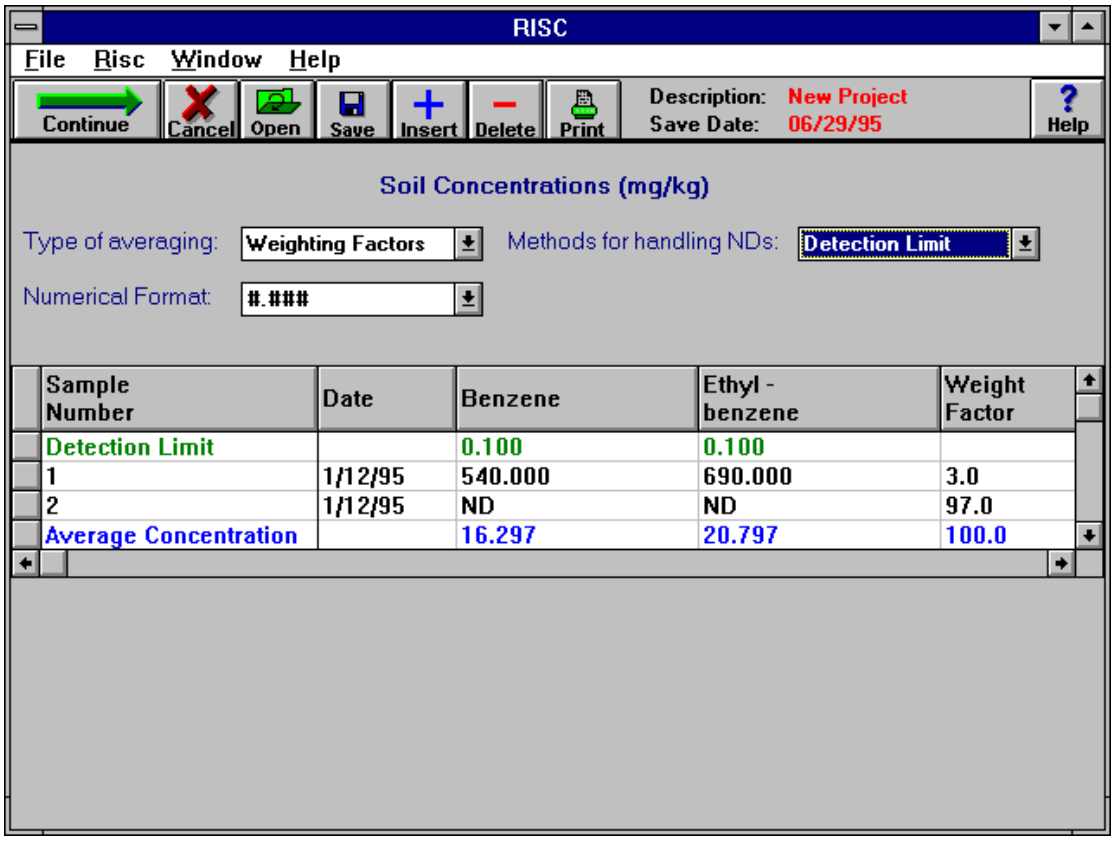


FIGURE 5-7. Using the Weight Factors

In this case, two samples are entered, one with a weight of "3" and one with a weight of "97". The two weights correspond to the areas of the site represented by each concentration. (The units for weighting factor could be in area or just a relative number and it is not necessary that the sum of the weighting factors equals 1, 10, or 100, etc.) It is very important to remember that the total area represented in the data base should correspond to the area that a receptor may come in contact with routinely. In other words, if the site is very large and it is reasonable to expect that a receptor may only work on a small area of the site, the data base should be used to estimate concentrations over that small area.

When all the weight factors are equal to one, the average concentration estimated using the weighting approach will equal the arithmetic mean.

Upper Confidence Levels of the Mean

The methods described here are based on guidance provided by EPA (May, 1992). The EPA guidance was developed for Superfund sites and should be used cautiously for sites that do not meet the assumptions outlined here.

The 95 percent Upper Confidence Level (UCL) of a mean is defined as a value that, when calculated repeatedly for randomly drawn subsets of site data, equals or exceeds the true mean 95 percent of the time. The 95% UCL provides a conservative estimate of the average concentration, however, it should not be confused with the 95th percentile on the probability density function of site concentration data. The UCL approach should only be used with a large sample data set that is based on random sampling. If the sampling performed at a given site targeted "hot spots" or contains few data points, this method may generate UCL means that are higher than the maximum concentration detected. EPA recommends that the data sets consist of 20 to 30 samples in order to provide fairly consistent estimates of the UCL mean. Of course, a higher number of samples is even better. Data sets containing less than 10 samples provide poor estimates of the UCL mean concentration (i.e., there is a large difference between the sample mean and the 95% UCL).

Method for Calculating the 95% UCL of the Mean Assuming a Normal Distribution

In this approach the underlying data is assumed to be normally distributed. The 95% UCL is calculated as follows:

$$UCL = \bar{C} + t\left(\frac{s}{\sqrt{n}}\right)$$

where

UCL	=	upper confidence limit (in units of concentration)
$\bar{C}$	=	arithmetic mean of the concentrations
s	=	standard deviation of the data
t	=	Student-t statistic (for 95% UCL)
n	=	number of samples

The Student-t statistic has been programmed in RISC to calculate the 95% UCL.

Method for Calculating the 95% UCL of the Mean Assuming a Log-Normal Distribution

In this approach the underlying data is assumed to be log-normally distributed (usually the case for random concentration data). This is the method recommended by EPA (May, 1992) for randomly sampled Superfund sites. In this approach, the concentrations are transformed by taking the log of each. Then the mean and standard deviation is calculated for the transformed data. The 95% UCL is calculated as follows:

$$UCL = e^{\left(\bar{C} + 0.5s^2 + \frac{sH}{\sqrt{n-1}}\right)}$$

where

UCL	=	upper confidence limit (in units of concentration)
$\bar{C}$	=	arithmetic mean of the **transformed** concentrations
s	=	standard deviation of the **transformed** data
H	=	H-statistic (for 95% UCL)
n	=	number of samples

Tables of the H-statistic can be found in Gilbert (1987). The H-statistic has been programmed in RISC to calculate the UCL. The 95% UCL cannot be calculated for a log-normal distribution when any individual data point is zero or NDs are considered to be zero. The user must choose between considering the NDs to be equal to the detection limit or 1/2 the detection limit.

5.2 FATE AND TRANSPORT MODELS

As an alternative to entering concentrations directly, fate and transport models can be used to estimate receptor point concentrations in groundwater, outdoor air, or indoor air. The models to be used in this step are chosen when the routes of concern are chosen (Step 2).

Figure 5-8 shows the four basic steps in using the fate and transport models.

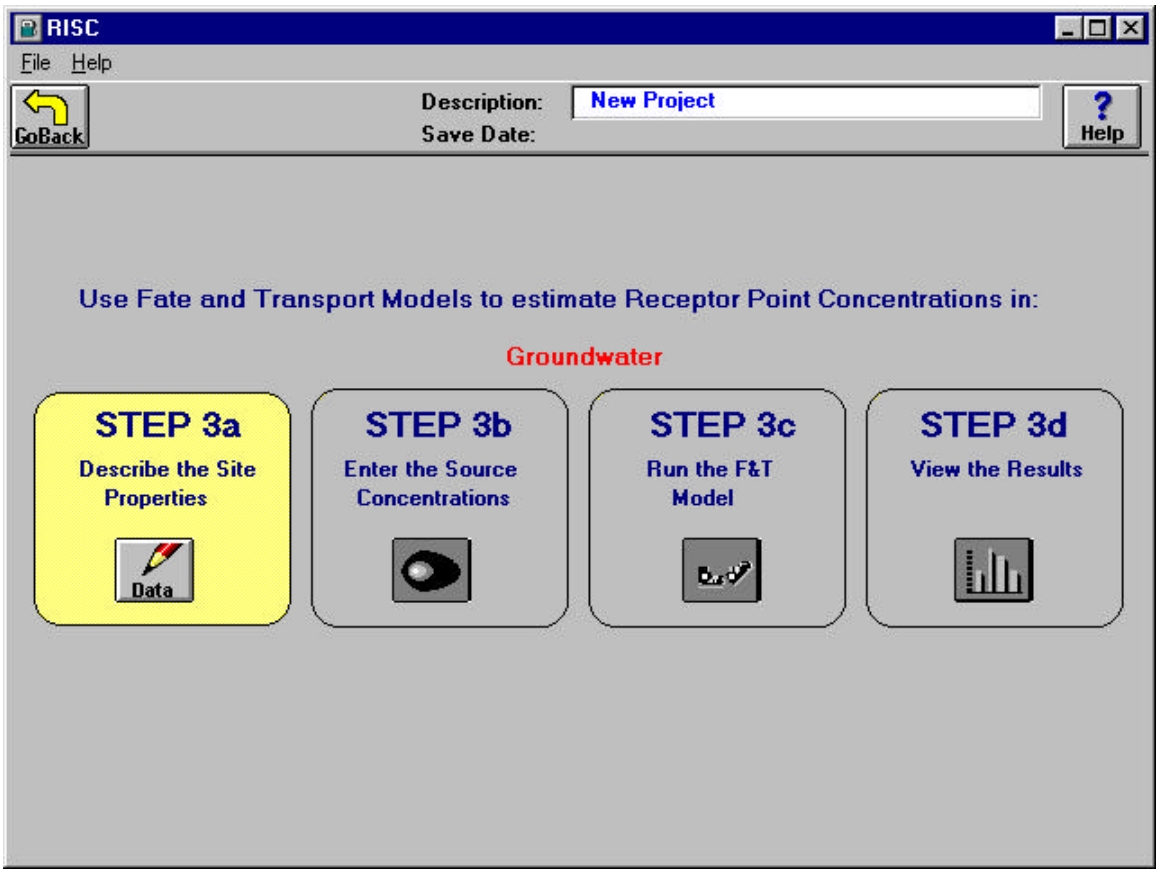


FIGURE 5-8. The Four Steps of the Fate and Transport Screen

Step 3a: Describe the Site Properties

In this step, the user is asked to enter site-specific data needed to run the model(s) chosen. Figure 5-9 shows the input screen that appears when a "Dissolved Concentrations Only" model is chosen for groundwater.

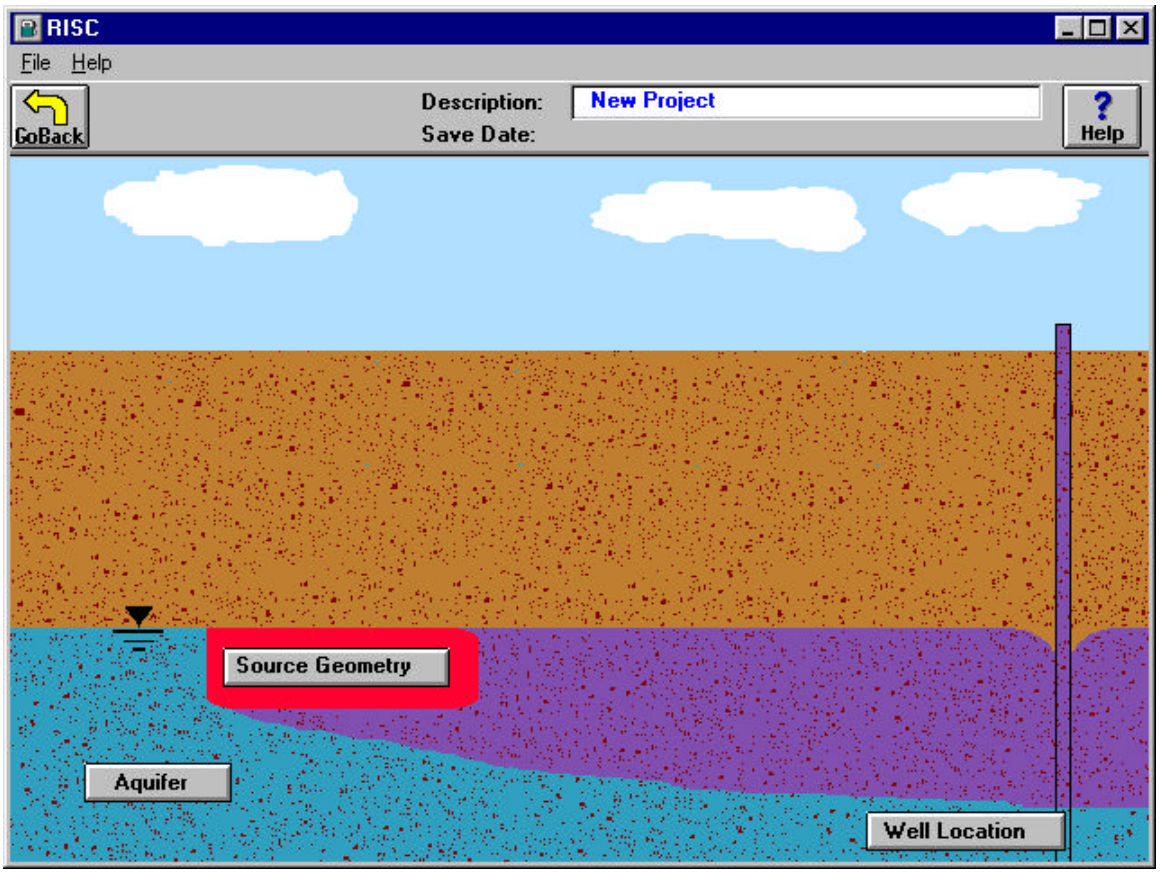


FIGURE 5-9. Describing the Site for the Dissolved Concentrations Model

In this example there are only three groups of data that need be entered: Source Geometry, Aquifer properties, and the Well Location. Depending on the model(s) chosen, the screen in Figure 5-9 will look different and there will be additional groups of data required. Note that when asked to specify aquifer or soil properties, the user is provided with suggested default values and parameter ranges for up to 9 soil types, ranging from gravel to clay. An example of the parameter input screens is shown in Figure 5-10. This screen shows the input parameters needed to specify aquifer properties in the saturated zone. The drop-down list (with "Example Problem" shown) allows the user to select a different default soil type. When the down arrow on the drop-down list is selected the vertical scroll bar (shown in Figure 5-11) can be used to view all the soil data types.

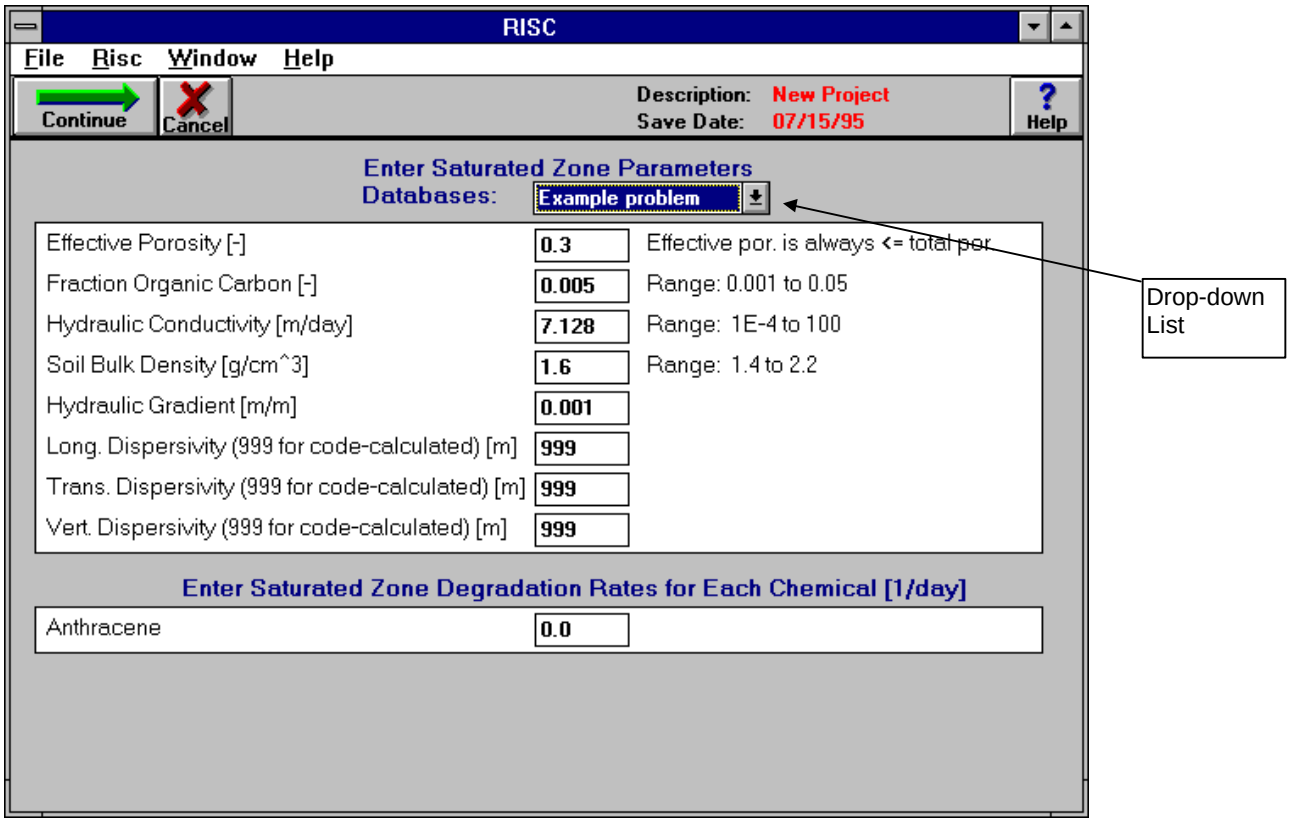


FIGURE 5-10. Input Parameter Screen for Aquifer

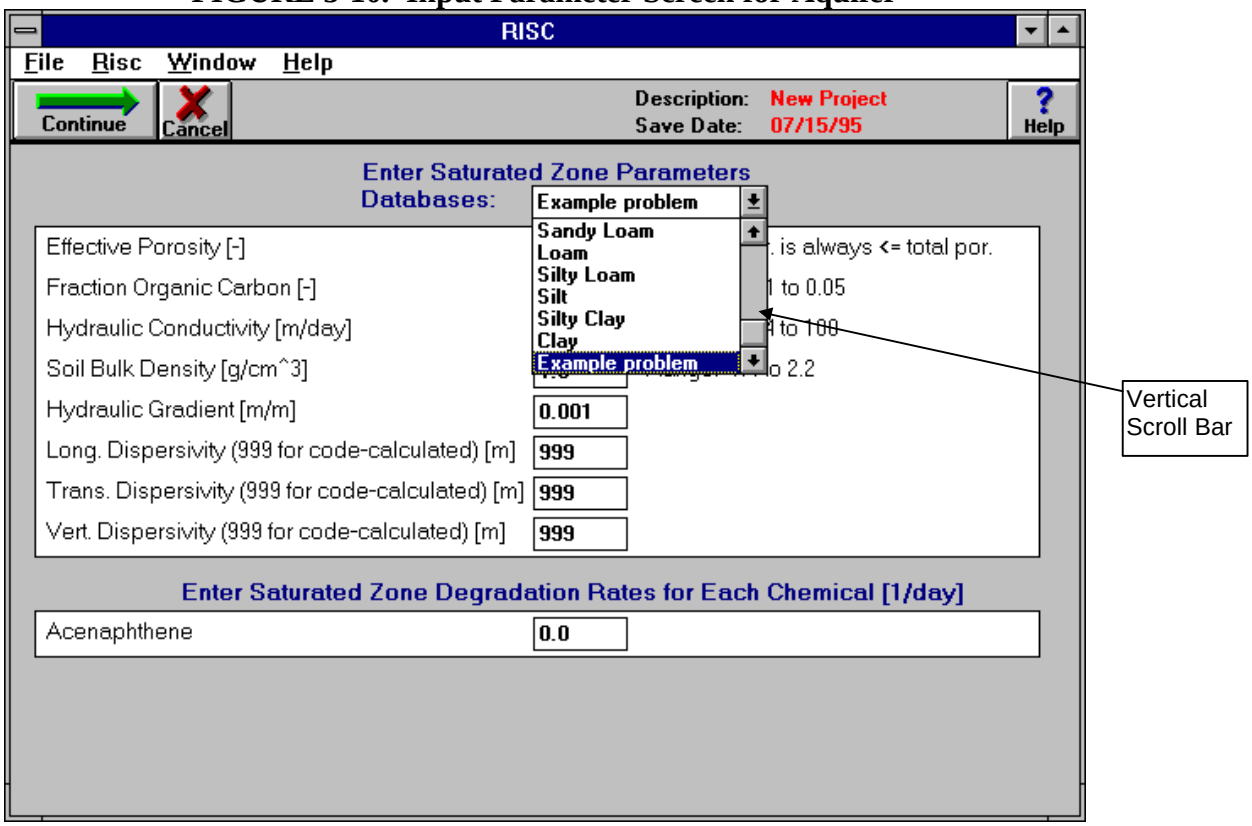


FIGURE 5-11. Input Parameter Screen Showing Soil Property Database Selection

Table 5-1 shows the default values contained in the soil properties database. The soil bulk density for all soil types has been set to 1.7 g/cm3. Since this parameter is almost always measured during field work, it is suggested that the user update it with the site specific value.

Table 5-1. Soil Properties Database

SOIL TYPE	Total Porosity *	Effective Porosity **	Irreducible Water Content	Fraction Organic Carbon	Saturated Conductivity	van Genuchten's n Parameter
	cm^3/cm^3	cm^3/cm^3	cm^3/cm^3	-	m/d	-
Clay	0.45	0.20	0.17	0.01	0.015	1.09
Silty Clay	0.40	0.25	0.21	0.01	0.022	1.09
Silt	0.35	0.25	0.21	0.005	0.25	1.37
Silty Loam	0.35	0.30	0.17	0.005	0.16	1.41
Loam	0.30	0.25	0.15	0.005	0.32	1.56
Sandy Loam	0.25	0.25	0.1	0.005	0.62	1.89
Silty Sand	0.25	0.20	0.12	0.005	0.86	1.5
Sand	0.30	0.30	0.05	0.002	5	2.68
Sandy Gravel	0.25	0.25	0.04	0.002	10	2.7
Gravel	0.30	0.30	0.03	0.002	20	2.7
Example Problem	0.35	0.25	0.05	0.005	7.13	2.68

*Total porosity is used in the vadose zone model.

**Effective porosity is used in the saturated zone model.

These soil properties are based on best professional judgment and are discussed in detail in the appendices containing the model descriptions (Appendices A through E). The van Genuchten's n parameter is used to calculate water content in the unsaturated zone and is described in both Appendix A and Appendix C.

Step 3b: Enter the Source Concentrations

The source concentrations required to run the fate and transport models are entered in this step. Depending on the model(s) selected, the source may be dissolved phase concentrations in groundwater, soil concentrations in the vadose zone, or soil concentrations in/at the water table. Table 5-2 lists the models available and the type of source term required.

Table 5-2. Source Term Required for Each Model

RECEPTOR POINT CONCENTRATION MEDIA	FATE AND TRANSPORT MODEL	SOURCE MEDIA
Groundwater	Dissolved Concentrations Only (No Soils Data)	Groundwater Concentrations in Source Area
	Vadose Soil to Groundwater Model	Soil Concentrations in Vadose Zone
	Saturated Soil to Groundwater Model	Soil Concentrations in Groundwater Zone or Capillary Fringe Area
Outdoor Air	Vadose Soil Model	Soil Concentrations in Vadose Zone
Indoor Air	Emissions from Soil	Soil Concentrations in Vadose Zone
	Emissions from Groundwater	Groundwater Concentrations Directly Under Building

Step 3c: Run the F&T Model

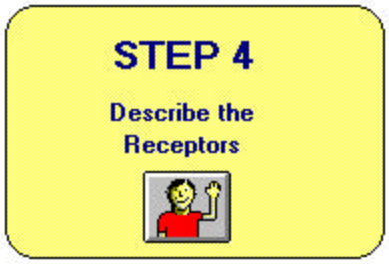
In this step, the simulation time and source pulse length are entered. The source pulse length, which is used for the dissolved concentrations groundwater model only, is the time the source is active, i.e. before it is either physically removed or assumed to be depleted (either intrinsically or by active remediation). The fate and transport models are run once for each chemical of concern. As each run is completed the chemical listed changes from red to green. When the simulations have finished the user is notified to continue.

Step 3d: View the Results

In this step, the user can view tables and charts of the model results. The options for the types of tables and charts will vary depending on the model(s) run. For every model, the "General Output File" may be chosen from the table option. This table summarizes all the input parameters as well as the model output. The other tables summarize concentrations

in one media (per table) and are designed for quick review or for inclusion in the modeling write-up.

Both the tables and charts can be transferred to another software application (such as a word processor) by clicking on the 'Copy' button. Then the user can minimize or close the RISC main screen, open the new destination software, and choose "Paste" (or the Shift and Insert keys). The tables and charts can also be printed directly from the model results screens.



6.0 DESCRIBE THE RECEPTORS

In this step, the receptor(s) of concern are chosen and the receptor-specific intake parameters are entered. The RISC software contains both deterministic and stochastic (Monte Carlo input) default data on exposure for many different types of receptors. The user is free to use the default data provided or to change the intake parameters to reflect actual site-specific values. Figure 6-1 shows the main screen for Step 4.

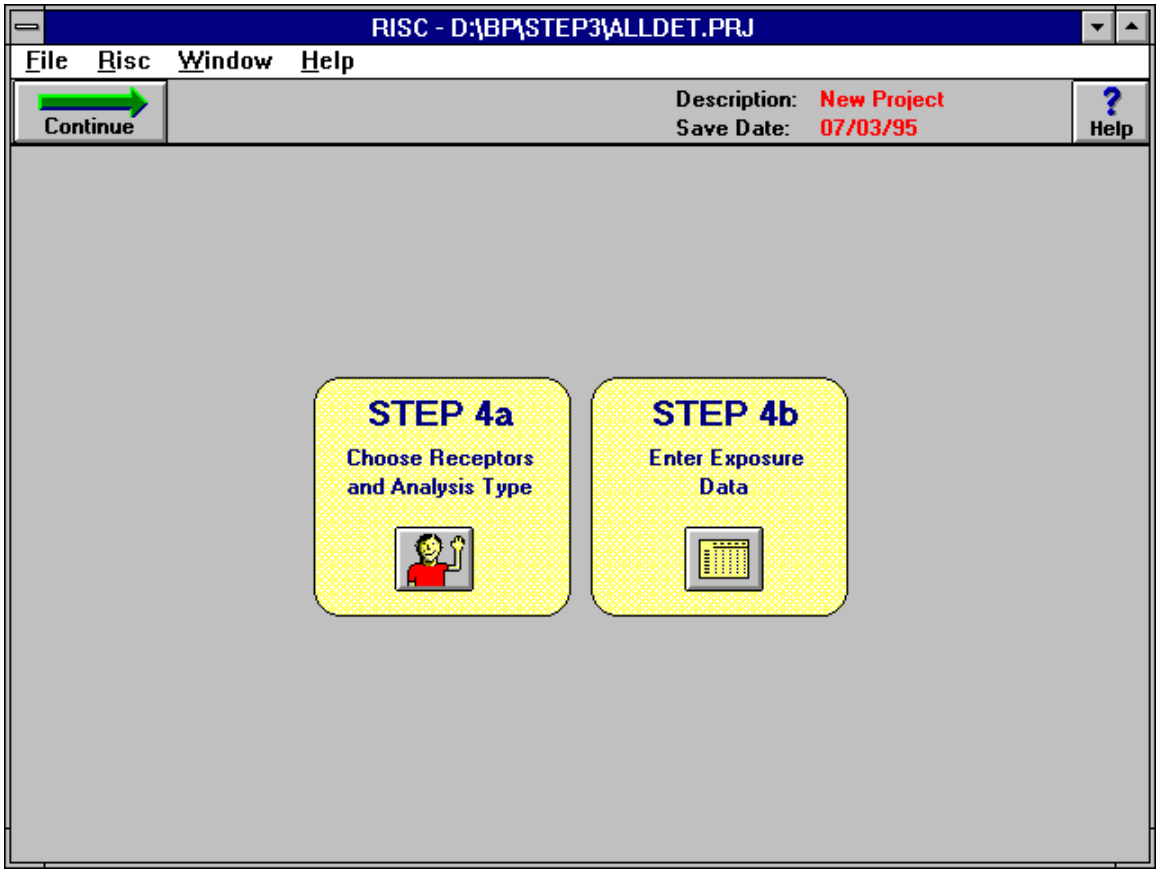


FIGURE 6-1. The Two Steps Required to Describe the Receptor(s)

6.1 STEP 4a: CHOOSE RECEPTORS AND ANALYSIS TYPE

The decisions that must be made in this step are:

- Will the analysis be deterministic or Monte Carlo?
- If deterministic, will one or two receptors of concern be considered?
- If two receptors are being considered, are the exposures to be summed (e.g. a receptor is considered as both a child and an adult)?
- Are default, or user-specified, site-specific exposure parameters and/or Monte Carlo distributions to be used?

Figure 6-2 shows the input screen for Step 4a.

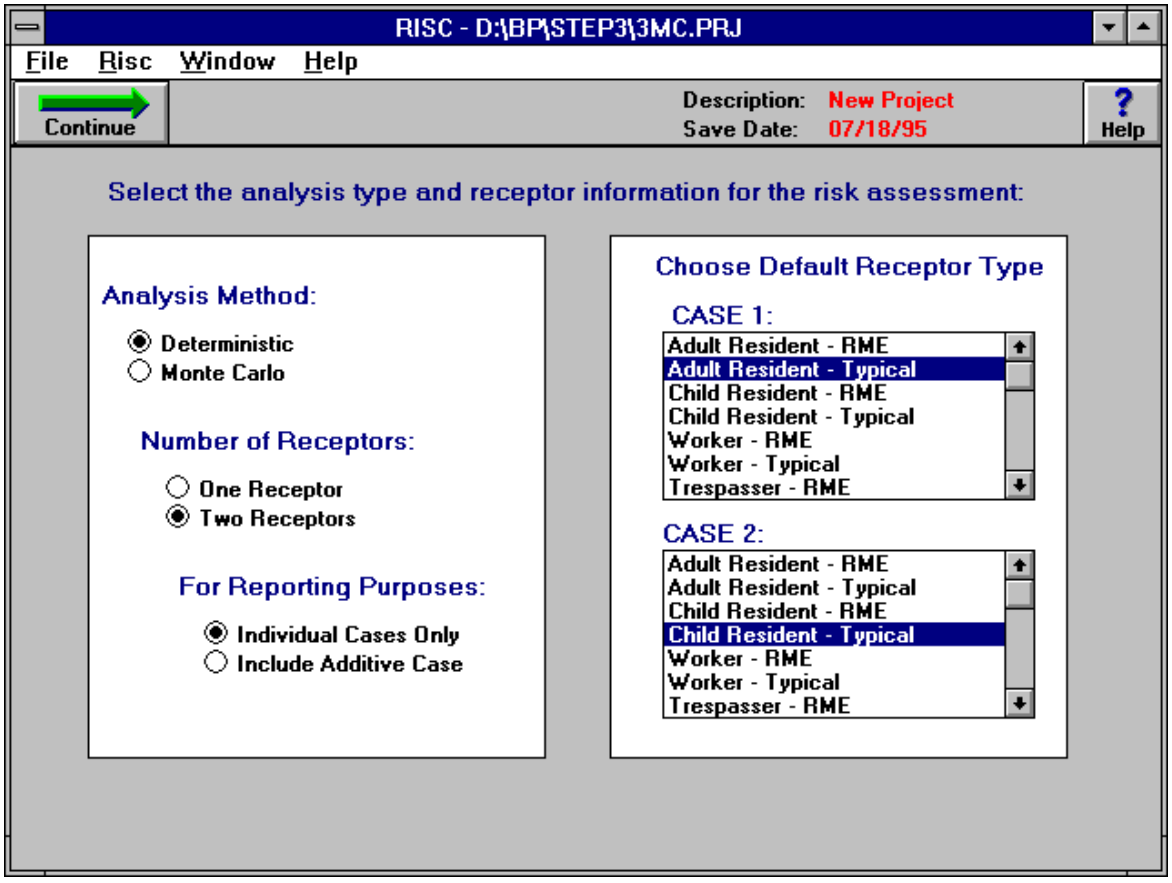


FIGURE 6-2. Input Screen for Step 4a

One the left side of the input screen the user must choose between: (1) performing a deterministic or Monte Carlo analysis, (2) if deterministic, to evaluate one or two

receptors, and (3) if two receptors, whether or not to calculate the additive case. These options are described in the following sections.

On the right side of the input screen the default receptor types are listed. If only one receptor is to be analyzed, then the lower box ("Case 2:") will not be shown. There are eight receptors types to choose from for the deterministic case and four for the "Monte Carlo" case. The default receptor types and the exposure routes considered for each are shown in Table 6-1. The choices made here will affect how the exposure data input screen appears.

6.1.1 Deterministic and Monte Carlo Analyses

The risk calculations may be performed in either a deterministic mode or using Monte Carlo sampling. The deterministic mode means that a single value (point estimate) will be used for each intake parameter and therefore a single value of risk will be calculated for the analysis.

In a Monte Carlo analysis, on the other hand, probability distributions are specified for each of the input parameters and values are randomly drawn from these input distributions. The model is run many times (recommended 1000 to 10,000 iterations) and the resultant risks are evaluated statistically. The Monte Carlo analysis is a powerful tool for estimating exposures when population distribution data exists. The results indicate the wide range of exposures that might occur as well as the probability of each exposure happening. The results from a Monte Carlo analysis can be presented by summarizing the output statistics in tabular form or by generating probability density functions or cumulative probability density functions of the output. These output options are described in Section 8.1 and 8.2.

6.1.2 One or Two Receptors

The risk analysis may be performed for one or two receptors simultaneously. When two receptors are chosen, the results between the two may be compared in the same table or chart. For example, one might examine the effect of changing exposure assumptions by comparing the exposure corresponding to very conservative parameter estimates with the exposure calculated for exposure input values more representative of an “average” member of the population. The default “typical” exposure inputs correspond to this latter

case, while the default "RME" (reasonable maximum exposure) inputs correspond to the conservative parameter estimates.

6.1.3 Additive Case

In the additive case the exposures for two receptors are evaluated and then summed. This option can be used for the situation where the user wants to consider a residential receptor that is assumed to be a child for a certain number of years (with appropriate child intake values) and an adult for a certain number of years.

6.2 STEP4b: ENTER EXPOSURE DATA

For deterministic analysis, default sets of intake parameters have been developed for a "Reasonable Maximum Exposure" (RME) and a "Typical Exposure" for adults, children, workers, and trespassers for a total of eight data sets. The "Reasonable Maximum Exposure" is a term originally used by USEPA to refer to an 85-95 percentile exposure when given a cumulative probability distribution of exposure values. It has since also been used to refer to an exposure scenario in which individual exposure parameters that define the scenario (e.g. risk of vapor inhalation in a shower) are conservatively selected from the 85-95 percentile of their individual distributions (e.g. time in the shower, flow and temperature of the water, etc). In this latter case, the scenario exposure often exceeds the 95 percentile of the cumulative probability distribution of exposure values. Thus, the RME exposure scenario is typically regarded as a very conservative exposure scenario, but is often used as a base case for calculations (e.g. in the development of a RBCA Tier 1 Look-Up Table). Because the RME exposure is generally considered to be overly conservative, a "Typical" default set of exposure inputs is also included in RISC. These are more representative of the characteristics of an "average" member of the general population, rather than a "maximum exposed individual" (MEI).

Tables 6-2 through 6-5 show the deterministic default values for the receptors. There are many parameters that are highly site-specific such as exposure duration and frequency. The database has default values for these parameters, however, it is important to use site-specific data where available. Figure 6-3 shows the input screen for a deterministic case with two receptors. Because ingestion of soil was chosen in Step 2, the user is asked to enter soil bioavailability values for each chemical. (Bioavailability reflects the fact that not all the contaminant that is present in the soil - and extractable with a solvent - is actually

toxic to a human because it is not available for uptake or capable of being metabolized.) If no soil routes had been chosen, this second window would not appear. Note the arrows indicate that additional exposure parameters must be accessed by using the scroll bar.

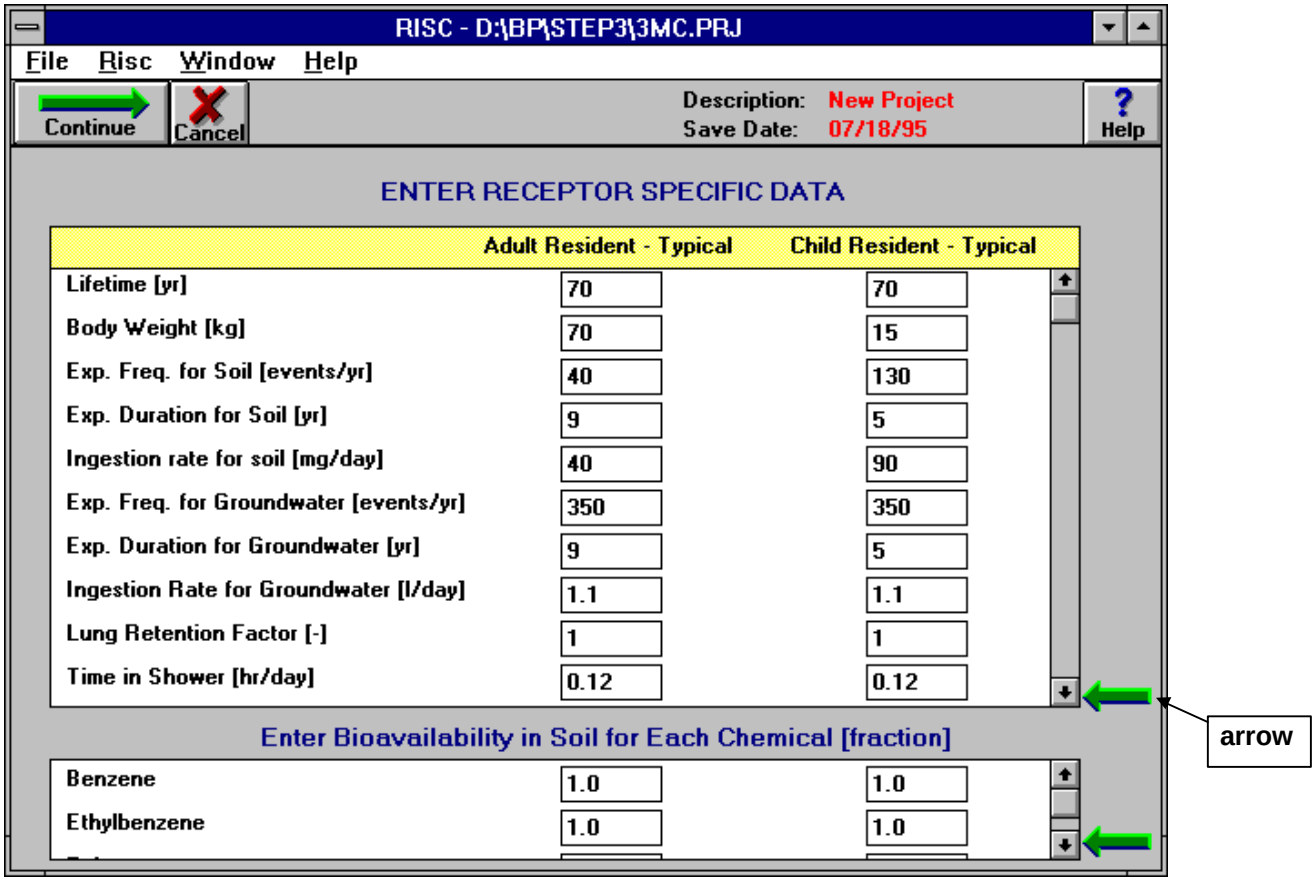


Figure 6-3. Input Screen for Step 4b for a Deterministic Analysis

Table 6-6 (at the end of this chapter) shows the default distributions for the Monte Carlo case. The majority of these distributions were extracted from the recently published guidance document from the American Institute of Health Council (AIHC), entitled "Exposure Factors Sourcebook" (1994). Appendix H describes the methodology behind the development of these distributions.

Figure 6-4 shows the input screen for a Monte Carlo analysis. The distribution types are selected from the drop-down lists shown. When a distribution type is changed (e.g. from "Constant" to "Log-Normal") the boxes to the right change to reflect the required statistics for the selected distribution.

The constant distribution is defined with a single value in the "Mean" column. The normal and log-normal distributions must be defined with four statistics: mean, standard deviation, minimum and maximum. The triangular distribution is defined by the expected value (the peak of the triangle) entered in the "mean" box and by a minimum and a maximum (the x-axis parameter values where the two lines on the probability density function cross this axis).

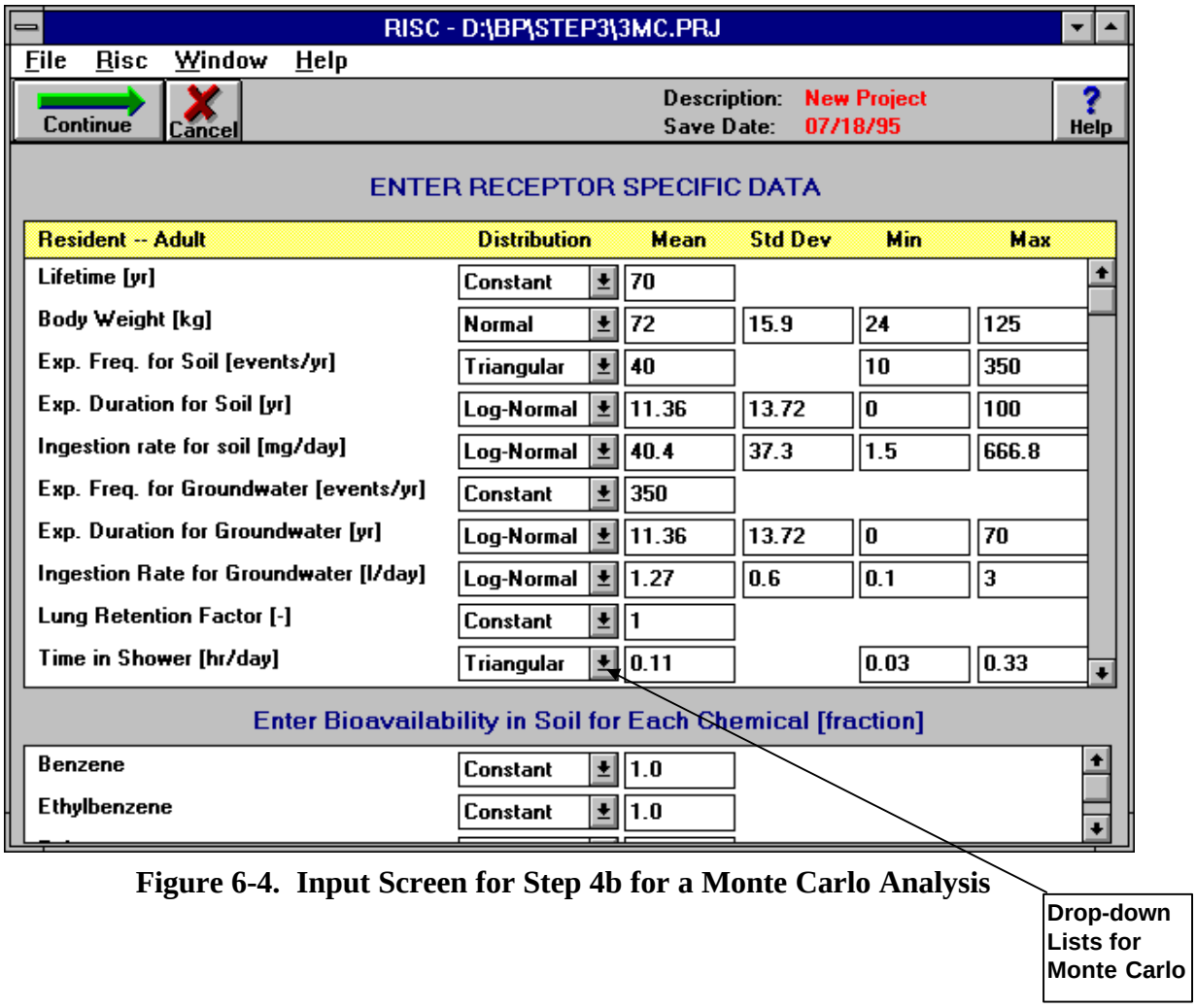


Figure 6-4. Input Screen for Step 4b for a Monte Carlo Analysis

Table 6-1. Default Receptor Types and Exposure Routes.

Default Receptors Types for the Deterministic Case	Default Receptors Types for the Monte Carlo Case	Exposure Routes Considered
Adult Resident - Typical Adult Resident - RME	Adult Resident	Ingestion of Soil Dermal Contact with Soil Ingestion of Groundwater Dermal Contact with Groundwater Inhalation in the Shower Inhalation of Outdoor Air Inhalation of Indoor Air Ingestion of Surface Water (Swimming) Dermal Contact with Surface Water
Child Resident - Typical Child Resident - RME	Child Resident	Ingestion of Soil Dermal Contact with Soil Ingestion of Groundwater Dermal Contact with Groundwater Inhalation in the Shower Inhalation of Outdoor Air Inhalation of Indoor Air Ingestion of Surface Water (Swimming) Dermal Contact with Surface Water
Trespasser - Typical Trespasser - RME	Trespasser	Ingestion of Soil Dermal Contact with Soil Inhalation of Outdoor Air Ingestion of Surface Water (Swimming) Dermal Contact with Surface Water
Worker - Typical Worker - RME	Worker	Ingestion of Soil Dermal Contact with Soil Ingestion of Groundwater Inhalation of Outdoor Air Inhalation of Indoor Air

Note: RME = Reasonable Maximum Exposure

Table 6-2. Intake Parameters for Adult Residents (page 1 of 2).

Parameter	Units	Reasonable Maximum Exposure	Typical Exposure
Common to All Routes			
Body Weight	[kg]	70	70
Lifetime	[years]	70	70
Ingestion of Drinking Water			
Exposure Duration	[years]	30	9
Exposure Frequency	[days/year]	350	350
Ingestion Rate	[l/day]	2	1.1
Dermal Contact While Showering			
Exposure Duration	[years]	30	9
Exposure Frequency	[days/year]	350	350
Exposure Time	[hours/day]	0.2	0.12
Skin Surface Area	[cm^2]	23,000	18,400
Inhalation During Shower			
Exposure Duration	[years]	30	9
Exposure Frequency	[days/year]	350	350
Exposure Time in Shower per day	[hours/day]	0.2	0.12
Inhalation Rate in Shower	[m^3/hr]	0.6	0.6
Volume of Bathroom	[m^3]	3	5.2
Flowrate of Shower Water	[l/min]	10	8
Temperature of Shower	[^oC]	48	45
Inhalation of Outdoor Air			
Exposure Duration	[years]	30	9
Exposure Frequency	[days/year]	350	350
Exposure Time Outdoors	[hours/day]	2.5	1.1
Inhalation Rate Outdoors	[m^3/hr]	0.83	0.83
Inhalation of Indoor Air			
Exposure Duration	[years]	30	9
Exposure Frequency	[days/year]	350	350
Exposure Time Indoors	[hours/day]	24	18.3
Inhalation Rate Indoors	[m^3/hr]	0.83	0.83

Table 6-2. Intake Parameters for Adult Residents (page 2 of 2).

Parameter	Units	Reasonable Maximum Exposure	Typical Exposure
Dermal Contact with Soil			
Exposure Duration	[years]	30	9
Exposure Frequency	[days/year]	350	40
Total Skin Surface Area	[cm^2]	23,000	18,400
Fraction of Total Skin Surface Area Exposed to Soil	[cm^2/cm^2]	0.56	0.11
Soil to Skin Adherence Factor	[mg/cm^2]	1	0.2
Ingestion of Soil			
Exposure Duration	[years]	30	9
Exposure Frequency	[days/year]	350	40
Ingestion Rate	[mg/day]	100	40
Bioavailability in Soil	[fraction]	Chemical-Specific	Chemical-Specific
Dermal Contact with Surface Water			
Exposure Duration	[years]	30	9
Exposure Frequency	[days/year]	36	5
Exposure Time	[hours/day]	2.6	2.6
Total Skin Surface Area	[cm^2]	23,000	18,400
Incidental Ingestion of Water While Swimming			
Exposure Duration	[years]	30	9
Exposure Frequency	[days/year]	36	5
Exposure Time	[hours/day]	2.6	2.6
Ingestion Rate	[ml/hr]	50	10

Table 6-3. Intake Parameters for Child Residents (page 1 of 2).

Parameter	Units	Reasonable Maximum Exposure	Typical Exposure
Common to All Routes			
Body Weight	[kg]	15	15
Lifetime	[years]	70	70
Ingestion of Drinking Water			
Exposure Duration	[years]	5	5
Exposure Frequency	[days/year]	350	350
Ingestion Rate	[l/day]	1	0.5
Dermal Contact While Showering			
Exposure Duration	[years]	5	5
Exposure Frequency	[days/year]	350	350
Exposure Time	[hours/day]	0.2	0.12
Skin Surface Area	[cm^2]	7280	6800
Inhalation During Shower			
Exposure Duration	[years]	5	5
Exposure Frequency	[days/year]	350	350
Exposure Time in Shower per day	[hours/day]	0.2	0.12
Inhalation Rate in Shower	[m^3/hr]	0.6	0.6
Volume of Bathroom	[m^3]	3	5.2
Flowrate of Shower Water	[l/min]	10	8
Temperature of Shower	[^oC]	48	45
Inhalation of Outdoor Air			
Exposure Duration	[years]	5	5
Exposure Frequency	[days/year]	350	350
Exposure Time Outdoors	[hours/day]	5	2.2
Inhalation Rate Outdoors	[m^3/hr]	0.83	0.83
Inhalation of Indoor Air			
Exposure Duration	[years]	5	5
Exposure Frequency	[days/year]	350	350
Exposure Time Indoors	[hours/day]	24	19.6
Inhalation Rate Indoors	[m^3/hr]	0.83	0.83

Table 6-3. Intake Parameters for Child Residents (page 2 of 2).

Parameter	Units	Reasonable Maximum Exposure	Typical Exposure
Dermal Contact with Soil			
Exposure Duration	[years]	5	5
Exposure Frequency	[days/year]	350	40
Fraction of Total Skin Surface Area Exposed to Soil	[cm^2/cm^2]	0.55	0.13
Soil to Skin Adherence Factor	[mg/cm^2]	1	0.2
Ingestion of Soil			
Exposure Duration	[years]	5	5
Exposure Frequency	[days/year]	350	130
Ingestion Rate	[mg/day]	200	90
Bioavailability in Soil	[fraction]	Chemical-Specific	Chemical-Specific
Dermal Contact with Surface Water			
Exposure Duration	[years]	5	5
Exposure Frequency	[days/year]	36	5
Exposure Time	[hours/day]	2.6	2.6
Skin Surface Area	[cm^2]	7280	6800
Incidental Ingestion of Water While Swimming			
Exposure Duration	[years]	5	5
Exposure Frequency	[days/year]	36	5
Exposure Time	[hours/day]	2.6	2.6
Ingestion Rate	[ml/hr]	50	10

Table 6-4. Intake Parameters for Workers.

Parameter	Units	Reasonable Maximum Exposure	Typical Exposure
Common to All Routes			
Body Weight	[kg]	70	70
Lifetime	[years]	70	70
Ingestion of Drinking Water			
Exposure Duration	[years]	25	8
Exposure Frequency	[days/year]	250	250
Ingestion Rate	[l/day]	1	0.5
Inhalation of Volatile Soil Emissions			
Exposure Duration	[years]	25	8
Exposure Frequency	[days/year]	250	250
Time Outdoors	[hours/day]	6	4
Inhalation Rate	[m^3/hr]	2.5	0.8
Dermal Contact with Soil			
Exposure Duration	[years]	25	8
Exposure Frequency	[days/year]	250	125
Fraction of Total Skin Surface Area Exposed to Soil	[cm^2/ cm^2]	0.57	0.11
Adherence Factor	[mg/cm^2]	1	0.2
Ingestion of Soil			
Exposure Duration	[years]	25	8
Exposure Frequency	[days/year]	250	125
Ingestion Rate	[mg/day]	100	40

Table 6-5. Intake Parameters for Trespassers.

Parameter	Units	Maximum Exposure Case	Typical Exposure
Common to All Routes			
Body Weight	[kg]	42	42
Lifetime	[years]	70	70
Inhalation of Volatile Soil Emissions			
Exposure Duration	[years]	12	9
Exposure Frequency	[days/year]	52	26
Exposure Time	[hours/day]	3	1.5
Inhalation Rate	[m^3/hr]	2.3	1.68
Dermal Contact with Soil			
Exposure Duration	[years]	12	9
Exposure Frequency	[days/year]	52	26
Fraction of Skin Surface Area Exposed to Soil	[fraction]	0.57	0.11
Adherence Factor	[mg/cm^2]	1	0.2
Ingestion of Soil			
Exposure Duration	[years]	12	9
Exposure Frequency	[days/year]	52	26
Ingestion Rate	[mg/day]	100	40
Dermal Contact with Surface Water			
Exposure Duration	[years]	12	9
Exposure Frequency	[days/year]	36	5
Exposure Time	[hours/day]	2.6	2.6
Skin Surface Area	[cm^2]	16550	14000
Incidental Ingestion of Water While Swimming			
Exposure Duration	[years]	12	9
Exposure Frequency	[days/year]	36	5
Exposure Time	[hours/day]	2.6	2.6
Ingestion Rate	[ml/hr]	50	10

Table 6-6. Monte Carlo Default Distributions

Parameter	Units	Distribution Type	Expected Value	Standard Deviation	Min.	Max.	Point Estimate		Reference for Monte Carlo Distributions
							Typical	RME	
Body Weight	kg								
Adult Resident		Normal	72	15.9	24	125	70	70	AIHC (1994)
Child Resident (Age 1-6)		Normal	15.6	3.7	6	30	15	15	Anderson et al. (1985)
Trespasser		Normal	47	8.3	20	120	42	42	Anderson et al. (1985)
Worker		Normal	72	15.9	24	125	70	70	AIHC (1994)
Lifetime	yr								
Adult Resident		Constant	70	NA	NA	NA	70	70	EPA (1989)
Child Resident (1-6)		Constant	70	NA	NA	NA	70	70	EPA
Trespasser		Constant	70	NA	NA	NA	70	70	EPA
Worker		Constant	70	NA	NA	NA	70	70	EPA
Exposure Duration (All Exposure Routes)	yr								
Adult Resident		Lognormal	11.36	13.72	0	70	9	30	Israeli and Nelson (1992); data for owners
Child Resident (1-6)		Uniform	NA	NA	1	5	5	5	Best Profession Judgement (BJP)
Trespasser		Lognormal	11.36	13.72	0	70	9	12	Israeli and Nelson (1992); data for owners
Worker		Lognormal	8.3	8.7	0	50	8	25	Bureau of Labor Statistics (1992)
Exposure Frequency (Indoor Air and Groundwater)	d/yr								
Adult Resident		Constant	350	NA	NA	NA	350	350	
Child Resident (1-6)		Constant	350	NA	NA	NA	350	350	Defaults to be modified based upon
Trespasser		NA	NA	NA	NA	NA	NA	NA	site-specific observations and information.
Worker		Constant	250	NA	NA	NA	250	250	
Exposure Frequency (Soil Routes)	d/yr								
Adult Resident		Triangular	40	NA	10	350	40	350	
Child Resident (1-6)		Triangular	130	NA	10	350	130	350	Defaults to be modified based upon
Trespasser		Triangular	26	NA	0	52	26	52	site-specific observations and information.
Worker		Triangular	125	NA	10	250	125	250	

Table 6-6. Monte Carlo Default Distributions

Parameter	Units	Distribution Type	Expected Value	Standard Deviation	Min.	Max.	Point Estimate		Reference for Monte Carlo Distributions
							Typical	RME	
Exposure Frequency (Swimming)	d/yr								
Adult Resident		Triangular	7	NA	0	60	5	36	Expected: EPA (1988); Remainder: BJP
Child Resident (1-6)		Triangular	7	NA	0	60	5	36	Expected: EPA (1988); Remainder: BJP
Trespasser		Triangular	7	NA	0	60	5	36	Expected: EPA (1988); Remainder: BJP
Worker		NA	NA	NA	NA	NA	NA	NA	
Total Skin Surface Area (Showering/Swimming)	cm^2								
Adult Resident		Normal	18400	2300	8000	30000	18400	23000	AIHC
Child Resident (1-6)		Normal	6800	600	5000	11000	6800	7280	Anderson et al.
Trespasser		Normal	14000	1700	7000	20000	14000	16550	AIHC
Worker		NA	NA	NA	NA	NA	NA	NA	
Fraction of Total Skin Surface Area Exposed to Soil (Soil Contact/Wading)	cm^2								
Adult Resident		Triangular	0.11	NA	0	0.56	0.11	0.56	Anderson et al. (1985)
Child Resident (1-6)		Triangular	0.13	NA	0	0.55	0.13	0.55	Anderson et al. (1985)
Trespasser		Triangular	0.11	NA	0	0.57	0.11	0.57	Anderson et al. (1985)
Worker		Triangular	0.11	NA	0	0.19	0.11	0.19	Anderson et al. (1985)
Soil Ingestion	mg/d								
Adult Resident		Lognormal	40.4	37.3	1.5	666.8	40	100	Assumed to be one-half child soil ingestion rate
Child Resident (1-6)		Lognormal	86	84	3	1854	90	200	Thompson and Burmaster (1991)
Trespasser		Lognormal	41	36.9	1.4	518.9	40	100	Assumed to be one-half child soil ingestion rate
Worker		Lognormal	40	37.3	1.8	437.1	40	100	Assumed to be one-half child soil ingestion rate

Table 6-6. Monte Carlo Default Distributions

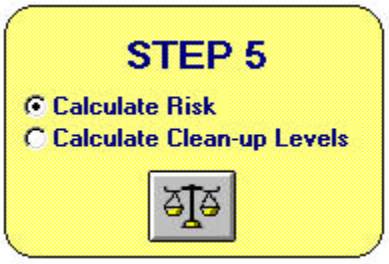
Parameter	Units	Distribution Type	Expected Value	Standard Deviation	Min.	Max.	Point Estimate		Reference for Monte Carlo Distributions
							Typical	RME	
Soil-On-Skin Adherence Factor	mg/cm^2								
Adult Resident		Triangular	0.2	NA	0.2	1	0.6	1	EPA (1992)
Child Resident (1-6)		Triangular	0.2	NA	0.2	1	0.6	1	EPA (1992)
Trespasser		Triangular	0.2	NA	0.2	1	0.6	1	EPA (1992)
Worker		Triangular	0.2	NA	0.2	1	0.6	1	EPA (1992)
Drinking Water Ingestion	l/d								
Adult Resident		Lognormal	1.27	0.6	0.1	3	1.1	2	Roseberry and Burmaster (1992): age group 20-65
Child Resident (1-6)		Lognormal	0.7	0.35	0.1	2	0.5	1	Roseberry and Burmaster (1992): age group 1-11
Trespasser		NA	NA	NA	NA	NA	NA	NA	
Worker		Lognormal	0.63	0.3	0.1	2	0.5	1	Assumed to be one-half adult res. water ing. rate
Swimming Ingestion Rate	l/d								
Adult Resident		Uniform	NA	NA	0	50	10	50	EPA (1988)
Child Resident (1-6)		Uniform	NA	NA	0	50	10	50	EPA (1988)
Trespasser		Uniform	NA	NA	0	50	10	50	EPA (1988)
Worker		NA	NA	NA	NA	NA	NA	NA	
Swimming Exposure Time	hr/d								
Adult Resident		Triangular	2.6	NA	0.5	6	2.6	2.6	Expected: EPA (1988); Remainder: BPJ
Child Resident (1-6)		Triangular	2.6	NA	0.5	6	2.6	2.6	Expected: EPA (1988); Remainder: BPJ
Trespasser		Triangular	2.6	NA	0.5	6	2.6	2.6	Expected: EPA (1988); Remainder: BPJ
Worker		NA	NA	NA	NA	NA	NA	NA	
Time Spent Outdoors	hr/d								
Adult Resident		Triangular	1.1	NA	0.25	2.5	1.1	2.5	Expected: AIHC (1994); Remainder: BPJ
Child Resident (1-6)		Triangular	2.2	NA	0.5	5	2.2	5	Expected: AIHC (1994); Remainder: BPJ
Trespasser		Triangular	1.5	NA	0.25	3	1.5	3	BPJ
Worker		Triangular	4	NA	2	6	4	6	BPJ

Table 6-6. Monte Carlo Default Distributions

Parameter	Units	Distribution Type	Expected Value	Standard Deviation	Min.	Max.	Point Estimate		Reference for Monte Carlo Distributions
							Typical	RME	
Time Spent Indoors	hr/d								
Adult Resident		Triangular	18.3	NA	8	24	18.3	24	Expected: EPA (1988); Remainder: BPJ
Child Resident (1-6)		Triangular	19.6	NA	10	24	19.6	24	Expected: EPA (1988); Remainder: BPJ
Trespasser		NA	NA	NA	NA	NA	NA	NA	Expected: EPA (1988); Remainder: BPJ
Worker		Triangular	4	NA	2	6	4	6	
Inhalation Rate (Indoor and Outdoor Air)	m^3/hr								
Adult Resident		Triangular	0.79	NA	0.25	1.33	0.83	0.83	AIHC (1994)
Child Resident (1-6)		Triangular	0.72	NA	0.35	1.18	0.83	0.83	AIHC (1994)
Trespasser		Triangular	1.68	NA	1.06	2.3	1.68	2.3	Anderson et al. (1985)
Worker		Triangular	0.8	NA	0.7	2.5	0.8	2.5	Anderson et al. (1985)
Inhalation Rate (In the Shower)	m^3/hr								
Adult Resident		Constant	0.6	NA	NA	NA	0.6	0.6	EPA (1989)
Child Resident (1-6)		Constant	0.6	NA	NA	NA	0.6	0.6	EPA (1989)
Trespasser		NA	NA	NA	NA	NA	NA	NA	
Worker		NA	NA	NA	NA	NA	NA	NA	
Flowrate of Shower (Showering)	l/min								
Adult Resident		Lognormal	8	2.7	0	30	8	10	Finley and Paustenbach (1994)
Child Resident (1-6)		Lognormal	8	2.7	0	30	8	10	Finley and Paustenbach (1994)
Trespasser		NA	NA	NA	NA	NA	NA	NA	
Worker		NA	NA	NA	NA	NA	NA	NA	
Water Temperature (Showering)	C								
Adult Resident		Triangular	45	NA	35	50	45	48	Smith (1994)
Child Resident (1-6)		Triangular	45	NA	35	50	45	48	Smith (1994)
Trespasser		NA	NA	NA	NA	NA	NA	NA	
Worker		NA	NA	NA	NA	NA	NA	NA	

Table 6-6. Monte Carlo Default Distributions

Parameter	Units	Distribution Type	Expected Value	Standard Deviation	Min.	Max.	Point Estimate		Reference for Monte Carlo Distributions
							Typical	RME	
Volume of Bathroom (Showering)	m^3								
Adult Resident		Triangular	2.9	NA	2	6	5.2	3	Smith (1994)
Child Resident (1-6)		Triangular	2.9	NA	2	6	5.2	3	Smith (1994)
Trespasser		NA	NA	NA	NA	NA	NA	NA	
Worker		NA	NA	NA	NA	NA	NA	NA	
Exposure Time (Showering)	hr/d								
Adult Resident		Triangular	0.11	NA	0.03	0.33	0.12	0.2	AIHC (1994)
Child Resident (1-6)		Triangular	0.11	NA	0.03	0.33	0.12	0.2	AIHC (1994)
Trespasser		NA	NA	NA	NA	NA	NA	NA	
Worker		NA	NA	NA	NA	NA	NA	NA	



7.0
CALCULATE RISK

The potential carcinogenic risk and non-carcinogenic hazard are calculated using equations presented in EPA's Risk Assessment Guidance for Superfund (EPA, 1989a). The following exposure routes are considered in the software:

1. Dermal contact with contaminated soil.
2. Ingestion of contaminated soil.
3. Ingestion of contaminated groundwater.
4. Dermal contact with contaminated groundwater (while showering).
5. Inhalation while showering.
6. Inhalation of outdoor air containing chemical vapors.
7. Inhalation of indoor air containing chemical vapors (in a building).
8. Ingestion while swimming.
9. Dermal contact with surface water (while swimming).

The first seven pathways represent some of the more common exposure pathways for many petroleum contaminated sites (e.g. former gas stations). If surface water bodies are present on the site, exposure pathways eight and nine may be important. As mentioned previously, the reader should note that throughout this document the term “risk” will be used to refer to the estimated potential for adverse human health impacts, for both carcinogenic and non-carcinogenic compounds. For some, this is a departure from the more rigorous use of the term “risk”, where it is sometimes only used to refer to the probability of developing cancer as a result of exposure to a chemical or group of chemicals.

7.1 DESCRIPTION OF EACH INTAKE ROUTE

The first step in the risk calculation is to estimate the intake rate for each chemical of concern from each exposure route. This intake rate, or dose, is expressed in milligrams per day of chemical taken into the body per unit body weight (mg/kg-d). EPA's Risk Assessment Guidance for Superfund (RAGS) manual (EPA, 1989a) recommends that when evaluating longer-term exposure to non-carcinogenic toxicants, the intake is to be calculated by averaging the intake over the period of exposure (or averaging time). The resulting term is called the chronic average daily dose (CADD) and is used to estimate the hazard quotient from each route by comparison with a safe "reference dose". Because this dose is derived for exposure periods greater than seven years, the *maximum 7-year average* concentration of the compound is used in the CADD calculations (rather than the average of the exposure duration). If the exposure duration is specified to be less than 7 years, the average concentration over the exposure duration is used.

For carcinogens, the intake rate is calculated by time-averaging the cumulative dose over a 70-year lifetime. In this case, the averaging time is considered to be the receptors lifetime, while the exposure duration may be considerably shorter. The Lifetime Averaged Daily Dose (LADD) is used to estimate the incremental excess lifetime cancer risk (IELCR) by multiplying the LADD by a toxicity factor (known as the slope factor). In cases where time-varying concentrations are considered, algorithms in the RISC software compute the maximum average of receptor point concentrations over the exposure duration.

Sections 7.1.1 through 7.1.8 present the equations used to estimate CADD and LADD for each exposure pathway. Section 7.2 discusses the calculation of carcinogenic risk and section 7.3 discusses calculation of the hazard quotients and resulting hazard index for non-carcinogens.

For reference, there is a detailed description of the absorption adjustment factors and their derivation in Appendix I. The numerical values are listed in Table 9-1. For a description of the skin permeability coefficients the reader is referred to the EPA Dermal Guidance (1992).

7.1.1 Ingestion of Soil

Adults working outdoors may ingest soil through incidental contact of the mouth with hands and clothing. Soil ingestion by children is often the primary exposure route of concern for contaminated soils (Paustenbach, 1989a,b). Intake of contaminants in soil by ingestion is estimated as follows:

$$CADD = 10^{-6}\, C_{s_{max}}\, IR\, AAF_{oral_S}\, EF\, BIO_i / (BW * 365) \qquad (7\text{-}1a)$$

$$LADD = 10^{-6}\, C_{s_{ave}}\, IR\, AAF_{oral_S}\, EF\, ED\, BIO_i / (LT\, BW * 365) \qquad (7\text{-}1b)$$

where

$CADD$ = chronic average daily dose (mg/kg-day)
$LADD$ = lifetime average daily dose (mg/kg-day)
$C_{s_{max}}$ = maximum 7-year average concentration in soil (mg/kg)
$C_{s_{ave}}$ = time-averaged concentration of chemical in soil (over the exposure duration (mg/kg)
IR = soil ingestion rate (mg/d)
AAF = chemical-specific oral-soil absorption adjustment factor (mg/mg)
BIO_i = bioavailability of chemical in soil (mg/mg)
EF = exposure frequency (days/year)
ED = exposure duration (years)
LT = lifetime = 70 years by definition
BW = body weight (kg)
365 = unit conversion factor (365 days/year)
10^{-6} = unit conversion factor (kg/mg)

7.1.2 Dermal Contact with Soil

Some soil contaminants may be absorbed across the skin into the bloodstream. Absorption will depend upon the amount of soil in contact with the skin, the concentration of chemicals in soil, the skin surface area exposed, and the potential for the chemical to be absorbed across skin. The intake is computed as follows:

$$CADD = 10^{-6}\, C_{s_{max}}\, SA\, AAF_{dermal_S}\, AF\, EF\, BIO_i / (BW * 365) \qquad (7\text{-}2a)$$

$$LADD = 10^{-6} C_{s_{ave}} SA AAF_{dermal_s} AF EF ED BIO_i / (LT BW *365) \quad (7\text{-}2b)$$

where

CADD = chronic average daily dose (mg/kg-day)

LADD = lifetime average daily dose (mg/kg-day)

$C_{s_{max}}$ = maximum 7-year average concentration of chemical in soil (mg/kg)

$C_{s_{ave}}$ = time-averaged concentration of chemical in soil (over the exposure duration (mg/kg)

SA = skin surface area exposed to soil (cm^2)

AAF = dermal-soil chemical specific absorption adjustment factor (mg/mg)

BIO_i = bioavailability of chemical in soil (mg/mg)

AF = soil-to-skin adherence factor (mg/cm^2/event)

EF = exposure frequency (events/year)

ED = exposure duration (years)

LT = lifetime = 70 years by definition

BW = body weight (kg)

365 = unit conversion factor (365 days/year)

10^{-6} = unit conversion factor (10^{-6} kg/mg)

The skin surface area available for soil exposure will vary seasonally and between receptors. For example workers would most likely have less skin exposed than children playing in the summer.

7.1.3 Ingestion of Groundwater

Intake from ingestion of contaminated water is estimated using the following equations:

$$CADD = C_{w_{max}} IR AAF_{oral_w} EF / (BW *365) \quad (7\text{-}3a)$$

$$LADD = C_{w_{ave}} IR AAF_{oral_w} EF ED / (LT BW *365) \quad (7\text{-}3b)$$

where

CADD = chronic average daily dose (mg/kg-day)

LADD = lifetime average daily dose (mg/kg-day)

$C_{w_{max}}$ = maximum 7-year average concentration of chemical in drinking water (mg/l)

$C_{w_{ave}}$ = time-averaged concentration of chemical in drinking water (mg/l)

IR = water ingestion rate (l/day)

BW = body weight (kg)
AAF = chemical-specific oral-water absorption adjustment factor (mg/mg)
EF = exposure frequency (days/year)
ED = exposure duration (years)
LT = lifetime = 70 years by definition
365 = unit conversion factor (365 days/year)

Note that in the above equations, IR is the rate of ingestion from the contaminated water source only, and is not necessarily equal to the total daily fluid intake.

7.1.4 Dermal Intake in the Shower

During showers and baths receptors may absorb dissolved contaminants across the skin into the bloodstream. The dose depends upon the absorption characteristics of the chemical (permeability coefficient), the surface area of skin in contact with the water, and the duration of the bath or shower:

$$CADD = 10^{-3}\, C_{w_{max}}\, SA\, AAF_{dermal_w}\, ET\, PC\, EF / (BW * 365) \quad (7\text{-}4a)$$

$$LADD = 10^{-3}\, C_{w_{ave}}\, SA\, AAF_{dermal_w}\, ET\, PC\, EF\, ED / (LT\, BW * 365) \quad (7\text{-}4b)$$

where

CADD = chronic average daily dose (mg/kg-day)
LADD = lifetime average daily dose (mg/kg-day)
$C_{w_{max}}$ = maximum 7-year average concentration of chemical in drinking water (mg/l)
$C_{w_{ave}}$ = time-averaged concentration of chemical in drinking water (mg/l)
SA = total skin surface area (cm^2)
AAF = dermal-water chemical specific absorption adjustment factor (mg/mg)
PC = chemical-specific skin permeability constant (cm/hr)
ET = bath or shower duration (hr/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
LT = lifetime = 70 years by definition
BW = body weight (kg)
365 = unit conversion factor (365 days/year)

10^{-3} = unit conversion factor (10^{-3} l/cm^3)

The permeability constant (PC) quantifies the diffusion properties of the skin and the chemical; values of PC are tabulated in EPA's Dermal Exposure Assessment: Principles and Applications (1992). This document also describes methods for estimating values of PC from other chemical parameters, such as octanol water partition coefficient (K_{ow}).

7.1.5 Inhalation in the Shower

While showering, chemicals in the shower water can volatilize into the air not only within the shower stall but into the bathroom and potentially the remainder of the house. Studies have shown that risks from inhalation while bathing can be comparable to, or greater than, risks from drinking contaminated water (McKone, 1987). Inhalation intake during showering is computed as a function of the concentration of volatiles in the shower air, the inhalation rate, and the duration of the shower:

$$CADD = C_{air_{max}} \, InhR \, ET \, AAF_{inhal} \, LRF \, EF / (BW * 365) \qquad (7\text{-}5a)$$

$$LADD = C_{air_{ave}} \, InhR \, ET \, AAF_{inhal} \, LRF \, EF \, ED / (LT \, BW * 365) \qquad (7\text{-}5b)$$

where

CADD = chronic average daily dose (mg/kg-day)

LADD = lifetime average daily dose (mg/kg-day)

$C_{air_{max}}$ = maximum concentration of chemical in bathroom air (mg/m^3) (calculated from the *maximum 7-year average groundwater* concentration)

$C_{air_{ave}}$ = time-averaged concentration of chemical in bathroom air (mg/m^3) (calculated from the *maximum average groundwater* concentration over the exposure duration)

InhR = inhalation rate while showering (m^3/hr)

ET = shower duration (hr/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

AAF = chemical-specific inhalation absorption adjustment factor (mg/mg)

LRF = lung retention factor (dimensionless)

LT = lifetime = 70 years by definition

BW = body weight (kg)
365 = unit conversion factor (365 days/year)

These equations assume that the concentration in the bathroom air is known. RISC calculates this concentration using a shower volatilization model developed by Foster and Chrostowski (1986). The equations used in this model are described in Appendix F.

7.1.6 Inhalation of Outdoor Air (Soil Emissions)

In this exposure pathway the inhalation of chemicals in outdoor air due to volatile chemical emissions is considered. The intake is computed as follows:

$$CADD = C_{air_{max}} \, InhR \, ET \, AAF_{inhal} \, LRF \, EF \, / \, (BW * 365) \qquad (7\text{-}6a)$$

$$LADD = C_{air_{ave}} \, InhR \, ET \, AAF_{inhal} \, LRF \, EF \, ED \, / \, (LT \, BW * 365) \qquad (7\text{-}6b)$$

where

CADD = chronic average daily dose (mg/kg-day)
LADD = lifetime average daily dose (mg/kg-day)
$C_{air_{max}}$ = maximum 7-year concentration of chemical in outdoor air (mg/m^3)
$C_{air_{ave}}$ = time-averaged concentration of chemical in outdoor air (mg/m^3)
InhR = inhalation rate (m^3/hr)
ET = exposure time (hr/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
AAF = chemical-specific inhalation absorption adjustment factor (mg/mg)
LRF = lung retention factor (mg/mg)
LT = lifetime = 70 years by definition
BW = body weight (kg)
365 = unit conversion factor (365 days/year)

For sites where hydrocarbon-contaminated soil is the primary media of concern, the chemicals in the air are assumed to have volatilized from the soil.

7.1.7 Inhalation of Indoor Air (Either from Soil or Groundwater Emissions)

In this exposure pathway the inhalation of chemicals in buildings is considered. Chemicals may volatilize from contaminated soil or groundwater and migrate through the vadose zone and into a building. The intake is computed using the same equations as for outdoor air:

$$CADD = C_{air_{max}} \, InhR \, ET \, AAF_{inhal} \, LRF \, EF \, / \, (BW * 365) \qquad (7\text{-}7a)$$

$$LADD = C_{air_{ave}} \, InhR \, ET \, AAF_{inhal} \, LRF \, EF \, ED \, / \, (LT \, BW * 365) \qquad (7\text{-}7b)$$

where

CADD = chronic average daily dose (mg/kg-day)
LADD = lifetime average daily dose (mg/kg-day)
$C_{air_{max}}$ = maximum 7-year averaged concentration of chemical in indoor air (mg/m^3)
$C_{air_{ave}}$ = time-averaged concentration of chemical in indoor air (mg/m^3)
InhR = inhalation rate (m^3/hr)
ET = exposure time (hr/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
AAF = chemical-specific inhalation absorption adjustment factor (mg/mg)
LRF = lung retention factor (mg/mg)
LT = lifetime = 70 years by definition
BW = body weight (kg)
365 = unit conversion factor (365 days/year)

7.1.8 Ingestion while Swimming

Water may be incidentally ingested while swimming. Chemical concentration in water should reflect unfiltered concentrations. Exposure duration and frequency will be less for recreational users than for residents living nearby. Intake is calculated similar to that for ingestion of drinking water (Equation 7-3):

$$CADD = C_{sw_{max}} \, IR \, AAF_{oral_w} \, EF \, / \, (BW * 365) \qquad (7\text{-}8a)$$

$$LADD = C_{sw_{ave}} \, IR \, AAF_{oral_w} \, EF \, ED \, / \, (LT \, BW * 365) \qquad (7\text{-}8b)$$

where

CADD = chronic average daily dose (mg/kg-day)

LADD = lifetime average daily dose (mg/kg-day)

$C_{sw_{max}}$ = maximum 7-year average contaminant concentration in surface water (mg/l)

$C_{sw_{ave}}$ = time-averaged contaminant concentration in surface water (mg/l)

IR = water ingestion rate (l/day)

BW = body weight (kg)

AAF = chemical-specific oral-water absorption adjustment factor (mg/mg)

EF = exposure frequency (days/year)

ED = exposure duration (years)

LT = lifetime = 70 years by definition

365 = unit conversion factor (365 days/year)

Workers are not expected to be exposed via this pathway.

7.1.9 Dermal Contact while Swimming

If a site contains surface water that is contaminated or has the potential of becoming contaminated, the risk to swimmers (or waders) should be evaluated. The intake from this exposure pathway is calculated similarly to that of dermal intake while showering (Section 7.1.5):

$$CADD = 10^{-3} C_{sw_{max}} SA\ AAF_{dermal_w}\ ET\ PC\ EF / (BW * 365) \quad (7\text{-}9a)$$

$$LADD = 10^{-3}\ C_{sw_{ave}}\ SA\ AAF_{dermal_w}\ ET\ PC\ EF\ ED / (LT\ BW * 365) \quad (7\text{-}9b)$$

where

CADD = chronic average daily dose (mg/kg-day)

LADD = lifetime average daily dose (mg/kg-day)

$C_{sw_{max}}$ = maximum 7-year average contaminant concentration in surface water (mg/l)

$C_{sw_{ave}}$ = time-averaged contaminant concentration in surface water (mg/l)

SA = total skin surface area exposed to surface water (cm^2)

AAF = dermal-water chemical specific absorption adjustment factor (mg/mg)

PC = chemical-specific skin permeability constant (cm/hr)

ET = exposure time in water (hr/day)

EF = exposure frequency (days/year)
ED = exposure duration (years)
LT = lifetime = 70 years by definition
BW = body weight (kg)
365 = unit conversion factor (365 days/year)
10^{-3} = unit conversion factor (10^{-3} l/cm^3)

The parameter values used in this calculation should reflect the a plausible situation. For example, if the surface water is a stream and swimming is impossible, intake values should reflect a more realistic case such as wading or playing in the water. In this situation the skin surface area exposed would be less than for a swimming scenario.

7.2 CALCULATION OF CARCINOGENIC RISK

For carcinogens, risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. This risk is referred to as the individual excess lifetime cancer risk (IELCR) or just carcinogenic risk. Published values of chemical carcinogenic toxicity (slope factor) are used to calculate risk from the LADD:

$$IELCR_{ij} = SF_{ij}\, LADD_{ij} \qquad (7\text{-}10)$$

where

$IELCR_{ij}$ = the individual excess lifetime cancer risk for chemical i, exposure route j (dimensionless)
SF_{ij} = the slope factor for chemical i, exposure route j $(mg/kg\text{-}d)^{-1}$
$LADD_{ij}$ = the lifetime average daily dose for chemical i, exposure route j (mg/kg-d)

This approach to estimating risk is based on the linear low-dose cancer risk model described by the EPA (1989a), and is considered valid for risks below 0.01. The model assumes that exposure to any amount of a carcinogen will increase the risk of cancer, i.e. there is no safe (no risk) dosage. This assumption is fundamentally different from that assumed for non-carcinogens, where a safe "reference dose" exists.

Ideally the slope factor used in Equation 7-10 should reflect the route of intake (e.g., ingestion, inhalation, or dermal absorption). Unfortunately, toxicological data is not always available for each route (e.g., inhalation data only might be available), and so route-to-route extrapolations must be made. In such cases one sometimes assumes that the slope factor for one unknown intake route is equal to the slope factor for some known route. (It is quite common to use the oral slope factor for dermal exposures.) Risks are assumed to be additive from multiple chemicals and routes, therefore the total risk is estimated by:

$$IELCR_t = \bullet \; IELCR_{ij} \qquad (7\text{-}11)$$

where

$IELCR_t$ = the total individual excess lifetime cancer risk
(or, incremental cancer occurrences/individuals exposed)

7.3 CALCULATION OF HAZARD INDEX

The potential for non-carcinogenic effects is evaluated by comparing an exposure level over the exposure duration with a reference dose derived for a similar exposure period. This ratio of exposure to toxicity for an individual pathway and chemical is called a hazard quotient. The hazard quotients are usually added across all chemicals and routes to estimate the hazard index. Some, however, will argue that it is more appropriate to only sum the hazard quotients for chemicals that affect the same target organ (e.g. liver).

The noncancer hazard quotient assumes that there is a level of exposure (RfD) below which it is unlikely that even sensitive populations would experience adverse health effects (EPA 1989a). The reference dose (or RfD) is a toxicity value for evaluating non-carcinogenic effects. It has the same units as intake and it is assumed that if the intake is below the RfD (hazard quotient < 1) no adverse health affects occur, even if the receptor is exposed to this dose continuously over a lifetime. Two types of RfDs are generally used: a subchronic RfD for short-term exposures and a chronic RfD for long-term exposure. The chemical database in RISC contains the values for chronic RfDs. If a subchronic case is being evaluated, it is important to modify the RfD.

The hazard quotient for an individual chemical and individual route is calculated by:

$$HQ_{ij} = CADD_{ij} / RfD_{ij} \qquad (7\text{-}12)$$

where

HQ_{ij}	=	the hazard quotient for chemical i, exposure route j (dimensionless)
$CADD_{ij}$	=	the chronic daily intake for chemical i, exposure route j (mg/kg-d)
RfD_{ij}	=	the reference dose for chemical i, exposure route j (mg/kg-d)

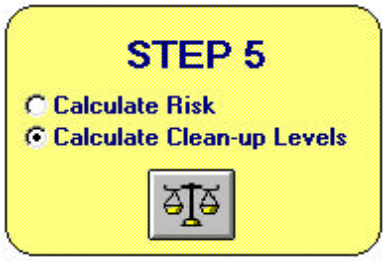
The hazard quotients from each chemical and route are then added to obtain the hazard index:

$$HI = \bullet \bullet HQ_{ij} \qquad (7\text{-}13)$$

where

HI	=	the hazard index
HQ_{ij}	=	the hazard quotient for chemical i, exposure route j (dimensionless)

As discussed previously, the hazard index is an indication of the potential for adverse noncarcinogenic effects, and is not a probabilistic risk. As a rule, the greater the value of the hazard index, the greater the level of concern. Hazard indices above one generally indicate the potential for adverse health effects and suggest the need to undertake a further level of investigation or even remedial action.



8.0
CALCULATE CLEAN-UP LEVELS

When this "back calculation" option is chosen from Step 5, the user specifies a target risk and hazard index and then the RISC code estimates source and/or receptor point concentrations for the chemicals of concern such that the risk levels are not exceeded.

8.1 SETUP THE SIMULATION

The first four steps involved in running the back calculation are the same first four steps used in running a "forward" calculation of risk. First, the user describes the scenario by choosing chemicals of concern (Step 1, main menu). In Step 2, the user chooses pathways and fate and transport models to be used, if any. Next, the receptor point concentrations are specified, and/or fate and transport models are run (Step 3). In Step 4, "Define the Receptors", one receptor is selected and the intake parameters describing the scenario are defined.

Clean-up levels can only be calculated for one receptor at a time and only under the deterministic scenario. However, multiple chemicals and exposure pathways may be considered simultaneously for that single receptor. Also, the reader is reminded that the ASTM Tier 1 spreadsheet distributed with RISC may be used to establish initial, relatively conservative, clean-up levels (without pathway or chemical additivity, however).

8.2 RUN THE "BACK-CALCULATION" CODE

Select "Calculate Clean-up Levels" in Step 5. Figure 8-1 shows the input screen used to specify the target risk and hazard index, and to run the "back-calculation".

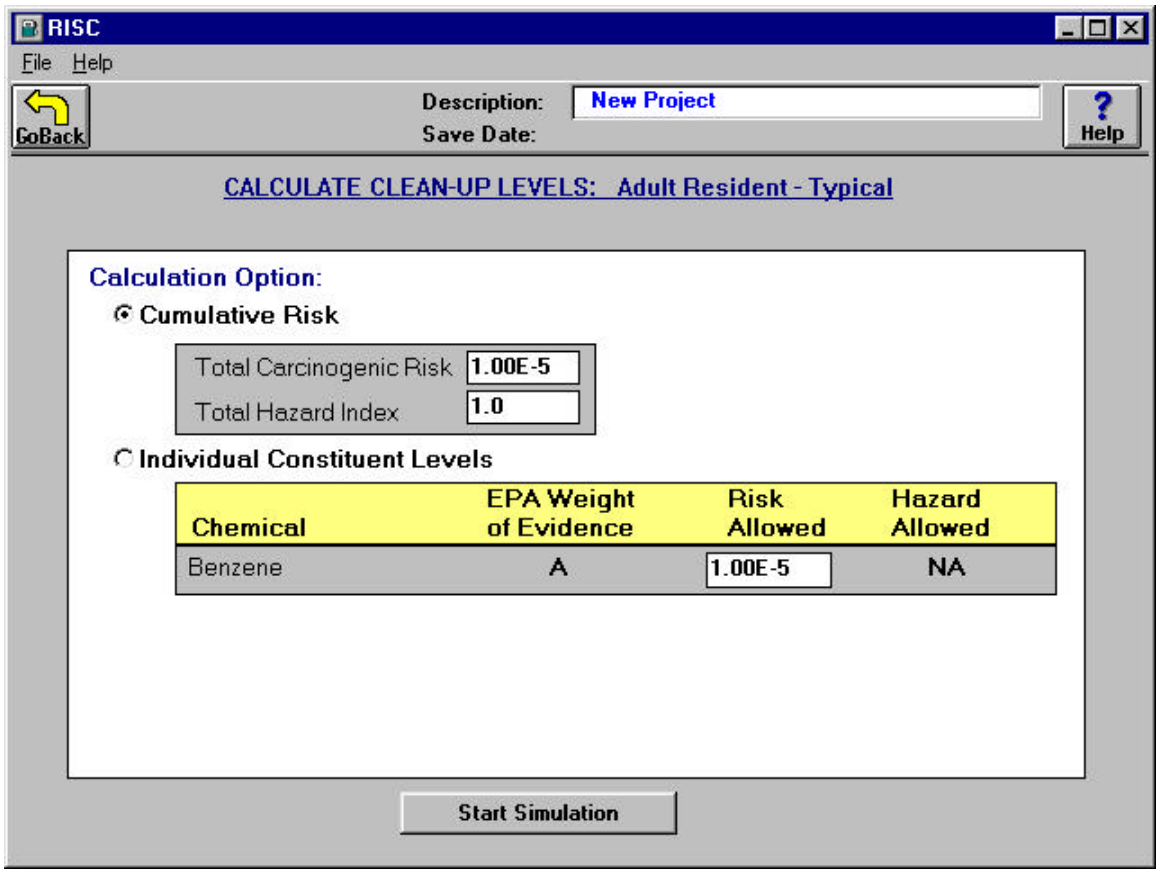


Figure 8-1. Target Risk Input Screen

During the back-calculation, each individual chemical source concentration used in the model is reduced or increased to achieve this level of risk. If multiple compounds are involved under an additive risk case, the concentrations of each compound are increased or reduced proportionately to each other in order to maintain the same relative concentrations.

After the target risk levels and method used to adjust source are specified, run the back-calculation code by clicking on the "Start Simulation" button. If no fate and transport models are used, the code should run quickly. If fate and transport models are used, however, they must be run iteratively until the optimal source concentrations or size is determined. This may require the models to be run up to 7 times, so the simulation time may be up to 7 times longer than running the fate and transport models in Step 3. The actual methods used to estimate the clean-up levels for the "direct pathways" and the "fate and transport pathways" are described in the following sections.

8.3 DESCRIPTION OF METHOD USED TO CALCULATE CLEAN-UP LEVELS

The risk and hazard are calculated just as if this were a “forward” calculation. These risk estimates and source concentrations serve as a starting point for the back-calculation mode. As the risk is calculated, the code generates a "risk coefficient matrix" and "hazard coefficient matrix":

$$\text{Risk} = A_{coeff} \times Conc_{gw} + B_{coeff} \times Conc_{outdoor\ air} + C_{coeff} \times Conc_{indoor\ air} + D_{coeff} \times Conc_{soil} + E_{coeff} \times Conc_{surface\ water} \quad (8\text{-}1)$$

where

Risk = the total hazard index or carcinogenic risk for one chemical.

A, B, C, D and E coefficients = functions of the intake parameters and chemical-specific toxicity parameters (these are calculated by RISC from the intake and specific toxicity parameters specified by the user).

NOTE: Some of the above coefficients may account for multiple exposure routes. For example, A_{coeff} accounts for the contribution from drinking water, dermal exposure to groundwater, and inhalation in the shower, if all of these routes were chosen. For media that are not linked together, e.g. all direct exposure media, the risk is calculated separately for each media. Media concentrations that are linked to one source (e.g., outdoor air concentrations arising from a soil source and groundwater concentrations calculated using the same vadose zone source linked with a saturated zone model) will be estimated so that the sum of all the risks arising from the same source (for all chemicals) add up to the target risk.

The first step in calculating clean-up levels is to determine how many source zones (e.g., contaminated soil, residual phase in groundwater, etc.) and/or direct media there are in the current scenario. The following steps are performed for each media or source zone.

Step 1: The risk factors from the portion of the risk equation that applies to the current media are determined. For each media or source zone, the risk factor may be written in the following form:

$$\text{RiskFactor}_{\text{media i}} = \bullet \quad \text{RiskCoeff(i,j)} \times \text{Conc}_{\text{rcpt}}\text{(i,j)}$$

$$j = 1, \text{number of chemicals} \qquad (8\text{-}2)$$

where

$\text{RiskFactor}_{\text{media I}}$ = risk factor (hazard index or carcinogenic risk) for media i

RiskCoeff(i,j) = risk factor coefficient for media i, and chemical j

$\text{Conc}_{\text{rcpt}}$(i,j) = receptor point concentration for media i, chemical j. (NOTE: this concentration is either the maximum or the running average for the exposure duration depending on whether hazard or carcinogenic risk, respectively, is being considered.)

Step 2: The code determines which type of risk is limiting for this source zone: hazard or carcinogenic risk. In order to determine which is limiting, the carcinogenic risk and hazard index are normalized and then compared to find the maximum:

$$max\left[\frac{|Risk - TargetRisk|}{TargetRisk}, \frac{|Hazard - TargetHazard|}{TargetHazard}\right] \qquad (8\text{-}3)$$

where:

Risk = the sum of all the risks associated with the current source term

Hazard = the sum of all of the hazard quotients for the current source term

TargetRisk = target carcinogenic risk specified by user

TargetHazard = target hazard index specified by user

Step 3: The chemical contributing the largest amount of risk (or hazard) from this source is determined along with how much risk it contributes.

$$RiskFactor_{\lim chem} = \max\left[\frac{\sum_{i=1}^{nRoutes} RiskCoeff\,(i,j) \times Conc_{rcpt}\,(i,j)}{Risk_{total}}, j = 1, nChem\right] \qquad (8\text{-}4)$$

where

$RiskFactor_{limchem}$ = the total risk contributed by the "worst chemical" for this source.

The fraction of total risk contributed by the limiting chemical is calculated from:

$$fraction_{\max} = \frac{RiskFactor_{\lim chem}}{Risk_{total}} \quad (8\text{-}5)$$

This fraction will be used to limit the amount of the target risk allocated to the limiting chemical as a starting point for the iterative back calculation.

$$RiskFactor_{max} = TargetRisk \times fraction_{max}$$

where:

$RiskFactor_{max}$ = the maximum risk or hazard allowed for the limiting chemical.

Step 4: The maximum receptor point concentration(s) is calculated:

$$Conc_{rcpt}(i, \lim chem)_{\max} = \frac{RiskFactor_{\max}}{RiskCoeff\,(i, \lim chem)} \quad (8\text{-}6)$$

The source concentrations are then calculated to meet the maximum risk factor allowed for the limiting chemical (within a tolerance). For direct pathways, the $Conc_{rcpt}$ is the clean-up level. For modeled pathways, the fate and transport model(s) are run in a forward mode iteratively changing the source term each time until the appropriate receptor point concentration(s) are calculated.

If the risk factor is within the target tolerance (0.1% of value) for the limiting chemical, the fate and transport codes are run for all the chemicals of concern (adjusting the source appropriately.) The total risk factor from all chemicals is then estimated and checked against the target. If the target has not been met, the new limiting risk fractions are calculated and the above steps are repeated (iterative solution).

If the overall risk factor equals the target for all the chemicals, the other risk factor (carcinogenic risk or hazard) is calculated to make sure the target has been met for both

risk and hazard. If the target level has been exceeded, then steps 2 through 4 are repeated. The procedure outlined in the above four steps are repeated for each media or source.

8.4 RESULTS OF THE CLEAN-UP LEVEL CALCULATION

For direct pathways (i.e., no fate and transport models), the code will calculate receptor point concentrations for each media so that the target risk and hazard index will not be exceeded *for that media.* If the pathways chosen include more than one contact media, the target risk will be met for each media, however, the total risk will equal the product of the specified target risk and the total number of media. For example, if the following pathways are chosen:

Soil Routes:

- Ingestion of soil
- Dermal contact with soil

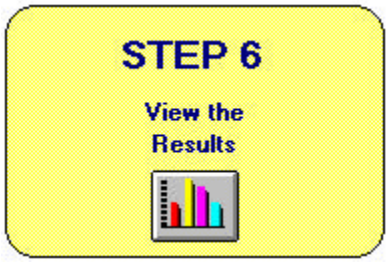
Groundwater Routes:

- Ingestion of groundwater
- Dermal contact with groundwater
- Inhalation in the shower

the clean-up level in soil will be calculated so that the sum of the risks from the two soil routes equals the target risk. Likewise, the clean-up level in groundwater will be calculated so that the sum of the risks for the three groundwater pathways will equal the target risk. If a receptor actually was exposed to both soil and groundwater at the clean-up levels calculated, the total risk would be equal to twice the target risk specified.

For direct pathways, if both carcinogens and non-carcinogenic chemicals are present, both the target risk and the target hazard will be met. Within each group of chemicals (carcinogenic or non-carcinogenic) the concentration ratios relative to each other (entered in Step 3) will be maintained. However, the concentration ratio between carcinogens and non-carcinogens will not be maintained.

The results are displayed in Step 6: “View Results”, from the main menu. “View Results” is described in Chapter 9.



9.0 RESULTS

After a successful risk calculation has been performed, the results can be viewed in the form of tables and charts selected from the main screen of Step 6 (Figure 9-1).

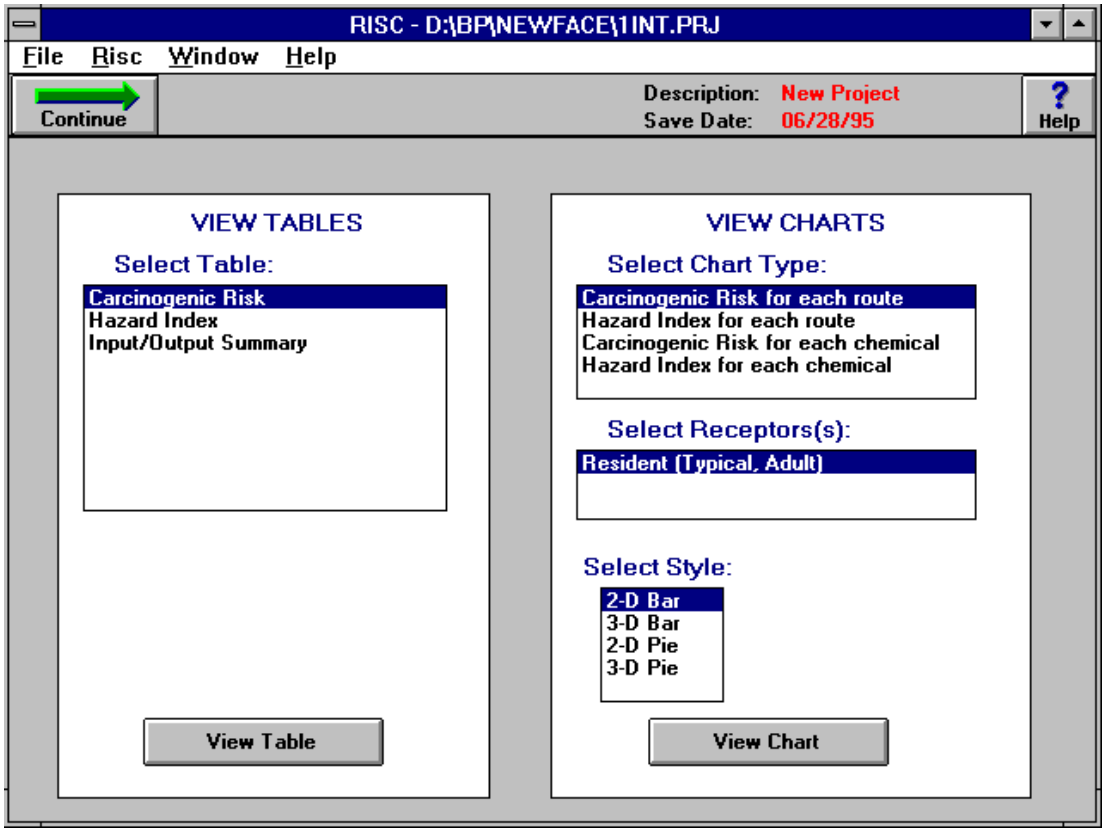


Figure 9-1. Menu for Viewing Results of a Deterministic Risk Assessment

9.1 DETERMINISTIC OUTPUT

Three different tables are available for all risk assessments: "Carcinogenic Risk", "Hazard Index", and the "Input/Output Summary" which lists the values used in the risk calculation.

The tables are viewed by first selecting the table type from the "Select Table" box and then choosing the "View Table" button. Figure 9-2 shows an example of a "Carcinogenic Risk" table.

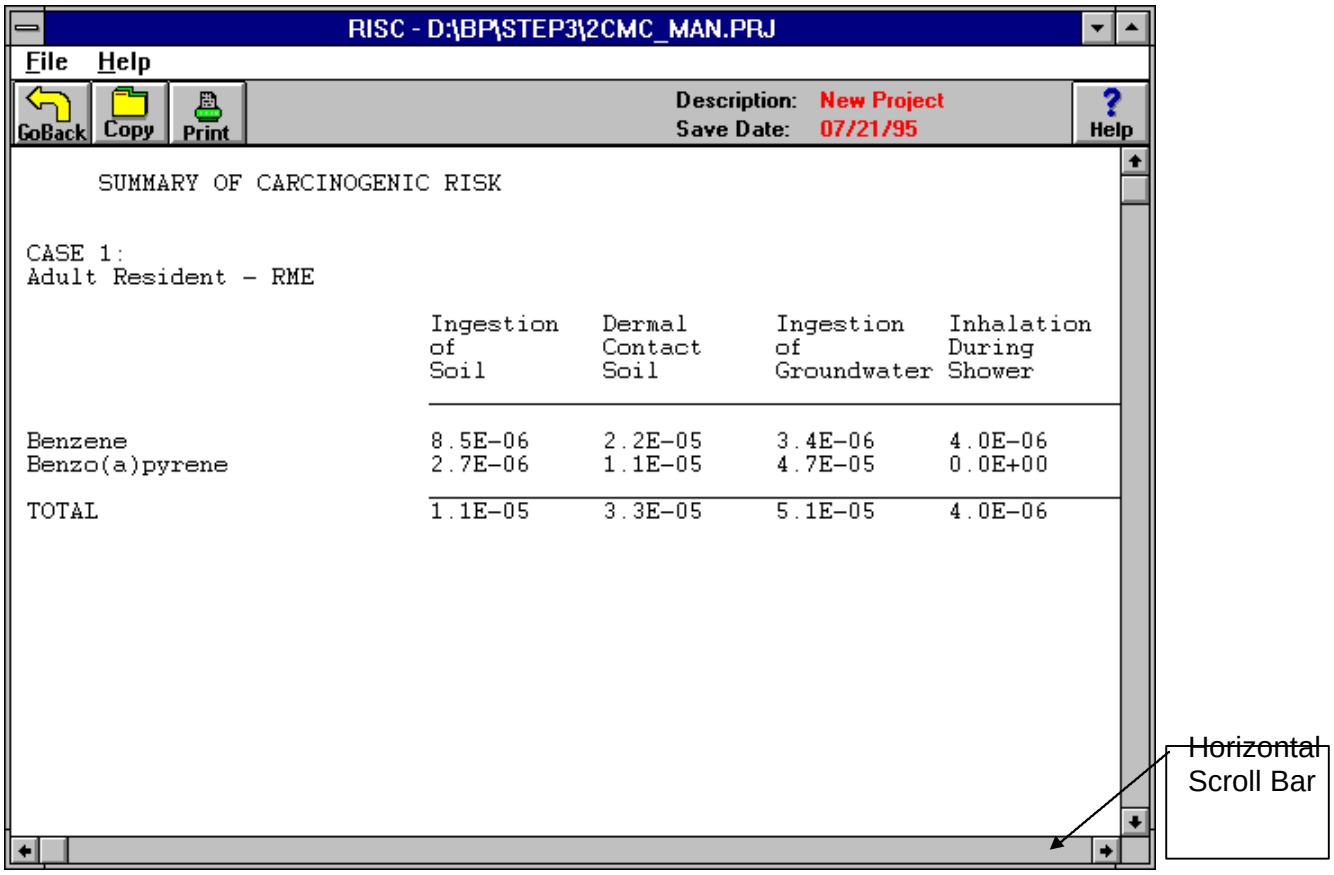


Figure 9-2. Example of Carcinogenic Risk Table

Note, the entire table is not shown in on the screen in Figure 9-2. The rest of the table may be viewed by using the vertical and horizontal scroll bars.

These tables may be copied and pasted into other applications for inclusion in reports. (This is discussed in section 9.3.) Examples of the "Carcinogenic Risk" and the "Input/Output Summary" tables (copied into Microsoft Word®) are shown in Tables 9-1 and 9-2 (at the end of this chapter). The "Input/Output Summary" lists all the input values used to calculate the risk and hazard index. This table is very useful as a concise summary of the entire risk analysis.

Charts are chosen similarly to the tables, however, there are more options for setting up charts (see Figure 9-1). Figure 9-3 shows "Carcinogenic Risk by each route" for the example presented in Tables 9-1 and 9-2.

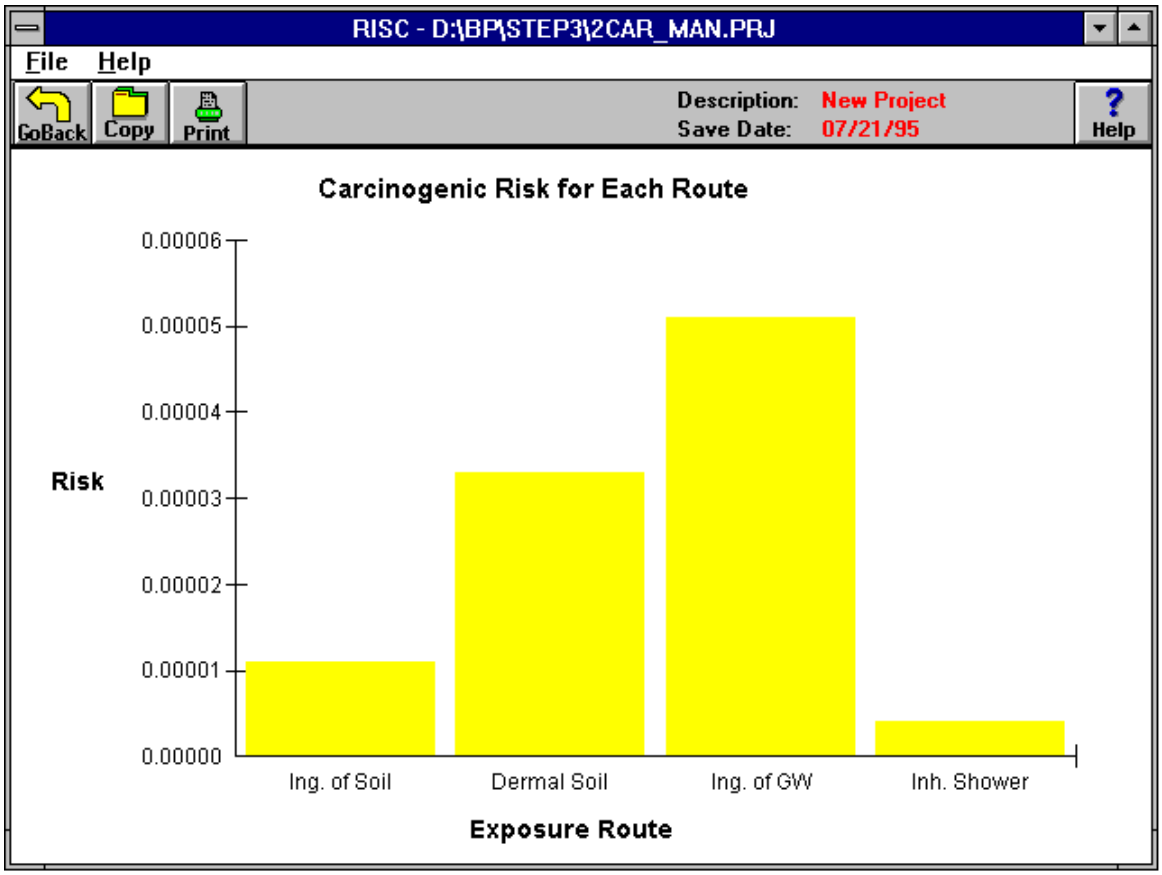


Figure 9-3. Chart of Carcinogenic Risk by Route

Most of the risk in this example is posed by ingestion of groundwater.

If more than one receptor is considered, (e.g. "Typical" and “RME” adult) the user has the option to view a chart of the results one at a time or for both receptors at once (select both receptors with the mouse). When both receptors are selected for plotting in one chart, the user may choose to either show the results in a "Clustered" or in a "Stacked" bar chart. Clustered bar charts are useful for making side-by-side comparisons of total risk or hazard between two receptors. Figure 9-4 shows an example of a "Clustered" bar chart comparing a “RME” and "Typical" residential adult receptor. Default values were used for all intake parameters.

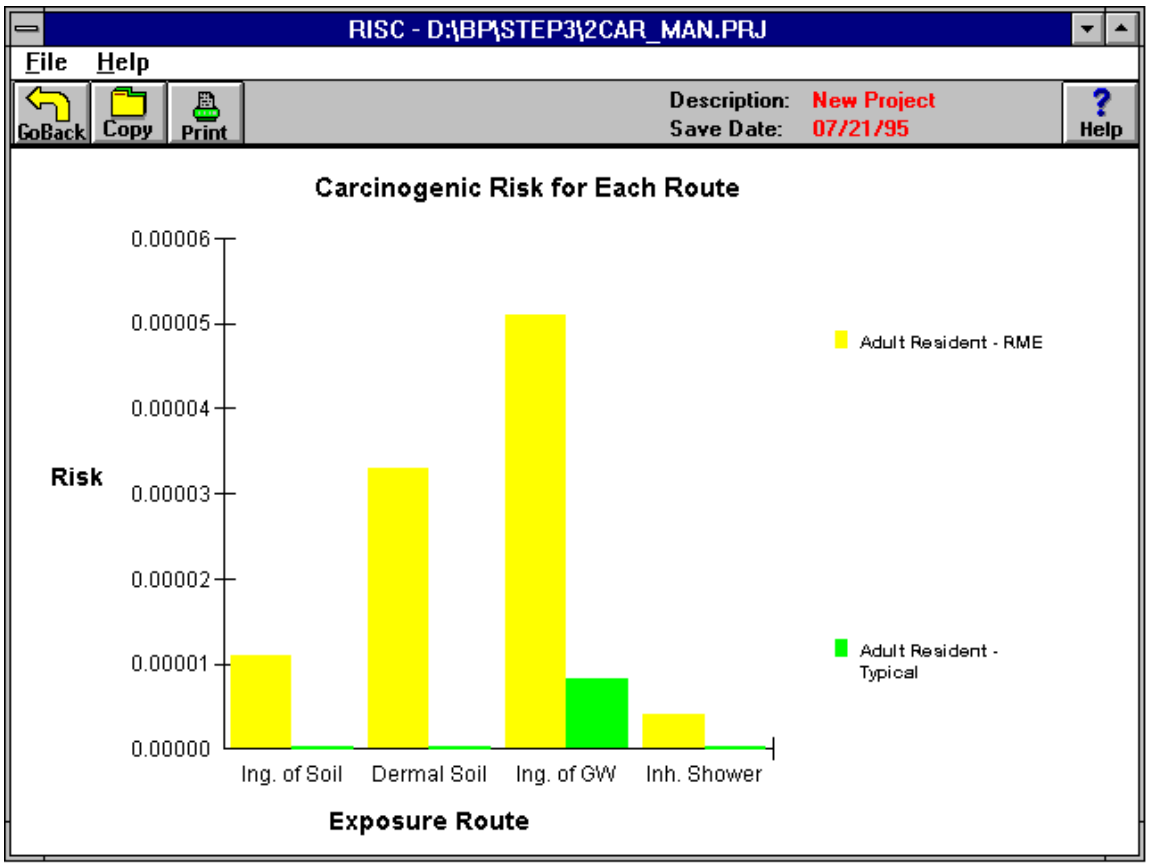


Figure 9-4. Chart of Carcinogenic Risk for Two Receptors

The results presented in Figure 9-4 were calculated using the example shown in Table 9-2 with a "Typical" receptor added. The total risk for the "Typical" residential adult receptor for this case is 8.8E-6 which is an order of magnitude less than the risk calculated for the RME receptor (9.9E-05). The clustered chart illustrates how the risk was distributed among the exposure routes and how the two receptors compare *risk-wise* for each route. Because the Y-axis is on a linear scale (as opposed to logarithmic) the bars indicating risk for the "Typical" receptor are quite small compared to the RME receptor.

Multiple receptor charts may also be presented using the "Stacked" option. This option is really only appropriate for cases when the additive risk to two receptors is being considered (e.g. an individual exposed as both a child and an adult). Figure 9-5 shows an example of a stacked chart for an RME adult and RME child.

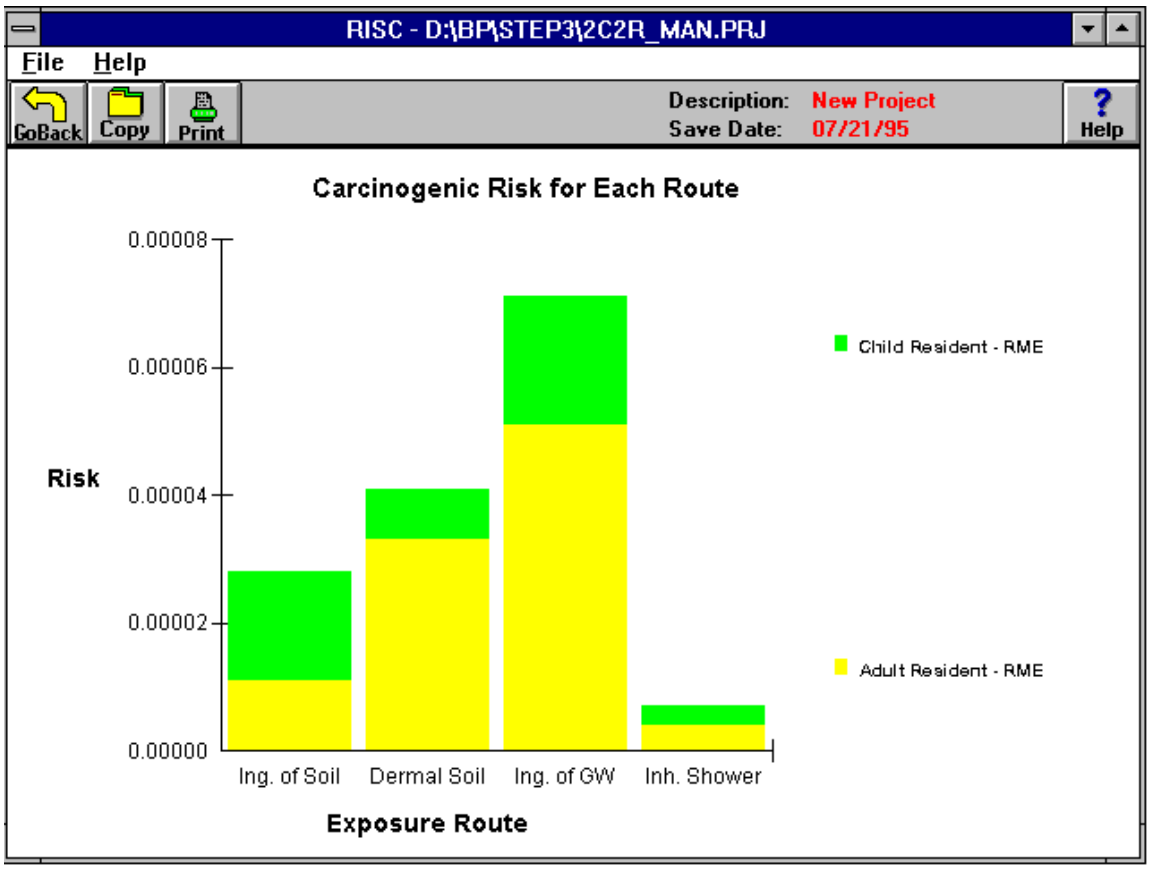


Figure 9-5. "Stacked" Chart for Additive Receptors

In this case the receptor is considered to be a child for 5 years and an adult for 30 years for a total exposure duration of 35 years. Since the behavior (and intake parameters) of children are different than adults, different risks will be calculated for the same length of exposure. The clustered option illustrates the contribution of both exposure periods to the total risk. In Figure 9-5, for example, just over one-half of the risk from ingestion of soil occurs while the receptor is a child (only 5 years of the 35 year exposure duration).

9.2 MONTE CARLO OUTPUT

When a Monte Carlo analysis is performed the types of tables and charts available are different than for the deterministic case. Figure 9-6 shows the options for the Monte Carlo analysis case.

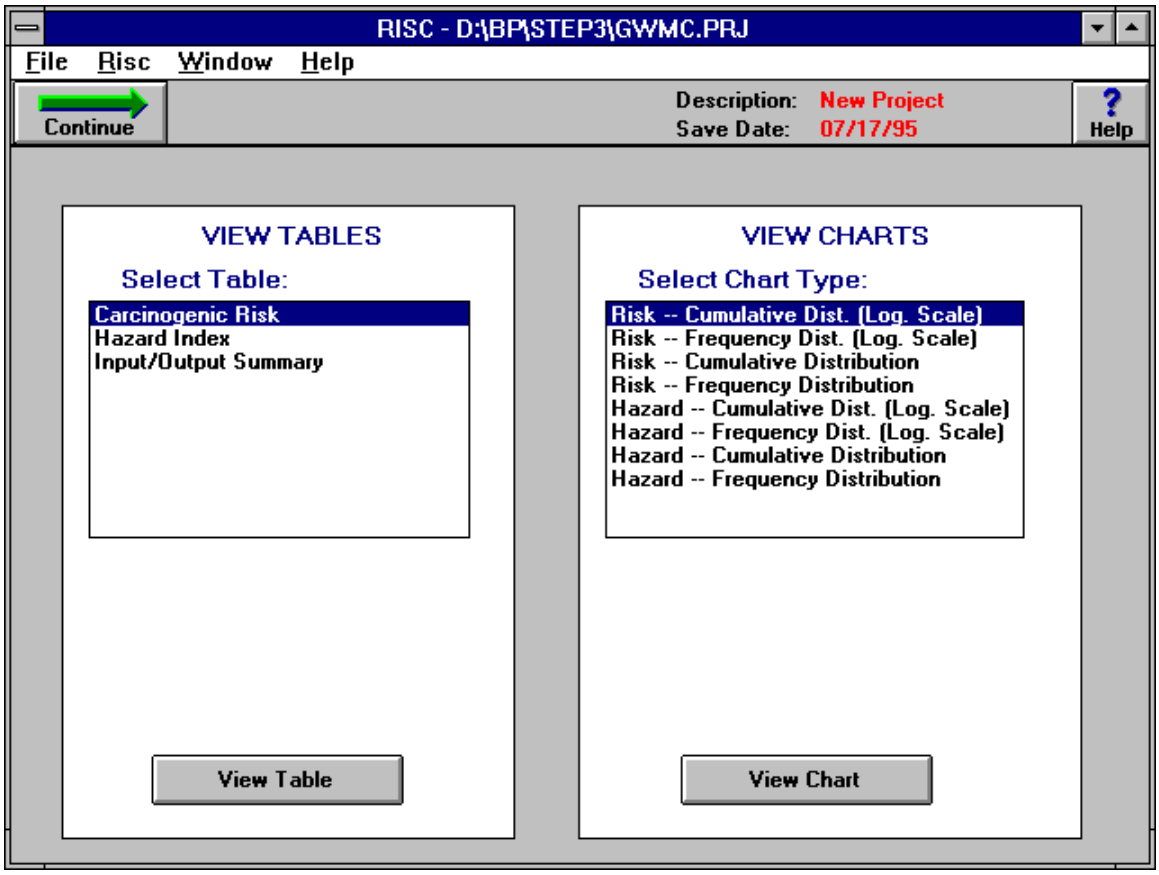


Figure 9-6. Menu for Viewing Results of a Monte Carlo Risk Assessment

9.2.1 Monte Carlo Tables

There are three table options for Monte Carlo similar to the three table options for the deterministic case. For the former, the carcinogenic risk and hazard index tables present the statistics calculated from the Monte Carlo output. Tables 9-3 and 9-4 (at the end of this chapter) show the "Carcinogenic Risk" and "Input/Output Summary" tables for a residential adult. The "Input/Output Summary" table presents all the input distributions specified for the intake parameters.

When using the Monte Carlo analysis an acceptable non-exceedence risk level must be decided. Typically this value is the 90th or 95th percentile. The statistical summary table of risk (Table 8-3) indicates that the Monte Carlo output generated total risk values that ranged from a minimum of 3.11E-07 (about 3 in 10,000,000) to a maximum of 1.93E-04 (about 2 in 10,000). The 95% exceedence value is 4.05E-05. The deterministic example presented in section 8.1 estimated a total risk of 9.9E-05 for the reasonable maximum exposure (RME) residential adult. One point of interest is to locate where the deterministic RME value falls on the range of Monte Carlo results. For this example, the RME value is above the 99th percentile but less than the maximum of the Monte Carlo results. This indicates that for this case, the risk estimated using the RME deterministic case would only be exceeded by less than 1% of the receptors exposed to this site.

9.2.2 Monte Carlo Charts

The charts available for a Monte Carlo analysis present summaries of *total* risk or *total* hazard, (not risk broken out from each route or chemical). These charts can be viewed as a frequency distribution or they can be viewed as a cumulative frequency distribution. Either type of chart may viewed on a linear- or logarithmic-scale.

9.2.2.1 Frequency Distributions

Frequency distributions are constructed from the Monte Carlo output by arranging the output values into classes and representing the frequency of occurrence in any class by the height of the bar. The frequency of occurrence corresponds to probability. Frequency distributions are sometimes called probability density functions (PDFs), however, a probability density function is a statistical term implying that the frequency distribution was constructed with an infinitely large data set and infinitely small class size (in essence a continuous curve). Frequency distributions are useful for evaluating the spread of the values and the shape of the "tails" (i.e. how narrow or wide they are). They are not as useful as cumulative distribution functions for evaluating probabilities of exceedence of a certain risk level.

Figure 9-5 shows an example of a frequency distribution of total risk on a log scale.

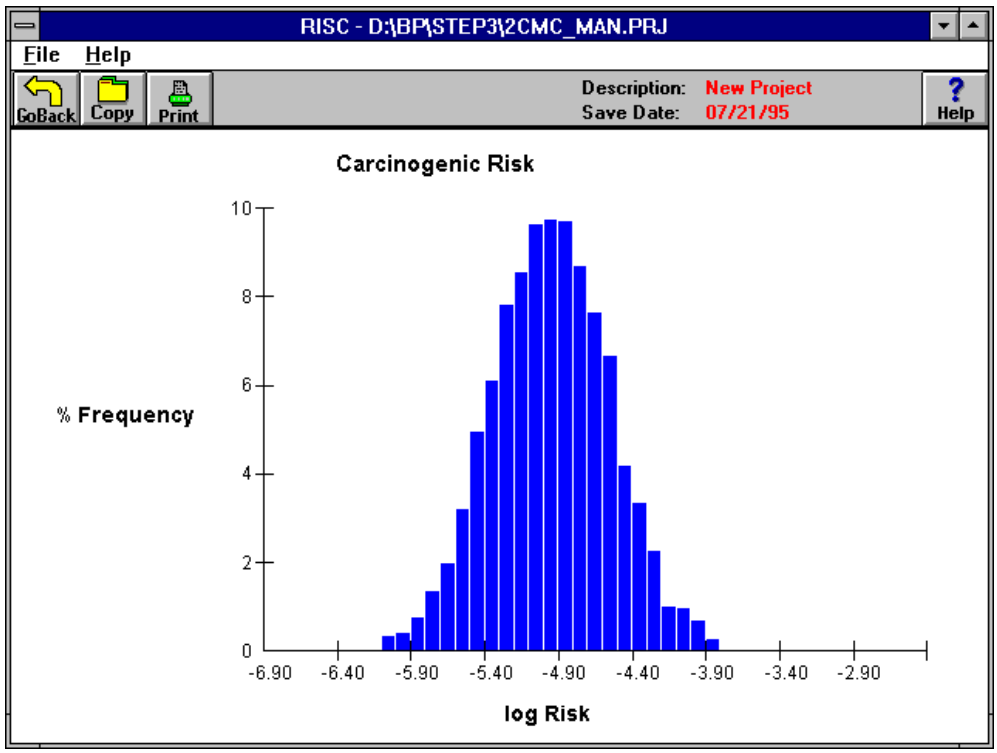


Figure 9-7. Frequency Distribution of Total Risk on a Logarithmic Scale

The most likely value (or mode) is the value that occurs most often (in other words, has the highest probability) in the set of values. In the histogram shown in Figure 9-7, the most likely value corresponds to a bar with a log risk of around -4.9. A log risk of -4.9 corresponds to a risk of 1.26E-5, which is very close to the 50th percentile of risk presented in Table 9-3. The most likely value is the center value of the class or bar with the highest probability, (in this case a log risk of -4.9) and does not necessarily equal the mean. (Consider a log-normal distribution where the most likely value occurs below the mean.)

9.2.2.2 Cumulative Frequency Distribution

Frequency distributions may also be presented in a cumulative form. A cumulative curve is typically scaled from 0 to 100% (or from 0 to 1 as a fraction) on the Y-axis, with Y-axis values representing the cumulative probability up to the corresponding X-axis value. For example, in a cumulative frequency distribution, the 50% cumulative value is the point of 50% probability. Fifty percent of the values in the distribution fall below this value and 50% are above. The 0 cumulative value is the minimum value and the 100% cumulative value is the maximum value of the distribution (100% of the values fall below this point).

The most likely value can be found at that point where the slope of the Cumulative Probability vs. the Risk curve is greatest.

Figure 9-8 shows a cumulative distribution of total risk on a log scale.

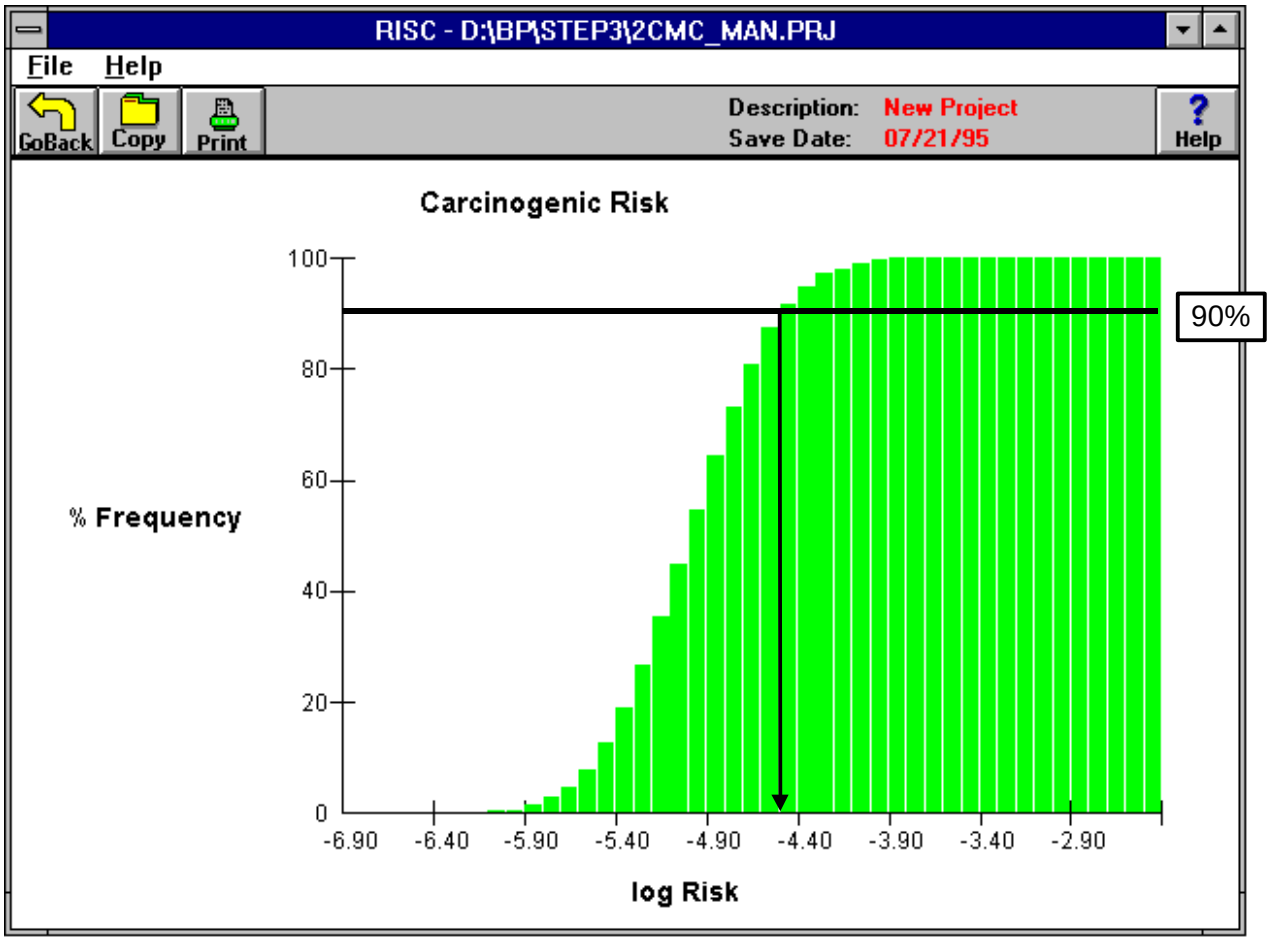


Figure 9-8. Cumulative Risk on a Logarithmic Scale

Lines have been added to the chart in Figure 9-8 indicating the 90th percentile and the corresponding log risk value of -4.54 (or non-log value of 2.87E-5, as taken from the 90% value in Table 9-3). Ninety percent of the risk results for this Monte Carlo analysis fall below the total risk of 2.87E-5 (or about 3 in 10,000). Most of the output values fall in the range of -5.5 to -4.5 (the area where the curve is the steepest or the percentile increases fastest for the increase in risk). Only 10% of the values fall in the range -4.5 to -1.6.

9.3 TRANSFERRING TABLES AND CHARTS TO OTHER APPLICATIONS

Both the tables and charts can be transferred to another software application (such as a word processor) by clicking on the 'Copy' button at the top of the table or chart. Then the user can minimize or close the RISC main screen, open the new destination software, and choose "Paste" (or the Shift and Insert keys). When many routes of concern are being evaluated, the risk and hazard summary tables may be too wide to print in a portrait mode. To print these, the printer configuration should be changed using the printer control from the Windows® Control Panel. Many laser printers allow text to be printed in a landscape mode and will accept scaling factors. If the report is copied into another software package, the report can be reformatted (font size may be reduced). The Carcinogenic Risk and Hazard Quotient Summary tables have tabs separating the data so that they can be transferred to a spreadsheet program directly (they are tab-delimited).

Table 9-1. Summary of Carcinogenic Risk

SUMMARY OF CARCINOGENIC RISK

CASE 1:
Adult Resident - RME

	Ingestion of Soil	Dermal Contact Soil	Ingestion of Groundwater	Inhalation During Shower	TOTAL
Benzene	8.5E-06	2.2E-05	3.4E-06	4.0E-06	3.8E-05
Benzo(a)pyrene	2.7E-06	1.1E-05	4.7E-05	0.0E+00	6.1E-05
TOTAL	1.1E-05	3.3E-05	5.1E-05	4.0E-06	9.9E-05

Table 9-2. Input/Output Summary (Page 1 of 3)

```
Title:
New Project
07/21/95

Scenarios:
Adult Resident - RME

Routes:
INGESTION OF SOIL
DERMAL CONTACT WITH SOIL
INGESTION OF GROUNDWATER
INHALATION DURING SHOWER

Chemicals:
   Benzene
   Benzo(a)pyrene


SUMMARY OF INPUT PARAMETERS                    Scenario 1
-----------------------------------------------------------------

Lifetime and Body Weight

   Body Weight (kg)                              70.00
   Lifetime (years)                              70.00

INGESTION OF SOIL

   Soil Ingestion Rate (mg/day)                 100.00
   Exp. Frequency Soil (events/year)            350.00
   Exp. Duration Soil (years)                    30.00
   Absorption Adjustment Factor for
      Ingestion of Soil (-)
                    Benzene                       1.0
                    Benzo(a)pyrene                .63

   Soil Bioavailability (-)
                    Benzene                       1.0
                    Benzo(a)pyrene                1.0

DERMAL CONTACT WITH SOIL

   Fraction Skin Exposed to Soil (-)              .56
   Adherence Factor for Soil (mg/cm^2)           1.00
   Exposure Freq. Soil   (events/year)          350.00
   Exposure Duration Soil (years)                30.00
   Absorption Adjustment Factor for
      Dermal Exposure to Soil (-)
                    Benzene                    2.00E-02
                    Benzo(a)pyrene             2.00E-02

   Soil Bioavailability (-)
                    Benzene                       1.0
                    Benzo(a)pyrene                1.0

INGESTION OF GROUNDWATER

   Ingestion rate (l/day)                        2.00
   Exp. Freq Groundwater (events/year)          350.00
   Exp. Duration Groundwater (years)             30.00
   Absorption Adjustment Factor for
      Ingestion of water (-)
                    Benzene                       1.0
                    Benzo(a)pyrene                1.1

INHALATION DURING SHOWER

   Volume of Bathroom (m^3)                      3.00
   Temperature of Shower Water (C)              48.00
   Shower Flow Rate (l/min)                     10.00
   Time in Shower (hour/day)                      .20
   Inhal. Rate in the Shower (m^3/hr)             .60
   Lung Retention Factor (-)                     1.00
```

Table 9-2. Input/Output Summary (Page 2 of 3)

```
Exp. Freq Groundwater (events/year)              350.00
   Exp. Duration Groundwater (years)              30.00
   Absorption Adjustment Factor for
      Inhalation (-)
                     Benzene                       1.0
                     Benzo(a)pyrene                1.0

   Henry"s Law Constant (-)
                     Benzene                       .25
                     Benzo(a)pyrene               2.77E-05

   Molecular Weight (g/mole)
                     Benzene                       78.
                     Benzo(a)pyrene               2.52E+02


MEDIA CONCENTRATIONS
--------------------
Concentration in Groundwater (mg/l)
     Used in calculating carcinogenic risk and hazard index
                     Benzene                      1.00E-02
                     Benzo(a)pyrene               5.00E-04

Concentration in Soil (mg/kg)
     Used in calculating carcinogenic risk and hazard index
                     Benzene                      5.00E+02
                     Benzo(a)pyrene                1.0

SLOPE FACTORS AND REFERENCE DOSES
---------------------------------

Ingestion Slope Factor [1/(mg/kg-day)]
                     Benzene                      2.90E-02
                     Benzo(a)pyrene                7.3

Ingestion Reference Dose (mg/kg-day)
                     Benzene                        ND
                     Benzo(a)pyrene               3.00E-02

Inhalation Slope Factor [1/(mg/kg-day)]
                     Benzene                      2.90E-02
                     Benzo(a)pyrene                 ND

Inhalation Reference Dose (mg/kg-day)
                     Benzene                        ND
                     Benzo(a)pyrene                 ND

Dermal Slope Factor [1/(mg/kg-day)]
                     Benzene                      2.90E-02
                     Benzo(a)pyrene                7.3

Dermal Reference Dose (mg/kg-day)
                     Benzene                        ND
                     Benzo(a)pyrene               3.00E-02


SUMMARY OF RESULTS
------------------------------------------------------------

INGESTION OF SOIL

   Benzene
     CDI (mg/kg-day)               6.85E-04
     LADD (mg/kg-day)              2.94E-04
     Cancer Risk (-)               8.51E-06
     Hazard Index (-)              0.00E+00

   Benzo(a)pyrene
     CDI (mg/kg-day)               8.63E-07
     LADD (mg/kg-day)              3.70E-07
     Cancer Risk (-)               2.70E-06
     Hazard Index (-)              2.88E-05
```

Table 9-2. Input/Output Summary (Page 3 of 3)

```
DERMAL CONTACT WITH SOIL

   Benzene
     CDI (mg/kg-day)                1.76E-03
     LADD (mg/kg-day)               7.56E-04
     Cancer Risk (-)                2.19E-05
     Hazard Index (-)               0.00E+00

   Benzo(a)pyrene
     CDI (mg/kg-day)                3.53E-06
     LADD (mg/kg-day)               1.51E-06
     Cancer Risk (-)                1.10E-05
     Hazard Index (-)               1.18E-04

INGESTION OF GROUNDWATER

   Benzene
     CDI (mg/kg-day)                2.74E-04
     LADD (mg/kg-day)               1.17E-04
     Cancer Risk (-)                3.41E-06
     Hazard Index (-)               0.00E+00

   Benzo(a)pyrene
     CDI (mg/kg-day)                1.51E-05
     LADD (mg/kg-day)               6.46E-06
     Cancer Risk (-)                4.71E-05
     Hazard Index (-)               5.02E-04

INHALATION DURING SHOWER

   Concentration in Bathroom Air (mg/m^3)
                    Benzene                        .195
                    Benzo(a)pyrene              2.055E-05
   Fraction Volatilized from Shower Water (-)
                    Benzene                        .488
                    Benzo(a)pyrene              1.027E-03
   Total Mass Volatilized per Shower (mg)
                    Benzene                        .586
                    Benzo(a)pyrene              6.164E-05
   Benzene
     CDI (mg/kg-day)                3.21E-04
     LADD (mg/kg-day)               1.38E-04
     Cancer Risk (-)                3.99E-06
     Hazard Index (-)               0.00E+00

   Benzo(a)pyrene
     CDI (mg/kg-day)                3.38E-08
     LADD (mg/kg-day)               1.45E-08
     Cancer Risk (-)                0.00E+00
     Hazard Index (-)               0.00E+00
```

Table 9-3. Summary Statistics of Carcinogenic Risk for a Monte Carlo Analysis

SUMMARY STATISTICS OF CARCINOGENIC RISK
(by route)

Route of Concern	Min.	5%	Mean	75%	90%	95%	99%	Max.	Std.Dev.
INGESTION OF SOIL	7.04E-10	2.49E-08	6.39E-07	6.71E-07	1.55E-06	2.45E-06	5.36E-06	3.72E-05	1.24E-06
DERMAL CONTACT WITH SOIL	2.07E-09	2.48E-08	6.92E-07	7.54E-07	1.69E-06	2.67E-06	5.94E-06	2.13E-05	1.26E-06
INGESTION OF GROUNDWATER	1.34E-07	1.23E-06	1.16E-05	1.40E-05	2.57E-05	3.72E-05	7.37E-05	1.91E-04	1.40E-05
INHALATION DURING SHOWER	1.90E-09	3.20E-08	6.97E-07	7.96E-07	1.73E-06	2.62E-06	5.65E-06	1.81E-05	1.12E-06
TOTAL	3.11E-07	2.02E-06	1.36E-05	1.66E-05	2.87E-05	4.05E-05	7.88E-05	1.93E-04	1.49E-05

SUMMARY STATISTICS OF CARCINOGENIC RISK
(by chemical)

Chemical	Min.	5%	Mean	75%	90%	95%	99%	Max.	Std.Dev.
Benzene	6.35E-08	4.01E-07	2.42E-06	3.03E-06	5.06E-06	7.01E-06	1.22E-05	3.34E-05	2.42E-06
Benzo(a)pyrene	2.09E-07	1.41E-06	1.12E-05	1.36E-05	2.43E-05	3.52E-05	6.92E-05	1.78E-04	1.31E-05
TOTAL	3.11E-07	2.02E-06	1.36E-05	1.66E-05	2.87E-05	4.05E-05	7.88E-05	1.93E-04	1.49E-05

Table 9-4. Input/Output Summary for a Monte Carlo Analysis (Page 1 of 2)

```
Title:
New Project
07/21/95

Scenarios:
Resident -- Adult

Routes:
INGESTION OF SOIL
DERMAL CONTACT WITH SOIL
INGESTION OF GROUNDWATER
INHALATION DURING SHOWER

Chemicals:
   Benzene
   Benzo(a)pyrene


 Number of Monte Carlo runs:       5000

SUMMARY OF INPUT PARAMETERS        Distribution    Mean   Std Dev    Min      Max
-------------------------------------------------------------------------------

Lifetime and Body Weight

Body Weight (kg)                     Normal      7.20E+01 1.59E+01 2.40E+01 1.25E+02
Lifetime (years)                     Constant    7.00E+01    NA       NA       NA

INGESTION OF SOIL

Soil Ingestion Rate (mg/day)         Lognormal   4.04E+01 3.73E+01 1.50E+00 6.67E+02
Exp. Frequency Soil (events/year)    Triangular  4.00E+01    NA    1.00E+01 3.50E+02
Exp. Duration Soil (years)           Lognormal   1.14E+01 1.37E+01 0.00E+00 1.00E+02
   Absorption Adjustment Factor for
      Ingestion of Soil (-)
                     Benzene                       1.0
                     Benzo(a)pyrene                .63

   Soil Bioavailability (-)
                     Benzene                       1.0
                     Benzo(a)pyrene                1.0

DERMAL CONTACT WITH SOIL

Fraction Skin Exposed to Soil (-)    Triangular  1.00E-01    NA    0.00E+00 5.60E-01
Adherence Factor for Soil (mg/cm^2)  Triangular  2.00E-01    NA    2.00E-01 1.00E+00
Exposure Freq. Soil   (events/year)  Triangular  4.00E+01    NA    1.00E+01 3.50E+02
Exposure Duration Soil (years)       Lognormal   1.14E+01 1.37E+01 0.00E+00 1.00E+02
   Absorption Adjustment Factor for
      Dermal Exposure to Soil (-)
                     Benzene                      2.00E-02
                     Benzo(a)pyrene               2.00E-02

   Soil Bioavailability (-)
                     Benzene                       1.0
                     Benzo(a)pyrene                1.0

INGESTION OF GROUNDWATER

Ingestion rate (l/day)               Lognormal   1.27E+00 6.00E-01 1.00E-01 3.00E+00
Exp. Freq Groundwater (events/year)  Constant    3.50E+02    NA       NA       NA
Exp. Duration Groundwater (years)    Lognormal   1.14E+01 1.37E+01 0.00E+00 7.00E+01
   Absorption Adjustment Factor for
      Ingestion of water (-)
                     Benzene                       1.0
                     Benzo(a)pyrene                1.1
```

Table 9-4. Input/Output Summary for a Monte Carlo Analysis (Page 2 of 2)

```
INHALATION DURING SHOWER

Volume of Bathroom (m^3)             Triangular  2.90E+00    NA    2.00E+00 6.00E+00
Temperature of Shower Water (C)      Triangular  4.50E+01    NA    3.50E+01 5.00E+01
Shower Flow Rate (l/min)             Lognormal   8.00E+00 2.70E+00 0.00E+00 3.00E+01
Time in Shower (hour/day)            Triangular  1.10E-01    NA    3.00E-02 3.30E-01
Inhal. Rate in the Shower (m^3/hr)   Constant    6.00E-01    NA       NA       NA
Lung Retention Factor (-)            Constant    1.00E+00    NA       NA       NA
Exp. Freq Groundwater (events/year)  Constant    3.50E+02    NA       NA       NA
Exp. Duration Groundwater (years)    Lognormal   1.14E+01 1.37E+01 0.00E+00 7.00E+01
   Absorption Adjustment Factor for
      Inhalation (-)
                     Benzene                       1.0
                     Benzo(a)pyrene                1.0

   Henry"s Law Constant (-)
                     Benzene                       .25
                     Benzo(a)pyrene               2.77E-05

   Molecular Weight (g/mole)
                     Benzene                       78.
                     Benzo(a)pyrene               2.52E+02


MEDIA CONCENTRATIONS
--------------------
Concentration in Groundwater (mg/l)
     Used in calculating carcinogenic risk and hazard index
       Benzene                       Constant    1.00E-02    NA       NA       NA
       Benzo(a)pyrene                Constant    5.00E-04    NA       NA       NA

Concentration in Soil (mg/kg)
     Used in calculating carcinogenic risk and hazard index
       Benzene                       Constant    5.00E+02    NA       NA       NA
       Benzo(a)pyrene                Constant    1.00E+00    NA       NA       NA

SLOPE FACTORS AND REFERENCE DOSES
---------------------------------

Ingestion Slope Factor [1/(mg/kg-day)]
                     Benzene                      2.90E-02
                     Benzo(a)pyrene                7.3

Ingestion Reference Dose (mg/kg-day)
                     Benzene                       ND
                     Benzo(a)pyrene               3.00E-02

Inhalation Slope Factor [1/(mg/kg-day)]
                     Benzene                      2.90E-02
                     Benzo(a)pyrene                ND

Inhalation Reference Dose (mg/kg-day)
                     Benzene                       ND
                     Benzo(a)pyrene                ND

Dermal Slope Factor [1/(mg/kg-day)]
                     Benzene                      2.90E-02
                     Benzo(a)pyrene                7.3

Dermal Reference Dose (mg/kg-day)
                     Benzene                       ND
                     Benzo(a)pyrene               3.00E-02


   Monte Carlo Output is summarized in separate tables.
 ---------------------------------------------
```

10.0
EXAMPLE RISK ASSESSMENT SCENARIOS

This chapter presents three risk assessment scenarios and discusses how to use RISC to evaluate the scenarios. These examples are designed to be worked through by the user on the computer. There are also saved project files shipped with the software for each of these three examples.

The first example is for a former gas station that is planned to be developed with single family homes. It has a creek nearby. In the second example, residents adjacent to an existing gas station use groundwater to irrigate their yards and gardens only (the indoor water is provided by a municipality). The gas station has impacted groundwater in the past. The third scenario is a proposed golf course to be built over soil containing VOCs. It is assumed that workers may be exposed to the VOCs while digging sand traps and irrigation lines.

The three examples are described in detail in the following sections.

10.1 RESIDENTIAL SCENARIO WITH A CREEK

Example #1

This example is saved in a project file called "Example1.prj". The reader is encouraged to work through the example and enter in the information for themselves.

In this scenario, it is assumed that a former gas station site containing contaminated soil (both at the ground surface and at depth) might be developed at some point in the future for single-family houses. A shallow, seasonal creek runs along one side of the site currently and will be left intact. There are two questions to be answered for this site: (1) what is the human health risk from the site if the soil is left as is?, and (2) what clean-up levels would be protective of human health?

Benzene, ethylbenzene and toluene have been detected in the top foot of soil and at depth. Three soil borings were made and samples collected at 0.5, 3.0, and 6.0 meters below ground surface. The creek has been sampled in two locations during a period of relatively low flow. The table below shows the analytical results. It is suspected that

the surficial contamination arose from surface spills or hose leaks and the contamination at depth resulted from a leaky storage tank. The tank has been removed along with any stained soil from the pit. (The soil samples were collected after the stained soil was removed.) Groundwater is at 6 meters below ground surface and is not potable (due to contamination from a neighboring silicon fabrication plant).

Chemical Concentrations Detected at Former Gas Station Site
Example #1

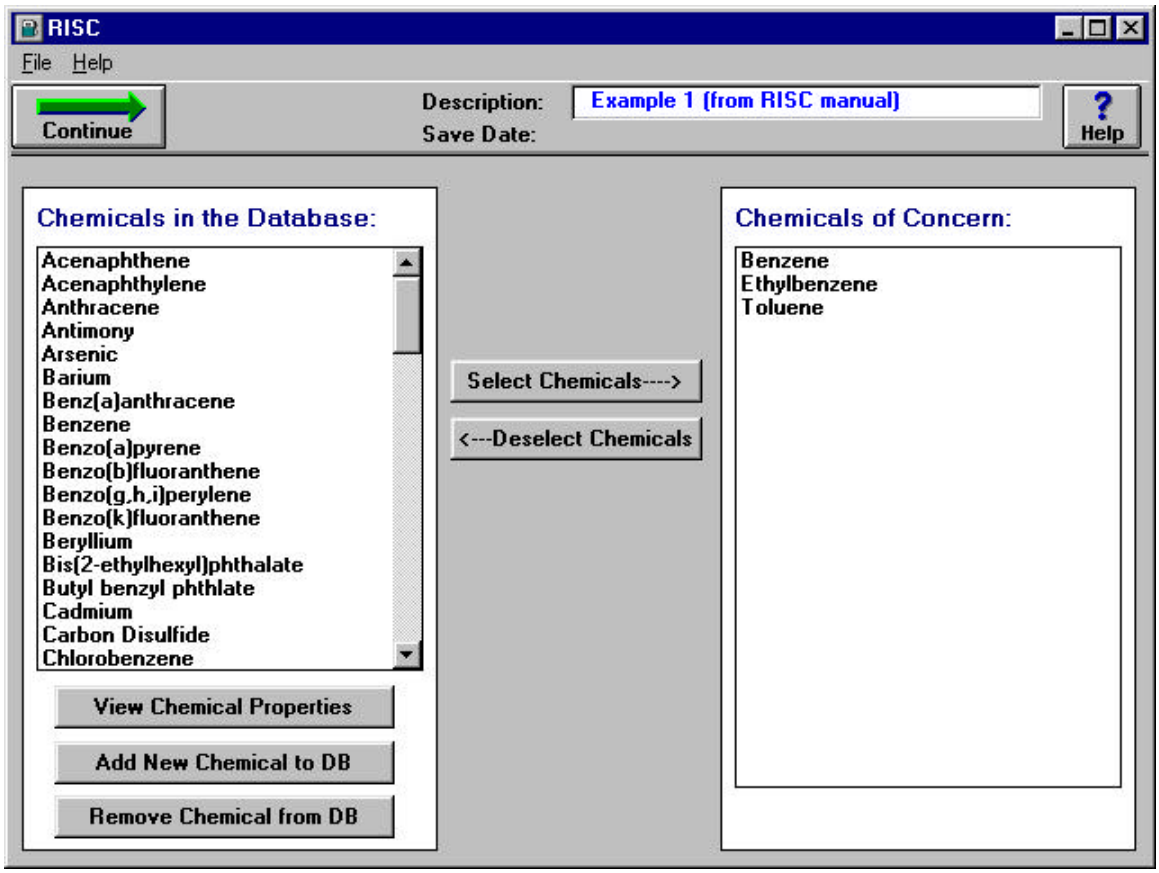
Sample Description	Units	Benzene Concentration	Ethylbenzene Concentration	Toluene Concentration
Soil Boring #1	mg/kg soil			
0.5 m depth		ND (0.005)	0.012	ND (0.005)
3.0 m depth		2.6	0.047	17
6.0 m depth		0.68	ND (0.005)	5.8
Soil Boring #2	mg/kg soil			
0.5 m depth		0.01	0.008	0.03
3.0 m depth		6	4.5	37
6.0 m depth		1.2	ND (0.005)	8.2
Soil Boring #3	mg/kg soil			
0.5 m depth		ND (0.005)	ND (0.005)	ND (0.005)
3.0 m depth		0.086	0.11	0.74
6.0 m depth		0.006	ND (0.005)	0.009
Creek Sample #1	mg/l water	0.007	ND (0.0005)	0.012
Creek Sample #2	mg/l water	0.016	ND (0.0005)	0.032

( ) = detection limit

Step 1: Choose Chemicals of Concern

Example #1

Benzene, ethylbenzene, and toluene were the only chemicals detected from an analysis that included BTEX, MTBE, the PAHs, and heavy metals. These three chemicals will be the chemicals of concern. The screen in Step 1 should look like the following after the chemicals of concern have been selected.



Step 1 in Example #1

Step 2: Identify Appropriate Exposure Pathways and Determine Method for Estimating Receptor Point Concentrations

Example #1

In this step any potential exposure pathways for a residential exposure at this site will be determined. It is assumed that a single-family house (with a backyard) will be built on the former gas station site. Both children and adults may live in the house and use the yard and the creek. There are restrictions preventing the residents from installing a well and using groundwater in this area. The next table lists the potential exposure pathways, contaminated media and contact media.

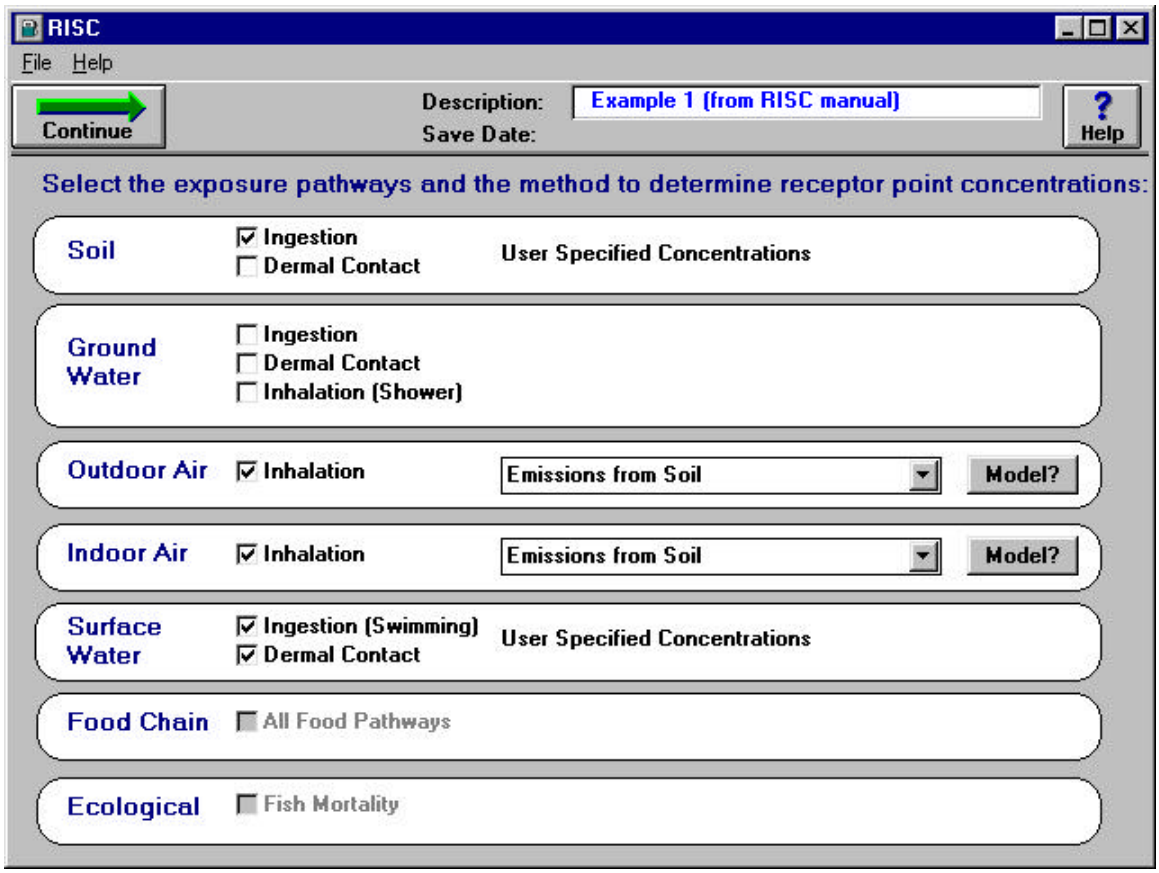
Exposure Pathways, Source Media, and Receptor Contact Media.
Example #1

Exposure Pathway	Source Media	Receptor Contact Media
Ingestion of soil	Surficial soil	Surficial soil (top 50 cm might be reasonable for a residential exposure)
Dermal contact with soil	Surficial soil	Surficial soil (top 50 cm might be reasonable for a residential exposure)
Volatilization from soil to indoor air	Soil (any depth)	Indoor air
Volatilization from soil to outdoor air	Soil (any depth)	Outdoor air
Incidental ingestion of creek water	Surface water	Surface water
Dermal contact with creek water	Surface water	Surface water

The above exposure pathways could apply to both children and adult residents. (It would however be reasonable to assume that the adult does not ingest creek water.)

After determining the potential exposure pathways the next step is to decide how to estimate receptor point concentrations. Four of the exposure routes (ingestion of soil, dermal contact with soil, ingestion of the creek water, and dermal contact with creek water) are direct exposure routes, that is, the source media is also the media that the receptor may contact. The contaminants in soil, however, may also volatilize into indoor and outdoor air and so the concentrations in air need to be estimated. Fate and transport models are used to estimate the receptor point concentrations in indoor and outdoor air. For estimating indoor air concentrations, the vapor transport model from soil into buildings will be used. For estimating outdoor air concentrations the vadose zone model linked with the box model will be used.

The following screen shows the choices entered into Step 2.



Step 2 for Example #1

Step 3: Estimate Receptor Point Concentrations

Example #1

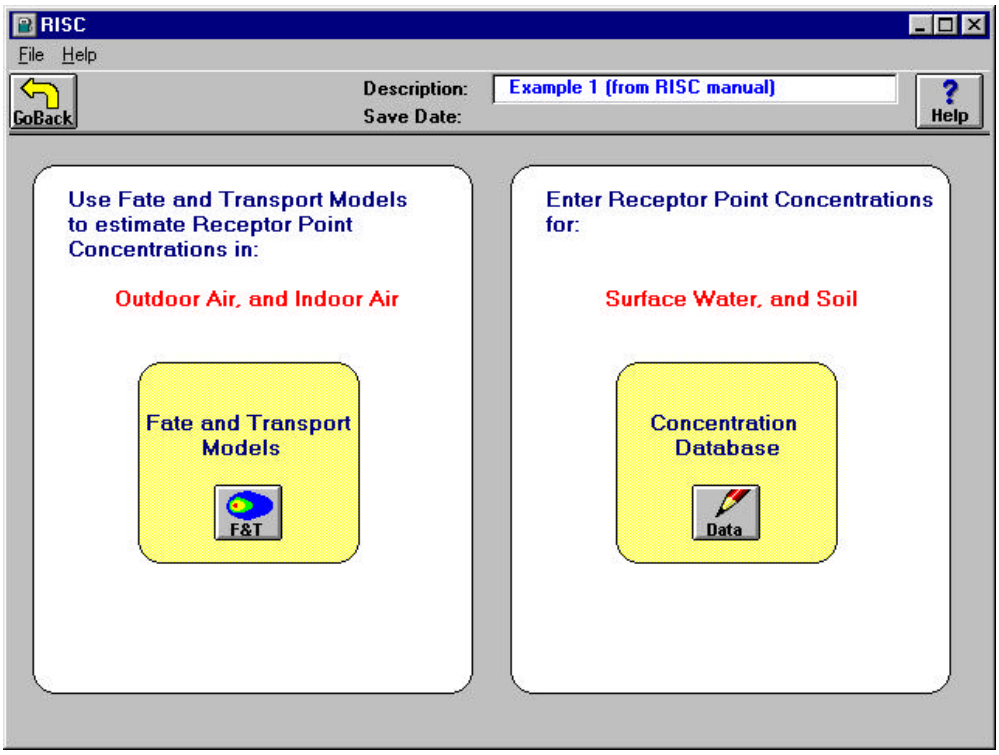
The receptor point concentrations for the direct contact media (surficial soil and surface water) will be taken from the analytical data. Since so few samples were collected, the maximum values detected in the two direct contact media will be used. The table below lists the receptor point concentrations used for the surficial soil and the creek.

Receptor Point Concentrations in Surficial Soil and Creek Water.
Example #1

Chemical	Total Soil Concentration (top 0.5 meter) [mg/kg]	Concentration in Creek [mg/l]
Benzene	0.01	0.016
Ethylbenzene	0.012	0.00025*
Toluene	0.03	0.032

* Ethylbenzene was not detected in the creek, ½ detection limit was used

The receptor point concentrations for soil and surface water (the creek) will be entered into the screens in Step 3. This process is illustrated in the following screens:



Main Screen of Step 3 for Example #1