**GWSCREEN: A Semi-Analytical Model for
Assessment of the Groundwater Pathway
from Surface or Buried Contamination**

**Theory and User's Manual
Version 2.0**

A. S. Rood

Published June 1994

**Idaho National Engineering Laboratory
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415**

MASTER

**Prepared for the
U.S. Department of Energy
Assistant Secretary for Environmental Management
Under DOE Operations Office
Contract DE-AC07-76ID01570**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *ds*

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

GWSCREEN was developed for assessment of the groundwater pathway from leaching of radioactive and non-radioactive substances from surface or buried sources. The code was designed for implementation in the Track I and Track II assessment of Comprehensive Environmental Response, Compensation, and Liability Act sites identified as low probability hazard at the Idaho National Engineering Laboratory.

The code calculates the limiting soil concentration such that, after leaching and transport to the aquifer, regulatory contaminant levels in groundwater are not exceeded. The code uses a mass conservation approach to model three processes: contaminant release from a source volume, contaminant transport in the unsaturated zone, and contaminant transport in the saturated zone. The source model considers the sorptive properties and solubility of the contaminant. Transport in the unsaturated zone is described by a plug flow model. Transport in the saturated zone is calculated with a semi-analytical solution to the advection dispersion equation in groundwater.

In Version 2.0, GWSCREEN has incorporated an additional source model to calculate the impacts to groundwater resulting from the release to percolation ponds. In addition, transport of radioactive progeny has also been incorporated. This revision covers Versions 2.0 to 2.4. In Version 2.3, health effects are calculated when concentration verses time output is selected. Version 2.4 also contains an optional three-dimensional dispersion solution.

GWSCREEN has shown comparable results when compared against other codes using similar algorithms and techniques. This code was designed for assessment and screening of the groundwater pathway when field data are limited. It was not intended to be a predictive tool.

CONTENTS

ABSTRACT	iii
1. INTRODUCTION	1
2. METHODOLOGY	3
2.1 Source Modeling	3
2.1.1 Surface or Buried Source Model	3
2.1.2 Pond Release Model	10
2.1.3 Tabulated Source Model	15
2.2 Unsaturated Zone Model	16
2.3 Saturated Zone Model	18
2.4 Radioactive Decay and Ingrowth	22
2.5 Limiting Soil Concentration	23
3. CODE IMPLEMENTATION	28
3.1 Computational Methods	28
3.2 Contaminant and Site-Specific Data File	31
3.2.1 Version 2.4 Input Files	36
3.2.2 Vertical Mixing Options	36
3.2.3 Integration Routine Options	37
3.3 Code Execution and Output	38
3.3.1 KFLAG, IMODEL, IMODE, INTIME, ITYPE	38
3.3.2 Solubility Limited Releases	40
3.3.3 Radioactive Progeny	40
4. REFERENCES	43
Appendix A—GWSCREEN Sample Problems	A-1
Appendix B—GWSCREEN Code Listing	B-1

FIGURES

1. Conceptual model of GWSCREEN for the source volume, unsaturated zone, and aquifer.	4
2. Volumetric moisture content verses hydraulic conductivity for vesicular basalt at the INEL.	7
3. Volumetric moisture content verses hydraulic conductivity for sediment at the INEL.	8
4. GWSCREEN percolation pond conceptual model.	11
5. Simplified hydraulic conceptual model for the GWSCREEN percolation pond model.	11
6. Plume geometry for the 3D dispersive solution and 2D vertically averaged solution in Version 2.4.	20
7. Flow chart for the GWSCREEN code (not all subroutines are shown in this figure).	39
8. Concentration as a function of time for sample problem #8.	42

TABLES

1. A brief description of the GWSCREEN subroutines	29
2. The GWSCREEN input file for contaminant and site-specific data	32

GWSCREEN: A Semi-Analytical Model for Assessment of the Groundwater Pathway from Surface or Buried Contamination

Theory and User's Manual Version 2.0

1. INTRODUCTION

Multimedia exposure assessment of hazardous chemicals and radionuclides requires that all pathways of exposure be investigated. In the assessment process, limited data are often encountered, and the primary purpose for performing initial screening is to identify priority contaminants and data needs. This process is accomplished by using simplified models that make best use of the available data and conservative assumptions. The GWSCREEN model was designed to perform initial screening calculations for groundwater pathway impacts resulting from the leaching of surficial and buried contamination at Comprehensive Environmental Response, Compensation, and Liability Act sites identified as low probability hazard at the Idaho National Engineering Laboratory (INEL) (DOE, 1992; 1994). In Version 2.0, an additional model was added to calculate impacts to groundwater from the operation of a percolation pond. The model was designed to make best use of the data that would potentially be available. These data include the area and depth of contamination, sorptive properties and solubility limit of the contaminant, depth to aquifer, and the physical properties of the aquifer (porosity, velocity, and dispersivity). For the pond model, data on effluent flow rates and operation time are required. In Version 2.4, three-dimensional dispersion was added.

The modeling approach used in GWSCREEN is a mass balance approach that has its roots in the methodology presented by the Nuclear Regulatory Commission (Codell et al., 1982; Kozak et al., 1990). Similar methodologies have also been employed in a number of other assessment codes including the Remedial Action Priority System (Whelan et al., 1987) and DECHEMA (Killogh et al., 1991). The groundwater transport model used in GWSCREEN has been used at the INEL for scoping and assessment purposes (Codell et al., 1982; Rood et al., 1989) and has been shown to give reasonable results when calibrated to measured data.

Model output includes the limiting soil concentration such that, after leaching and transport to the aquifer, regulatory contaminant levels in groundwater are not exceeded. Also, groundwater concentration as a function of time may be calculated. The model considers only drinking water consumption and does not include the transfer of contamination to food products due to irrigation with contaminated water. However, these pathways may be taken into account by adjusting the water consumption rate. Both radiological and non-radiological contaminants are considered in GWSCREEN.

GWSCREEN was not intended to be a predictive tool; rather, it was intended to provide the framework to calculate bounding impacts to groundwater from the leaching of surficial and buried

contamination. The conservatism of the results are dependent on the choice of input parameters used in the evaluation.

Differences between GWSCREEN, Version 1.5 (Rood, 1992) and GWSCREEN, Version 2.0 are as follows:

- Concentrations of radioactive progeny in groundwater are calculated.
- Carcinogenic risk for radionuclides is calculated.
- A model to simulate releases from percolation ponds and subsequent impacts to groundwater was added.
- Radiological dose, carcinogenic risk, and the hazard quotient are calculated for the peak time using the user-defined input mass (or activity).
- A user-defined tabulated source function may be used instead of the GWSCREEN source models.
- Number of Gaussian Quadrature points was increased from 24 to 34.
- Numerical integration may be performed by Simpson's rule or Gaussian Quadrature.
- Up to nine time periods may be calculated for concentration as a function of time output.
- Solubility release time for decaying source terms was changed.
- Rate constants for additional loss mechanisms were added.
- Three-dimensional dispersion in the aquifer was added (Version 2.4)
- Health effects are calculated for concentration versus time output.

2. METHODOLOGY

Three primary models are employed in GWSCREEN (Figure 1): the source model, the unsaturated zone mass transport model, and the saturated zone (aquifer) mass transport model. These models are coupled together by the contaminant fluxes across the interface between source, unsaturated, and saturated zone boundaries. Three types of source release models may be employed in GWSCREEN. These are the surficial or buried source model, the percolation pond release model, and the tabulated source model. GWSCREEN calculates the source mass fluxes for the surficial or buried source model and the percolation pond release model. The user provides the source mass fluxes for the tabulated source model by generating an ASCII file containing mass flux at the source volume-unsaturated zone interface as a function of time. The unsaturated zone model uses a simplified plug flow model, and the saturated zone model uses a semi-analytical solution to the advection-dispersion equation for transient mass flux as described by Codell et al. (1982).

2.1 Source Modeling

2.1.1 Surface or Buried Source Model

The source volume for the surface or buried source model is defined as the zone in which contaminants have been observed or are suspected to be present. This zone, in most cases, occupies the volume bounded by the soil surface to some finite depth below the soil surface, but may also include buried waste. Release from the source volume is modeled as a first-order leaching process that accounts for decay and sorption. The contaminant is assumed to be homogeneously mixed in a finite volume, and a steady-state infiltration rate is assumed. The leaching process is described mathematically by a first-order leach-rate constant. The differential equation that describes the mass balance of contaminant in the source volume is given by

$$\frac{dQ}{dt} = -(\lambda_L + \lambda_d + \lambda_o)Q \quad (1)$$

where

- λ_d = decay rate constant (y^{-1})
- λ_L = leach rate constant (y^{-1})
- λ_o = rate constant for other loss mechanisms (y^{-1})
- Q = mass (or activity) in the source volume (mg or Ci).

The solution to Equation (1) is

$$Q(t) = Q_o e^{-(\lambda_L + \lambda_d + \lambda_o)t} \quad (2)$$

where

- Q_o = the initial mass or activity in the source volume (mg or Ci)
- t = time (years).
- The initial mass or activity in the source volume (Q_o) is given by

Figure 1. Conceptual model of GWSCREEN for the source volume, unsaturated zone, and aquifer.

$$Q_o = C_o \times L \times W \times T \quad (3)$$

where

L, W, T = the length, width, and thickness of the source volume (m)

C_o = the initial concentration (Ci or mg m⁻³) in the solid and liquid phases.

The leach rate constant (λ_L) and decay rate (λ_d) constant are given by

$$\lambda_L = \frac{P}{\theta_c R_{dc} T} \quad \lambda_d = \frac{\ln(2)}{T_{1/2}} \quad (4)$$

where

P = the net water percolation rate (m y⁻¹)

θ_c = the volumetric moisture content in the source volume (m³ m⁻³)

R_{dc} = the retardation factor in the source volume

T_{1/2} = the contaminant half life (y⁻¹).

The leach rate constant was originally described by Baes and Sharp (1983). The formulation given in Equation (4) was taken from Gilbert et al. (1989).

The net water percolation rate (P) is the amount of water that enters the soil per unit time that is not lost to evapotranspiration or runoff. Under steady-state condition (no net storage), this can be approximated by

$$P = P_r - R - E \quad (5)$$

where

P_r = precipitation (m y⁻¹)

R = runoff (m y⁻¹)

E = evapotranspiration (m y⁻¹).

The value P/ θ_c represents the pore velocity in the contaminated zone and is based on the unit gradient model, which assumes that the hydraulic conductivity is equal to the net percolation rate. Darcy's law states that:

$$q_w = K \frac{dH}{dX} \quad (6)$$

where

q_w = net water infiltration rate (percolation rate, P) or Darcy flux ($m\ y^{-1}$)
 dH/dX = change in hydraulic head with respect to distance ($m\ m^{-1}$)
 K = hydraulic conductivity of the contaminated zone ($m\ y^{-1}$).

In the unit gradient model, $dH/dX = 1.0$; thus, $q_w = K = P$. Saturated hydraulic conductivity and the volumetric moisture content differ for different rock types. When a porous media is saturated (i.e., all the pore spaces are filled with water), the volumetric moisture content is equal to the effective porosity of the media. (In this model, the effective porosity is assumed equal to the total porosity.) The volumetric moisture content is related to the effective porosity by the fraction of the pore spaces that are saturated. The volumetric water content for a given material and a given water flux is usually determined using equations that have been fitted to field data relating suction head to volumetric moisture content and hydraulic conductivity. Curves generated using the van Genuchten (1978) fitting parameters for basalt and surface sediment at the Radioactive Waste Management Complex at the INEL are presented in Figures 2 and 3. These materials were characterized in detail by Bishop (1991) and McElroy and Hubbell (1990), and the van Genuchten fitting parameters, α and n , were given by Baca et al. (1992).

The retardation factor in the source volume (R_{dc}) is given by

$$R_{dc} = 1 + \frac{K_{dc} \rho_c}{\theta_c} \quad (7)$$

where

K_{dc} = the distribution coefficient in the source volume ($mL\ g^{-1}$)
 ρ_c = the bulk density of the source volume ($g\ cm^{-3}$).

For organic contaminants, the sorption coefficient is derived from the organic carbon partitioning coefficient (K_{oc}) and the fraction of organic material in the medium (f_{oc}). The sorption coefficient for organics is given by Equation (8):

$$K_d = f_{oc} K_{oc} \quad (8)$$

The contaminant flux out the base of the source volume can now be calculated. The contaminant flux is given by

$$q_c(t) = \lambda_L Q(t) \quad (9)$$

where

$q_c(t)$ = the contaminant flux out the bottom of the source volume (mg or $Ci\ y^{-1}$).

Figure 2. Volumetric moisture content versus hydraulic conductivity for vesicular basalt at the INEL.

Figure 3. Volumetric moisture content versus hydraulic conductivity for sediment at the INEL.

The concentration of the leachate ($C_{leachate}(t)$) is given by Equation (10):

$$C_{leachate}(t) = \frac{Q(t)}{LxWxTx\theta_c x R_{dc}} \quad (10)$$

For some contaminants, the initial concentration of the leachate exceeds the solubility limit of the contaminant. In this case, the concentration of the leachate and the mass flux from the source volume will be governed by the solubility limit of the contaminant. The mass balance of the contaminant in the source volume is then given by Equation (11):

$$\frac{dQ}{dt} = -(\lambda_d + \lambda_o)Q - R \quad (11)$$

where

$R = C_{sl} \times P \times L \times W$ (mg y^{-1}) (contaminant flux out bottom of source)

C_{sl} = the solubility limit of the contaminant (mg m^{-3}).

The solution to Equation (11) for the initial conditions $Q = Q_o$ at $t=0$ is

$$Q(t) = Q_o e^{-(\lambda_d + \lambda_o)t} - \frac{R}{\lambda_d + \lambda_o} (1 - e^{-(\lambda_d + \lambda_o)t}) \quad (12)$$

After a period of time, the mass in the source volume is depleted sufficiently to allow for leaching to be controlled by the contaminant sorptive properties and not the solubility limit. The amount of mass in the source volume (Q_{sl}) where leaching by sorptive properties takes over is given by Equation (13):

$$Q_{sl} = C_{sl} x L x W x T x \theta_c x R_{dc} \quad (13)$$

When decay or other first-order loss processes are insignificant, the time required for the mass in the source volume to decrease to Q_{sl} is simply $t_{sl} = (Q_o - Q_{sl})/R$, and the mass balance equation is $Q(t) = Q_o - Rt$. Decay and degradation are considered insignificant if the sum of the rate constants ($\lambda_d + \lambda_o$) is less than $6.93E-11 y^{-1}$ (effective half time of 1×10^{10} years). If decay is significant during the release, then the solubility limited release time is given by the following:

$$t_{sl} = \frac{-\ln \left(\frac{Q_{sl} + \frac{R}{\lambda_d + \lambda_o}}{Q_o + \frac{R}{\lambda_d + \lambda_o}} \right)}{\lambda_d + \lambda_o} \quad \text{for } \lambda_d + \lambda_o > 6.93 \times 10^{-11} \quad (14)$$

$$t_{sl} = \frac{Q_o - Q_{sl}}{R} \quad \text{for } \lambda_d + \lambda_o < 6.93 \times 10^{-11}$$

For radionuclides, total activity in the source volume must be converted to mass so that the quantity of the radionuclide may be related to its solubility limit. The conversion from activity to mass is given by

$$Q_{(mass)} = \frac{Q_{(activity)} (3.7 \times 10^{10} \text{ dps Ci}^{-1}) (3.1536 \times 10^7 \text{ s y}^{-1}) (MW)}{\lambda_d N_A} \quad (15)$$

where

$Q_{(mass)}$ = the mass of the radionuclide in the source volume (g)

N_A = Avogadro's number (6.023×10^{23} atoms mole⁻¹)

$Q_{(activity)}$ = the total activity of the radionuclide in the source volume (Ci)

dps = number of nuclear transformations per second

MW = the molecular weight of the radionuclide (g mole⁻¹).

Solubility limited releases for radionuclides usually only affects nuclides with large half-lives since little mass is associated with nuclides with short half-lives.

Output from the source model is then given by Equation (9) for releases not controlled by the contaminant's solubility, and by the term R in Equations (11) and (12) for solubility limited releases. These releases provide the contaminant flux at the boundary between source volume and unsaturated zone for the surficial or buried source model.

2.1.2 Pond Release Model

The percolation pond conceptual model (Figure 4) accounts for the flow of water into the pond, the concentration of the contaminant in the pond water, sorption and decay of the contaminant in the pond sediments, and the operational lifetime of the pond. A simplified hydrologic conceptual model is used to describe flow from the pond to the aquifer. Consider the hypothetical pond illustrated in Figure 5. The flow rate into the pond is assumed to be constant, and the pond depth (h_1) is also assumed to remain constant throughout time. The pond sediments are assumed to be saturated, at least to some depth, h_2 . In order for a pond to form under constant flow and steady-state conditions, the hydraulic conductivity of the pond sediments must be less than the infiltration rate. The infiltration rate into the pond sediments is given by q_1 . At some point below the base of the pond, unsaturated conditions may exist. This is true for conditions at the INEL where the vadose zone consists of fractured basalt that has measured hydraulic conductivities around 10,000 m/y. This assumption may not be true for other sites where complete saturation may exist from the base of the pond to the aquifer. If steady state conditions exist, then $q_1 = q_2 = q_3$.

The contaminant flux into the pond is assumed to be equal to the contaminant flux out of the pond and into the pond sediments. Equilibrium between the pond water and sediments is assumed to occur instantaneously. Release from the pond sediments is modeled then as a first-order process with constant input. The mass balance equation that describes the mass of contaminant in the pond sediments is given by the following:

Figure 4. GWSCREEN percolation pond conceptual model.

Simplified Hydraulic Conceptual Model for the GWSCREEN Pond Model

Figure 5. Simplified hydraulic conceptual model for the GWSCREEN percolation pond model.

$$\frac{dM}{dt} = R_p - (\lambda_L + \lambda_d + \lambda_E)Q \quad (16)$$

where

- Q = mass or activity of contaminant in the pond sediments (Ci or mg)
- λ_L = leach rate constant from pond sediments (y^{-1})
- λ_E = rate constant for other loss processes from the pond sediments (y^{-1})
- R_p = mass flux of the contaminant into the pond (Ci or mg y^{-1}).

The leach rate constant for pond sediments (λ_L) is given by

$$\lambda_L = \frac{Q_{pond}}{\Theta_p T R_d L W} \quad (17)$$

where

- Q_{pond} = net water input rate into the pond ($m^3 y^{-1}$)
- Θ_p = volumetric moisture content in the pond sediments ($m^3 m^{-3}$)
- R_d = retardation factor in the pond sediments
- T = pond sediment thickness (m)
- L, W = length and width of the pond (m).

The volumetric moisture content of the pond sediments may be estimated by the effective porosity of the pond sediments *if* a pond has formed. If a pond has formed, then the pond sediments are saturated, at least to some depth, and the volumetric moisture content is given by the effective porosity of the pond sediments. For saturated conditions, the unit gradient assumption used in the leach rate constant is violated because the hydraulic gradient in the pond sediments is no longer unity, resulting in faster water travel times through the saturated portion of the sediment. This deficiency in the model can be compensated by choosing a conservative value for the pond sediment thickness, thereby reducing the residence time of the contaminant in the pond sediment compartment.

If a pond forms periodically or exists for only part of the year, then the volumetric water content can be estimated by the hydraulic conductivity curve for the pond sediments. The infiltration rate (annual discharge rate to the pond (Q_{pond}) divided by the pond area) can be compared to the saturated hydraulic conductivity of the pond sediments. If the infiltration rate is less than the saturated hydraulic conductivity, then unsaturated conditions can be assumed, and the moisture content can be estimated by a curve similar to Figure 3 for pond sediments. The moisture content in the unsaturated zone (see Section 2.2) should be estimated in the same manner, using the infiltration rate into the pond sediments ($Q_{pond}/(L \times W)$) to determine the moisture content.

From Equation (17), it is evident that the pond sediment thickness is inversely related to the rate at which contaminants are leached from the pond sediments. Therefore, selection of the pond sediment thickness is an important factor in determining impacts of the pond. The movement of contaminants through a soil column underlying a percolation pond is transient in nature and is not

treated explicitly in the pond model. Rather, a sediment layer is defined where the contaminants are free to mix, adsorb and desorb, and then leave the space. Engineered percolation ponds are not designed to retain water; rather, the hydraulic characteristics of the material underlying the pond are designed to transmit water from the pond to the underlying strata. Over time, however, the hydrologic characteristics of the pond base may change due to infilling of the pore space from fine-grained sediments suspended in the discharge water. Several approaches to estimate the pond sediment thickness are presented next. The incorporation of any of these approaches depends on site-specific considerations and available data.

The first approach makes use of any site-specific data that may exist. If characterization data indicate the presence of a sediment layer at the base of the pond that is distinctively different from the material the pond has been constructed over, then the thickness of this layer can be used as the pond sediment thickness. These data should include some estimate of the effective porosity of the pond sediments.

The second approach considers a sediment layer underlying the pond, and overlying strata that has a significantly higher conductivity. This approach is applicable when the majority of the unsaturated zone (from the base of the pond to the aquifer) is composed of materials having a higher saturated hydraulic conductivity than the pond infiltration rate ($K_{sat} > \{Q_{pond} \times L \times W\}$). In this case, unsaturated flow can be assumed in this strata. Such is the case at the INEL where relatively thin surface sediments overlie thick sections of fractured basalt. The pond sediment thickness in this case may be assumed to be some fraction of the surface sediment thickness.

The third approach employs a default pond sediment thickness to be used when data are lacking or no defensible argument can be made to define a thickness. A value of 1.0 m is suggested as a minimum default pond sediment thickness. A sediment thickness of 1.0 m results in equilibrium conditions being established in a relatively short amount of time under most conditions except when the contaminant has a high sorption coefficient. Once equilibrium is established, contaminant flow rates in to and out of the pond sediments are equal resulting in the maximum possible release to the unsaturated zone. The 1 m default thickness was also used as a contaminant layer thickness default value in the RESRAD code (Gilbert et al., 1989).

The width of the pond is defined as the dimension of the pond that lies perpendicular to groundwater flow. The retardation factor for the pond sediments is given by Equation 7, substituting Θ_p for Θ_c . The solution to Equation (16) for the initial conditions, $Q = Q_0$ when $t = 0$ is

$$Q(t) = \frac{R_P}{\lambda_L + \lambda_d + \lambda_E} (1 - e^{-(\lambda_L + \lambda_d + \lambda_E)t}) + Q_0 e^{-(\lambda_L + \lambda_d + \lambda_E)t} \quad (18)$$

After operation of the pond ceases, the contaminant inventory remaining in the pond sediments are subsequently leached by percolating rainwater and snowmelt. The inventory of contaminants in the pond sediments at the end of operation is given by $Q(t)$ in Equation (18), evaluated at time t_{op} , the operational lifetime of the pond. Post-pond operation leaching is evaluated using Equation (2) where $Q_0 = Q(t_{op})$ and $\lambda_E = 0$.

The flux to the unsaturated zone (q_u) during the operation period of the pond is given by

$$q_c(t) = \lambda_L \left(\frac{R_P}{\lambda_L + \lambda_d + \lambda_E} (1 - e^{-(\lambda_L + \lambda_d + \lambda_E)t}) + Q_o e^{(\lambda_L + \lambda_d + \lambda_E)t} \right) \quad (19)$$

and the flux to the unsaturated zone after the operational period is given by Equation (9).

The pond model ignores additional dilution in the aquifer from percolating pond water. In most cases, the volume of water derived from rain and snowmelt that reaches the aquifer from the source area is insignificant compared to the volume of water flowing in the aquifer across the same area. For the pond model, this assumption may not be true; therefore, caution must be exercised when using this model. The value of Q_{pond} should be compared to the flow in the aquifer across the cross-sectional area of the source that is perpendicular to the groundwater flow. If Q_{pond} is greater than the aquifer flow across the cross-sectional area of the source, then an "effective" pond width should be calculated. The effective pond width (W_e) is given by

$$W_e = \frac{Q_{\text{pond}} + q_a W b}{q_a b} \quad (20)$$

where

q_a = darcy velocity in the aquifer (m y^{-1})

b = aquifer or mixing thickness (m) {see Section 2.3, m}

W = width of the pond perpendicular to groundwater flow (m).

The darcy velocity in the aquifer is the pore (or average linear) velocity times the effective porosity. The effective pond width is the width such that Q_{pond} plus the aquifer flow across the actual width of the pond is equal to, or less than, the aquifer flow across the cross-sectional area of the aquifer using the effective width. For example, suppose the liquid effluent flow rate into a $20 \text{ m} \times 20 \text{ m}$ pond is $1 \times 10^4 \text{ m}^3/\text{y}$ and the Darcy velocity in a 10-m-thick aquifer lying below the pond is 20 m/y. The aquifer flow across the cross-sectional area of the source is $20 \text{ m/y} \times 20 \text{ m} \times 10 \text{ m} = 5,000 \text{ m}^3/\text{y}$. Since the flow out of the pond is significant compared to the flow in the aquifer, the effective pond width should be calculated. The effective pond width is then:

$$\text{Effective Width} = \frac{1 \times 10^4 \text{ m}^3/\text{y} + 5 \times 10^3 \text{ m}^3/\text{y}}{20 \text{ m/y} \times 10 \text{ m}} = 75 \text{ m}.$$

The effective width of the pond is a user-required input variable in GWSCREEN (WAEFF), and if the flow from the pond is insignificant, the effective width can be set equal to the true width of the pond.

2.1.3 Tabulated Source Model

The user may choose to calculate a mass flux from the source volume using another model. In such cases, the user provides contaminant mass fluxes as a function of time from the source volume, and only the saturated zone and unsaturated zone model employed in GWSCREEN are used to

calculate groundwater concentrations at the receptor point. The unsaturated zone model may also be ignored by setting its thickness equal to zero.

2.2 Unsaturated Zone Model

The unsaturated zone is defined as the zone between the base of the source volume and the top of the aquifer. The unsaturated zone is assumed to be a homogeneous, isotropic, porous media with constant, unidirectional flow in the vertical (downward) direction. The model allows for differences in the transport properties between the unsaturated zone, source volume, and saturated zone. Due to the complexities and inherent uncertainties in modeling unsaturated flow and transport, a simplified plug-flow model was adapted that does not account for dispersion. In the plug flow model, non-sorbing contaminants move with the vertical velocity of the water. This velocity is calculated assuming the unit gradient condition as discussed previously. For most contaminants, the plug flow model is a conservative assumption since the peak flux to the aquifer exceeds the peak flux when dispersion is considered. For contaminants with short half-lives relative to their residence time in the unsaturated zone, the plug flow assumption may not be conservative since the contaminant will arrive sooner (lower residence time in the unsaturated zone) when dispersion is considered, therefore allowing less time to decay. This observation was noted by Seitz et al. (1991) and may become a significant factor when the unsaturated transit time [see Equation (21)] is greater than 10 times the half-life of the contaminant. Dispersion coefficients in the unsaturated zone would not be readily available during the initial groundwater assessment process. Since other conservative assumptions, such as increasing the percolation rate and reducing the unsaturated zone thickness, may be assumed to compensate for the effect of dispersion on short half-lived contaminants, dispersion was not considered and the simpler plug-flow model was used. A rule of thumb to ensure conservatism is to make sure the contaminant transit time in the unsaturated zone (T_u) does not exceed 10 times the half-life of the contaminant. If T_u exceeds 10 times the half-life, then the unsaturated thickness can be reduced such that T_u is equal to $10 \times T_{1/2}$. If radioactive contaminants with progeny are being modeled, then other factors may also have to be considered. These factors include the half-lives and equilibrium conditions of the progeny at the time of maximum parent concentration, and the dose conversion and slope factors for the parent and progeny. See the discussion in Section 3.3.

The amount of decay that occurs during transit is a function of the contaminant transit time in the unsaturated zone. The transit time in the unsaturated zone (T_u) is given by the following:

$$T_u = \frac{X_u}{U_u} R_{du} \quad (21)$$

where

X_u = the distance from the base of the source volume to the top of the aquifer (m)

U_u = the unsaturated pore velocity (m y⁻¹)

R_{du} = the retardation factor in the *unsaturated* zone.

The unsaturated pore velocity (U_u) is given by

$$U_u = \frac{P}{\theta_u} \quad (22)$$

where

θ_u = the volumetric water content in the unsaturated zone ($\text{m}^3 \text{m}^{-3}$).

Volumetric water content as a function of infiltration can be determined using graphs as illustrated in Figures 2 and 3. For the pond model, P is given by $Q_{\text{pond}} \div (\text{AL} \times \text{WA})$. If the pond model is being used and sedimentary interbeds are present in the unsaturated zone as is the case at the INEL, then the presence of perched water should be investigated. If perched water is present, and only flow through the sedimentary interbeds is considered, then saturated conditions may be assumed. However, a hydrogeologist should be consulted at this point because the travel time through the interbeds can be underestimated because of the presence of a hydraulic gradient in the interbeds that is greater than unity. Remember, the purpose of estimating the moisture content in the unsaturated zone is to arrive at an estimate of the water travel time from the source to the aquifer. A representative moisture content that yields a water travel time that is consistent with observations can always be used instead of the methods presented in this document for estimation of moisture content. If observations and data are available, it is strongly recommended that these be incorporated into the simulation.

The retardation factor (R_{du}) in the unsaturated zone is given by

$$R_{du} = 1 + K_{du} \frac{\rho_u}{\theta_u} \quad (23)$$

where

K_{du} = the distribution coefficient in the unsaturated zone (mL g^{-1})

ρ_u = the bulk density in the unsaturated zone (g cm^{-3}).

The fraction of mass or activity that remains after transit through the unsaturated zone (f) is given by Equation (24):

$$f = e^{-\lambda_d T_u} \quad (24)$$

The contaminant flux to the aquifer (q_a) is given by Equation (25), and it is through this term that the unsaturated zone and saturated zone models are coupled.

$$q_a = f \lambda_L Q(t) \text{ (leaching releases)} \quad (25)$$

$$q_a = f R \text{ (solubility limited releases)}$$

For the pond model, the unsaturated travel time is different before and after the operational period. After discharge to the pond ceases, leaching is by rainwater or snowmelt, and this usually results in lower contaminant flux to the groundwater and longer transit times in the unsaturated zone because the net percolation rate is lower. For simplicity and conservatism in GWSCREEN, the

transit time in the unsaturated zone was assumed to remain the same both before and after the operational period of the pond.

2.3 Saturated Zone Model

The saturated zone model is based on an analytic solution to the advection dispersion equation for contaminants in a saturated porous media. These solutions were originally developed by Codell et al. (1982) and have been used for assessment of radionuclide transport in groundwater. These solutions apply equally as well to non-radiological contaminants. The model contains the following assumptions and limitations:

1. The model uses a cartesian coordinate system (x,y,z) as a frame of reference. The positive x direction is in the direction of flow.
2. The flow is uniform and unidirectional. No sources or sinks are accounted for.
3. The aquifer is modeled as an isotropic, homogeneous porous media of infinite lateral extent and finite thickness.
4. Molecular diffusion is assumed to be negligible.
5. The source can be represented by a rectangular area of length L and width W and centered at the origin (0,0,0).
6. The dispersion coefficients remain constant over the domain.
7. Transport is limited to a single specie that may decay or degrade as a function of time. Radioactive progeny are assumed to travel at the same rate as their parent.
8. The contaminant is assumed to move as a dissolved substance. Transport in liquid organic and vapor phases are not considered.
9. Solid and liquid phases are in equilibrium and concentrations are related by the linear sorption coefficient (K_d).
10. The two-dimensional solution assumes that the contaminant is mixed vertically (z direction) in a zone defined by the length of a typical well screen for a drinking water well or the thickness of the aquifer. The three-dimensional solution considers vertical dispersion in the aquifer.

Assumption 10 states that groundwater concentrations will be averaged (mixed) over the thickness of the well screen for the 2D solution. This assumption is reasonable for receptor wells close to the source since contaminants poorly mixed in the vertical direction will be diluted by water drawn over the *entire* well screen interval. For receptor wells located farther downgradient from the source, the estimated concentration will be conservative since the contaminant plume will likely extend to greater depths than the assumed well screen thickness. In these cases, a larger "mixing thickness" may be

justified. In Version 2.4, the user may select a 3D dispersion solution. Concentrations calculated using the 3D solution may be averaged over any well screen thickness, and the contaminant mass is not restricted to the mixing thickness; rather, it is restricted to the thickness of the aquifer (see Figure 6).

Calibration studies at the INEL using the groundwater model described in this document have been performed by Codell et al. (1982) and Rood et al. (1989). Tritium plumes from the Idaho Chemical Processing Plant injection well and the Test Reactor Area percolation ponds were modeled. The predicted concentration matched measured data reasonably well considering the simplifications and assumptions of the model; however, the results were not as accurate as those made by a finite difference model (Robertson, 1974). The differences were attributed to the ability of the finite difference model to incorporate spatial differences in the flow field. This problem is reduced in simulations where the hypothetical well to be modeled is relatively close to the source (about 100 m), thereby reducing the effect of spatial variability in groundwater flow.

The mass balance equation that describes contaminant transport for the stated assumptions is

$$\frac{\partial C}{\partial t} + \frac{U}{R_d} \frac{\partial C}{\partial x} = \frac{D_x}{R_d} \frac{\partial^2 C}{\partial x^2} + \frac{D_y}{R_d} \frac{\partial^2 C}{\partial y^2} + \frac{D_z}{R_d} \frac{\partial^2 C}{\partial z^2} - \lambda_d C \quad (26)$$

where

C = concentration (mg or Ci m^{-3})

U = groundwater pore velocity ($m\ y^{-1}$)

$D_x\ D_y\ D_z$ = dispersion coefficient in the x , y , and z direction ($m^2\ y^{-1}$)

R_d = retardation factor in the aquifer

t = time (y)

x = distance from center of area source to receptor parallel to groundwater flow (m)

y = distance from center of area source to receptor perpendicular to groundwater flow (m)

z = distance from the surface of the aquifer (m).

The retardation factor in the aquifer is given by

$$R_d = 1 + K_{da} \frac{\rho_a}{\eta} \quad (27)$$

where

η = the effective porosity of the aquifer ($m^3\ m^{-3}$)

K_{da} = the distribution coefficient in the aquifer ($mL\ g^{-1}$)

ρ_a = the bulk density in the aquifer ($g\ cm^{-3}$).

The dispersion coefficients (D_x , D_y , D_z) are given by

Plume Geometry for the 3D Dispersive Solution and 2D Vertically Averaged Solution

Figure 6. Plume geometry for the 3D dispersive solution and 2D vertically averaged solution in Version 2.4.

$$D_x = \alpha_L U \quad D_y = \alpha_T U \quad D_z = \alpha_V U \quad (28)$$

where

- α_L = the longitudinal dispersivity (m)
- α_T = the transverse dispersivity (m)
- α_V = the vertical dispersivity (m) (generally, $\alpha_T = \alpha_V$).

The vertically averaged Green's function solution to Equation (26) for instantaneous release of mass, Q_a , at $t = 0$ at the surface of the source area and initial concentration of zero everywhere in the domain is given by

$$C(x,y,t) = \frac{Q_a}{\eta R_d} \frac{1}{2L} \frac{1}{b} \left(\operatorname{erf} \left(\frac{x + \frac{L}{2} - \frac{Ut}{R_d}}{\sqrt{\frac{4D_x t}{R_d}}} \right) - \operatorname{erf} \left(\frac{x - \frac{L}{2} - \frac{Ut}{R_d}}{\sqrt{\frac{4D_x t}{R_d}}} \right) \right) \times \frac{1}{2W} \left(\operatorname{erf} \left(\frac{\frac{W}{2} + y}{\sqrt{\frac{4D_y t}{R_d}}} \right) + \operatorname{erf} \left(\frac{\frac{W}{2} - y}{\sqrt{\frac{4D_y t}{R_d}}} \right) \right) e^{-\lambda_d t} \quad (29)$$

where

- b = the well screen thickness or mixing depth (m)
- Q_a = the initial total mass in the volume defined by $L \times W \times b$
- erf = the error function
- L = length of source parallel to groundwater flow (m)
- W = width of source perpendicular to groundwater flow (m).

The terms L and W are identical to those defined in Equation (3). For the 3D solution, Equation (29) is multiplied by the term Z_1 , given by

$$Z_1 = \left(1 + 2 \sum_{m=1}^{\infty} \exp \left(-\frac{m^2 \pi^2 D_z t}{b^2 R_d} \right) \cos m \pi \frac{z}{b} \right) \quad (30)$$

where

- z = receptor distance below the aquifer (m).

The 3D solution gives the concentration at a point specified by (x,y,z) in the aquifer. Often, the average concentration over a screened interval is more useful than concentration at a point. The average concentration over a screened well interval, b_w (from the surface of the aquifer to depth b_w), for the three-dimensional solution is given by

$$C_{3Davg}(x,y,z,t) = \frac{\int_0^{b_w} C(x,y,z,t) dz}{b_w} \quad (31)$$

For an arbitrary release, the concentration may be found by the convolution integral:

$$C(x,y,z,t) = \int_0^t C_i(x,y,z,t-\tau) F(\tau) d\tau \quad (32)$$

where

$C(x,y,z,t)$ = the concentration at time t for the arbitrary release (mg or Ci m^{-3})

$C_i(t - \tau)$ = the concentration at time, $t - \tau$, for an instantaneous release at time $t - \tau = 0$ (mg or Ci m^{-3})

$F(\tau)$ = the mass flux of the contaminant at time τ (mg or Ci y^{-1}).

$F(\tau)$ is given by Equation (25). Equation (32) gives the instantaneous concentration at time t . For some contaminants, the average concentration over a period of exposure is desired. If the peak concentration (maximum concentration observed at the specified receptor point) is bounded by the time periods, T_a and T_b , then the maximum average concentration is given by

$$C_{avg} = \frac{\int_{T_a}^{T_b} C(x,y,z,t) dt}{T_b - T_a} \quad (33)$$

where

T_a, T_b = averaging time period (years).

2.4 Radioactive Decay and Ingrowth

To evaluate the movement of radioactive progeny, the model makes the simplifying assumption that radioactive progeny travel at the same rate as the parent. This assumption has been shown to be conservative (Codell et al., 1982) and greatly simplifies the calculations. The assumption is also made that no progeny exist at the time of waste emplacement. The concentration of the i^{th} progeny in a decay chain at the receptor location is

$$C_i = C_{parent} \frac{DIF_i R_{d_{parent}}}{DIF_{parent} R_{d_i}} \quad (34)$$

where

DIF_i = decay-ingrowth factor of the i^{th} progeny

DIF_{parent} = decay-ingrowth factor of the parent

R_{di} = retardation factor of the i^{th} progeny

$R_{d_{parent}}$ = retardation factor of the parent

C_{parent} = groundwater concentration of the parent (Ci m^{-3}).

The decay ingrowth factor is given by the following (Scrabble et al., 1974):

$$DIF_i(t) = \frac{\lambda_i}{\lambda_1} \left[\left(\prod_{m=1}^{i-1} \lambda_m \right) \sum_{j=1}^i \left(\frac{e^{-\lambda_j t}}{\prod_{k \neq j} (\lambda_k - \lambda_j)} \right) \right] \quad (35)$$

where

- λ_1 = decay constant for the parent (y^{-1})
- λ_i = decay constant for the i^{th} progeny (y^{-1})
- t = time from waste emplacement (years).

2.5 Limiting Soil Concentration

Assessment of groundwater at a contaminated site usually involves evaluation of following criteria:

- Maximum contaminant levels (MCLs) in groundwater
- Chemical toxicity (carcinogenic and non-carcinogenic) from the ingestion of contaminated groundwater
- Committed effective dose equivalent (CEDE) from the ingestion of contaminated groundwater (radionuclides only).

MCLs and CEDE limits are listed in 40 CFR 141 and associated amendments. At sites identified under the Comprehensive Environmental Response, Compensation, and Liability Act, maximum allowable concentrations are based on chemical toxicity. Toxicity is quantified in terms of carcinogenic risk and non-carcinogenic effects. Carcinogenic risk represents the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (EPA, 1989). Chronic exposure to radionuclides are considered a carcinogenic risk. Non-carcinogenic effects are evaluated based on a hazard quotient that relates an exposure level over a lifetime with a reference dose derived for a similar exposure period. Other dose and risk criteria may be implemented depending on site-specific considerations.

The limiting soil concentration is the soil concentration such that, after leaching and transport, MCLs, toxicity, and CEDE limits are not exceeded. Because the concentration in groundwater is proportional to the soil concentration (excluding solubility limited releases), the limiting soil concentration may be found by a simple ratio:

$$C_s = \frac{C_L}{C_u} C_{us} \quad (36)$$

where

C_s = limiting soil concentration (Ci or mg in aqueous and solid phases m^{-3})
 C_L = limiting groundwater concentration (Ci or $mg\ m^{-3}$)
 C_u = groundwater concentration resulting from leaching and transport of a unit inventory source (Ci or $mg\ m^{-3}$)
 C_{us} = soil concentration (Ci or mg in aqueous and solid phase m^{-3}) for a unit inventory source.

For the pond model, a limiting effluent concentration is calculated. The limiting effluent concentration is given by

$$C_E = \frac{C_L R}{Q_{pond} C_x} \quad (37)$$

where

C_x = the maximum groundwater concentration calculated using the user input contaminant mass flux rate into the pond (Ci or $mg\ m^{-3}$)
 C_E = the limiting concentration in the pond effluent (Ci or $mg\ m^{-3}$).

If the release is solubility-limited, then the limiting soil concentration is calculated with Equation (36), using Equation (9) (the leaching model) or Equation (19) (the pond release model) to provide the mass flux, and the user is warned that the solubility limit of the contaminant was exceeded.

The limiting *groundwater* concentration (C_L) may be based on carcinogenic risk, non-carcinogenic toxicity, radiological dose, or a maximum contaminant limit. Calculation of the limiting soil concentration based on a maximum groundwater contaminant limit involves setting C_L equal to the MCL and calculating C_s or C_u using Equation (36) or (37). If radionuclides with progeny are modeled, then the maximum contaminant limit of the parent is adjusted for the maximum contaminant limits of the progeny. (See sample problem #1 for the adjustment calculation.) For a limiting soil concentration based on carcinogenic risk, non-carcinogenic toxicity, or radiological dose, the limiting groundwater concentration (C_L) must first be calculated. For chronic exposure scenarios (greater than one year), such as the lifetime cancer risk, the maximum average concentration integrated over the exposure period [Equation (33)] is calculated and set equal to C_u ; otherwise (for exposure periods one year or less), the maximum concentration is set equal to C_u .

The limiting groundwater concentration for a radionuclide based on a maximum CEDE limit is

$$C_L = \frac{D_L}{\left(DCF_{parent} + \sum_{i=1}^n \frac{DIF_i R_{d_{parent}}}{DIF_{parent} R_{d_i}} DCF_i \right) I EF} \quad (38)$$

where

D_L = applicable CEDE limit, (rem y^{-1})
 DCF_i = dose conversion factor for the i^{th} progeny (rem Ci^{-1})
 DCF_{parent} = dose conversion factor for the parent (rem Ci^{-1})
 I = water intake rate ($L\ d^{-1}$)

C_L = limiting *parent* groundwater concentration (Ci L^{-1})
 EF = exposure frequency (d y^{-1}).

The limiting groundwater concentration for a radionuclide based on carcinogenic risk is formulated slightly different because the average concentration over the exposure period must be considered. The limiting groundwater concentration for a nuclide with "n" members in the decay chain is given by

$$C_L = \frac{C_{\text{risk}} C_{\text{parent}}}{\left(\sum_{i=1}^n C_i SF_i \right) I EF ED} \quad (39)$$

where

SF_i = slope factor for i^{th} member of the decay chain (Ci^{-1})
 C_{parent} = parent groundwater concentration averaged over the exposure period (Ci L^{-1})
 C_i = groundwater concentration averaged over the exposure period for the i^{th} member of the decay chain (Ci L^{-1})
 I = water intake rate (L d^{-1})
 ED = exposure duration (y)
 C_{risk} = acceptable carcinogenic risk factor (1×10^{-4} to 1×10^{-6} , see EPA, 1989).

The quantity in parentheses in the denominator of Equation (38) has been termed as the "composite dose conversion factor." Progeny that are in secular equilibrium (activity of the parent equals activity of the progeny) with their parent can be treated simply by summing the dose conversion factors or the slope factors of the parent and progeny. Slope factors with the "+D" designation already include progeny that are in equilibrium with the parent in the groundwater.

The limiting groundwater concentration for non-radiological carcinogens was derived from EPA (1989):

$$C_L = \frac{C_{\text{risk}} BW AT}{SF I EF ED} \quad (40)$$

where

BW = body weight (kg)
 AT = averaging time (d)
 SF = slope factor (mg/kg/d^{-1}).

For non-carcinogenic toxicity assessment, the point of departure from an acceptable concentration is given by the hazard quotient, HQ (EPA, 1989):

$$HQ = \frac{E}{RfD} \quad (41)$$

where

RfD = reference dose (mg/kg/d)

E = contaminant exposure or intake (mg/kg/d).

Contaminant intake or exposure is given by Equation (42):

$$E = \frac{C_L I E F E D}{B W A T} \quad (42)$$

In most cases, an HQ of unity is considered acceptable (EPA, 1989). The limiting groundwater concentration for non-carcinogens is given by Equation (43):

$$C_L = \frac{H Q B W A T R f D}{I E F E D} \quad (43)$$

The methodology presented so far is applicable for sites that contain single contaminants. Some sites may contain multiple contaminants having the same regulatory criteria endpoint (radiological dose, carcinogenic risk, or hazard quotient). In these cases, several approaches are recommended. First, the transit time of each contaminant should be considered. If the contaminant transit times are significantly different, then the contaminants can be treated separately because the maximum concentrations will not overlap. For contaminants that have approximately the same transit time, the regulatory criteria limit can be scaled for each contaminant. The general form of the scaling equation for n number of radionuclides limited by CEDE is

$$D_{L_j} = \frac{D C F_j}{\sum_{i=1}^n D C F_i} \times D_L \quad (44)$$

where

D_{L_j} = CEDE limit for the j^{th} nuclide (rem y^{-1})

$D C F_j$ = dose conversion factor for the j^{th} nuclide (rem Ci^{-1}).

The general form of the scaling equation for carcinogens is

$$C_{risk_j} = \frac{S L_j}{\sum_{i=1}^n S L_i} \times C_{risk} \quad (45)$$

where

C_{risk_j} = probability risk factor for the j^{th} contaminant

$S L_j$ = slope factor for the j^{th} contaminant (mg/kg/d) $^{-1}$.

The general form of the scaling equation for non-carcinogens is

$$HQ_j = \frac{RfD_j}{\sum_{i=1}^n RfD_i} \times HQ \quad (46)$$

where

HQ_j = hazard quotient for the j^{th} contaminant

RfD_j = reference dose for the j^{th} contaminant (mg/kg/d).

3. CODE IMPLEMENTATION

GWSCREEN is written, for the most part, in standard FORTRAN and compiled for operation on a personnel computer with a DOS operating system. Non-standard extensions are mainly violations of the six-character limit used for naming variables. The FORTRAN source code is also compatible with most FORTRAN compilers on UNIX operating systems. Input to GWSCREEN is through one free-format ASCII file. This file contains the contaminant and site-specific data such as sorption coefficients and regulatory limits, and exposure scenario data such as drinking water consumption rates and standard body weight. This file is assigned a name by the user, and the user is prompted for this file name during execution of the program. The default input file name is **GWSCREEN.PAR**, and the default output file name is **GWSCREEN.OUT**. In Version 2.03, a second file is written when concentration versus time output is selected and the limiting groundwater concentration is based on toxicity or radiological dose. This file, called **DOSE.OUT**, contains the calculated health effects for each time period in the concentration versus time output. Line by line input for the user-defined input file for Versions 2.0 through 2.03 and Version 2.4 is found in Table 2 (see Section 3.2).

Equations (1) to (50) are implemented in numerous subroutines in the code. These subroutines and the equations embedded in them are cross referenced and briefly described in Table 1. The program flow and execution, and an explanation of output from several sample problems are described in Section 3.3. Nine sample problems that demonstrate the options in GWSCREEN are presented in Appendix A. Appendix B contains the source code listing.

3.1 Computational Methods

The methodology presented in Section 2 requires numerical integration to calculate the instantaneous groundwater concentration [Equation (32)] and the average integrated concentration [Equations (31) and (33)]. Equation (31) is used for the vertically averaged concentration using the 3D dispersion model, and Equation (33) is used for time-averaged concentration. GWSCREEN Version 2.0 uses two algorithms, Gauss-Legendre and Simpson's rule, to integrate Equation (32) (Press et al., 1986). Equations (31) and (33) are calculated using Gauss-Legendre only. Gauss-Legendre routines are computationally efficient for relatively smooth integrals and, if a preselected number of weight points are used, integration variables are not needed, thereby simplifying the required input for the user. For integrands that are not approximated very well by polynomials, or that are unpredictable and erratic, the Gaussian-Legendre algorithms may become unstable and produce erroneous results. The Simpson rule routine, which is a more robust solver, may be used in such cases. The computational time using the Simpson's rule routine, however, is usually longer and also requires the user to input integration variables. In general, Gauss-Legendre integration should be used for the surface and buried-source model, and Simpson rule integration should be used for the pond model. For a source defined by a tabulation of contaminant mass fluxes, the integration routine selected should be based on the smoothness of the flux versus time curve. If the flux versus time curve is relatively smooth, then the Gauss-Legendre routine can be used; otherwise, the Simpson's rule routine should be used.

Table 1. A brief description of the GWSCREEN subroutines.

Subroutine	Description
AREA	Calculates Green's function for an area source. Called by FUNC. Equations used: 28, 29
ASSIGN	Assigns a value to the dummy variable, XDUMMY and selects the units of the calculation. Called by GWS6
CARCIN	Calculates limiting soil and pond effluent concentration for non-radiological carcinogenic effects. Called by GWS6. Equations used: 36,37,40
CHECKN	Checks parameter values in input file with acceptable limits. Called by INPUT
CRAD	Calculates limiting soil concentration for radiological carcinogenic effects. Called by GWS6. Equations used: 36,37,39
CTIME	Calls FUNC to calculate concentration as a function of time and calculates risk values or radiological dose that is output to DOSE.OUT. Called by GWS6
ERF	Exponential and error function subroutine. Includes functions ERX, EXPF, ERROR, GAMMP, GCF, GAMMLN; Called by AREA
FLUXES	Calculates cumulative source flux and aquifer flux at each print step. Called by CTIME. Equations used: 25
FUNC	Calls SIMPSON or QGAUS2 to compute the convolution integral. Called by CTIME, GOLDEN, QGAUS1
GOLDEN	Determines the maximum concentration and the time of maximum. Called by PEAK
GWINT	Calculates the average integrated concentration. Called by GWS6. Equations used: 33
GWS6	Main program unit. calls INPUT, ASSIGN, CTIME, CARCIN, CRAD, MAXRAD, MAXNRAD, NCARCIN
INPUT	Reads GWSCREEN input file and calls CHECKIN. Called by GWS6
LICENSE	Writes disclaimer and licensing agreement to output file.
LIMITS	Calculates integration limits. Called by SIMPSON and QGAUS2. Equations used: 47
LINT	Linear interpolates the tabulated source function. Called by SRCTERM
MAXNRAD	Calculates the limiting soil and pond concentration for a nonradiological contaminant based on MCL. Called by GWS6. Equations used: 36,37
MAXRAD	Calculates the limiting soil and pond concentration for a radiological contaminant based on MCL. Called by GWS6. Equations used: 36, 37
NCARCIN	Calculates the limiting soil and pond concentration for a nonradiological contaminant based on HQ. Called by GWS6. Equations used: 36,37,41,42,43
PEAK	Calculates the maximum groundwater concentration. Called by GWS6
QGAUS1	Performs Gauss Legendre integration on groundwater concentration as a function of time. Called by GWINT. Equations used: 33
QGAUS2	Performs Gauss Legendre integration to compute the convolution integral. Called by FUNC. Equations used: 32
RAD	Calculates the limiting soil and pond concentration for a radiological contaminant based of CEDE. Called by GWS6. Equations used: 36,37,38
RDKGWS	Computes the decay-ingrowth factors. Called by CTIME, RAD, CRAD, MAXRAD. Equations used: 35
ROOT	Computes the solubility limited mass release time. Called by SOURCX. Equations used: 14
SIMPSON	Performs Simpson rule integration to compute the convolution integral (includes subroutine TRAPZ). Called by FUNC. Equations used: 32
SOURCEX	Calculates fixed transport parameter values. Called by GWS6. Equations used: 4,7,10,12,13,15,17,21,22,23,24
SRCPOND	Calculates flux from pond to unsaturated zone. Called by SRCTERM. Equations used: 19
SRCTERM	Calculates flux from surface or buried source to unsaturated zone. Called by QGAUS2, SIMPSON. Equations used: 9, 11, 19.
WRITEO	Writes limiting soil or pond concentration to output file. Called by GWS6
ZARG	Calculates Z_1 term and vertically averaged concentration. Called by AREA. Equations used: 30,31

Variations of the Gauss-Legendre integration routine are found in the subroutines QGAUS1 and QGAUS2, and in the function ZARG. In QGAUS1 and ZARG, an eight-point Gauss-Legendre routine (eight pairs of abscissas and weights) is used to integrate the instantaneous groundwater concentration over time and to vertically integrate the concentration in the aquifer. In QGAUS2, a 17-point Gauss-Legendre integration routine is used to compute the convolution integral and to calculate the instantaneous groundwater concentration. The abscissas and weights for these routines were calculated using a FORTRAN routine adapted from Press et al. (1986). It was necessary to use more weight points in the QGAUS2 subroutine in order to achieve a stable solution to the convolution integral.

The integration limits in Equation (33) often result in values of the function $C(x,y,z,t-\tau)$ that are near zero, add little to the integrand, and decrease the overall accuracy of the solution. Codell derived expressions for the integration limits, T_1 and T_2 , such that for each function call of $C(x,y,z,t-\tau)$, significant values to the integrand were added. These limits were presented (in Codell) for a line source with a decay term and for an area source without a decay term. The limits for an area source were modified to include a decay term in GWSCREEN. The limits (T_1 , T_2) are given by

$$T_1, T_2 = t - \frac{1}{2} \left(\frac{\frac{2U(x \pm L/2) + 4D_x \gamma}{R_d}}{\left(\frac{U}{R_d} \right)^2 + \frac{4D_x \lambda}{R_d}} \right) \quad (47)$$

$$\pm \frac{1}{2} \left(\sqrt{\left(\frac{\frac{2U(x \pm L/2) + 4D_x \gamma}{R_d}}{\left(\frac{U}{R_d} \right)^2 + \frac{4D_x \lambda}{R_d}} \right)^2 - \frac{4(x - L/2)^2}{\left(\frac{U}{R_d} \right)^2 + \frac{4D_x \lambda}{R_d}}} \right)$$

where

T_1, T_2 = upper and lower limits of integration (years)

γ = arbitrary value such that $e^{-\gamma} \approx 0.0$ when $T_1 < (t-\tau) < T_2$

λ = radiological decay constant (y^{-1}).

A value of 50 was found to be adequate for γ . These limits are calculated in the subroutine LIMITS.

Equation (29) in subroutine AREA requires evaluation of error functions. The error function routine was also adapted from Numerical Recipes (Press et al., 1986) and contained in subroutines ERRORF, GAMMP, GSER, GCF, and GAMLIN.

Maximum concentration is determined in the subroutines PEAK and GOLDEN. The subroutine PEAK uses Equation (48) to calculate points that are known to lie on either side of the peak: where

$$ZMIN = \frac{\left(T_{oper} + \left((x-L) \frac{R_d}{U} \right) \right)}{5} \times \frac{T_{1/2} U}{(0.1+x) R_d} \quad (48)$$

$$ZMAX = \left(T_{oper} + (x+L) \frac{R_d}{U} \right) 4$$

ZMIN = minimum bound (y)

ZMAX = maximum bound (y)

T_{op} = operational time of pond, $T_{op} = 0$ if surface or buried source model is used (y).

These points, along with their midpoint, are passed to the subroutine GOLDEN (golden section routine adapted from Press et al., 1986) that calculates the maximum concentration and the time at which the maximum concentration occurred.

3.2 Contaminant and Site-Specific Data File

Variables and structure for the required input file for Versions 2.0 through 2.03 and Version 2.4 are presented in Table 2. The variables that are used only in Version 2.4 are noted. A value for each variable must be included in the input file whether or not that value is used in the calculation. If more than one value is read on a line, then the values must be separated by spaces or commas. Comments may follow the last value on a line.

Line 15 lists six variables; however, only one value is read. The first value read on line 15 is assigned to one of the following variables: DCF, RCSF, SFACTOR, RFD, RADMAX, or ZRADMAX depending on the value of IMODE (see Table 2). Units of the contaminant (Ci or mg) are also selected by the IMODE variable. If the IMODE variable is 1, then the first value on line 15 is read as DCF(I), the ingestion dose conversion factor (rem Ci^{-1}), and the units of the contaminant are curies. If IMODE=2, then the first value on line 15 is read as RCSF(I), the radiological carcinogenic slope factor (Ci^{-1}), and the units of the contaminant are curies. If IMODE=3, then the first value on line 15 is read as RADMAX(I), the maximum radionuclide concentration in groundwater (Ci L^{-1}), and the units of the contaminant are curies. If the IMODE variable is 4, then the first value on line 15 is read as ZRADMAX, the maximum allowable non-radiological contaminant concentration in groundwater (mg L^{-1}), and the units of the contaminant are mg. If the IMODE variable is 5, then the first value on line 15 is read as SFACTOR, the carcinogenic slope factor (kg d mg^{-1}), and the units of the contaminant are mg. If the IMODE variable is 6, then the first value on line 15 is read as RFD, the reference dose for non-carcinogens (mg/kg/d), and the units of the contaminant are mg. Note that the variables AKD(I), THALF(I), DCF(I), RCSF(I), and RADMAX(I) are arrays where the number of elements in the array is given by NPROG+1.

Table 2. The GWSCREEN input file for contaminant and site-specific data. Variables given the same line number must appear in the same order on the line as presented in this table. A value for each variable listed must be present whether or not that variable is used in the calculation. Minimum and maximum acceptable values are noted by MIN and MAX designations.

Line No.	Variable	Code Variable	Type	Description
1	—	TITLE	CHARACTER	80-character title of project
2	—	KFLAG	INTEGER	Flag variable to select the type of calculation. If KFLAG=0, then concentration versus time is calculated. If KFLAG=1, then peak concentration and limiting soil concentration is calculated. KFLAG must equal 0 if IMODEL = 3. MIN:0 MAX:1
2	—	NPROG	INTEGER	Number of radioactive progeny. MIN:0 MAX:9
3	$T_b - T_a$	INTIME	INTEGER	Groundwater concentration integration time for calculation of average concentration (y). If INTIME equals zero, then integration is not performed. MIN:0 MAX:1000
3.	—	ITYPE	INTEGER	Version 2.4 only: Defines type of groundwater solution. ITYPE=0, then 2D vertically averaged solution, ITYPE=1, then 3D point concentration solution, ITYPE=2, then 3D vertically averaged solution. MIN:0 MAX:2
4	L	AL	REAL	Length of source parallel to groundwater flow (m). MIN:1 MAX:1E4
4	W	WA	REAL	Width of source perpendicular to groundwater flow (m). MIN:1 MAX:1E4
4	T	THICKS	REAL	Thickness of source volume (m) if IMODEL=1 or thickness of pond sediments if IMODEL=2. This variable is ignored if IMODEL=3. MIN:1E-3 MAX:1E4
5	P	PERC	REAL	The net water percolation rate (m y^{-1}). MIN:1E-4 MAX:1E6
5	θ_c	THETAS	REAL	Volumetric moisture content in contaminated zone ($\text{m}^3 \text{m}^{-3}$). MIN:1E-8 MAX:0.9999999
5	θ_u	THETAU	REAL	Volumetric moisture content in the unsaturated zone ($\text{m}^3 \text{m}^{-3}$). MIN:1E-8 MAX:0.9999999
6	ρ_c	RHOS	REAL	Bulk density in the contaminated zone (g cm^{-3}). MIN:0.01 MAX:10.0
6	K_{dc}	ZKDS	REAL	Sorption coefficient in contaminated zone (mL g^{-1}). MIN:0 MAX:1.0E18
6	λ_o	RC2	REAL	Loss rate constant from source zone for mechanisms other than decay (y^{-1}). MIN:0 MAX:1.0E18
7	ρ_u	RHOU	REAL	Bulk density in unsaturated zone (g cm^{-3}). MIN:0.01 MAX:10.

Table 2. (continued).

Line No.	Variable	Code Variable	Type	Description
7	K_{du}	ZKDU	REAL	Sorption coefficient in unsaturated zone (mL g^{-1}) MIN:0 MAX:1.0E18.
8	$T_{1/2}$	ATHALF(I)	REAL	Half Life(s) of contaminant and radioactive progeny. Array of NPROG+1 number of elements (years). MIN:0 MAX:1E38. Note: The value of ATHALF is reset to 1.0E38 if ATHALF=0.
9	Q_0	QI	REAL	Initial mass in source volume or in pond sediment (Ci or mg)
9	MW	ZMW	REAL	Molecular weight of contaminant (g mole^{-1})
9	C_d	SL	REAL	Contaminant solubility limit (mg L^{-1})
10	ρ_s	RHOA	REAL	Bulk density in saturated zone (g cm^{-3}). MIN:0.01 MAX:10
10	η	PHI	REAL	Porosity of saturated zone ($\text{m}^3 \text{m}^{-3}$). MIN:1E-10 MAX: 0.999999
10	K_{ds}	AKD(I)	REAL	Sorption coefficient(s) in the saturated zone of contaminant and radioactive progeny. Array of NPROG+1 number of elements (mL g^{-1}). Code variable ZKDA=AKD(1). MIN:0 MAX:1.0E18
11	α_L	AX	REAL	Longitudinal dispersivity (m). MIN:1E-10 MAX:1E6
11	α_T	AY	REAL	Transverse dispersivity (m). MIN:1E-10 MAX:1E6
11	α_v	AZ	REAL	Version 2.4 only: Vertical dispersivity (m). MIN: 1E-10 MAX:1E6
11	U	VX	REAL	Saturated pore velocity (m y^{-1}). MIN:1E-10 MAX:1E6
12	b	THICK	REAL	Well screen (mixing) thickness (m). In version 2.4, THICK is the well screen thickness if ITYPE=0. If ITYPE=1 or 2, then THICK is the aquifer thickness. MIN:1E-10 MAX:1E6
12	X_u	DEPTH	REAL	Thickness of unsaturated zone (m) MIN:1E-10 MAX:1E6
13	—	IMODE	INTEGER	Flag variable to select type of groundwater criteria. IMODE=1 Radiological dose; IMODE=2 Radioactive carcinogenic risk; IMODE=3 Maximum radionuclide concentration; IMODE=4 Maximum non-radiological groundwater concentration; IMODE=5 Carcinogenic risk; IMODE=6 Non-carcinogenic reference dose. MIN:1 MAX:6
13	—	IMODEL	INTEGER	Flag variable to indicate what source model to run. IMODEL=1, surface or buried source leaching model, IMODEL=2, pond release model, IMODEL=3, tabulated source function. MIN:1 MAX:3
NOTE: Line 14 variables are used only in the pond model (IMODEL=2)				
14	R_p	RMI	REAL	Rate of mass input into disposal pond (Ci or mg y^{-1})

Table 2. (continued).

Line No.	Variable	Code Variable	Type	Description
14	t_{op}	TOPER	REAL	Operation time of pond facility (y)
14	Q_{pond}	PNDFLX	REAL	Water flux into pond ($m^3 y^{-1}$)
14	Θ_p	THETAP	REAL	Volumetric water content of pond sediments ($m^3 m^{-3}$)
14	λ_E	EVAP	REAL	Evaporation or other loss rate constant for the contaminant in the pond (y^{-1})
14	W_e	WAEFF	REAL	Effective pond width at aquifer (m). See equation 20
15	DCF	DCF(I) ^a	REAL	Radiological dose conversion factor(s) for NPROG+1 elements (rem Ci^{-1})
15	SF	RCSF(I) ^a	REAL	Radiological carcinogenic slope factor(s) for NPROG+1 number elements (Ci^{-1})
15	C_L	RADMAX(I) ^a	REAL	Maximum allowable radionuclide concentration(s) in groundwater for NPROG+1 elements ($Ci L^{-1}$)
15	C_L	ZRADMAX ^a	REAL	Maximum allowable non-radiological groundwater contaminant concentration ($mg L^{-1}$)
15	SF	SFACTOR ^a	REAL	Carcinogenic risk slope factor ($mg/kg/d$) ⁻¹
15	RfD	RFD ^a	REAL	Reference dose for non-radiological contaminants ($mg/kg/d$)
16	x	XD	REAL	Receptor distance from center of source parallel to groundwater flow (m)
16	y	YD	REAL	Receptor distance from center of source perpendicular to groundwater flow (m)
16	z	ZD	REAL	Version 2.4 only: Receptor distance from surface of aquifer for ITYPE=1, or averaging thickness from surface of aquifer for ITYPE=2. Ignored if ITYPE=0. MIN:0 MAX:value of variable THICK
17	BW	BW	REAL	Body weight of standard man (kg)
17	AT	AT	REAL	Averaging time (days)
17	I	WI	REAL	Water intake rate ($L d^{-1}$)
17	EF	EF	REAL	Exposure frequency ($d y^{-1}$)
17	ED	ED	REAL	Exposure duration (y)
17	D_L	DLIM	REAL	Radiological CEDE limit (rem y^{-1})

Table 2. (continued).

Line No.	Variable	Code Variable	Type	Description
17	—	CRISK	REAL	Acceptable carcinogenic risk factor (unitless)
17	HQ	HQ	REAL	Hazard quotient (unitless)
18	—	ISOLVE	INTEGER	Flag variable to select numerical integration method. ISOLVE=1, Gaussian Quadrature; ISOLVE=2, Simpson Rule. MIN:1 MAX:2
18	—	JSTART	INTEGER	Number of iterations to perform in the Simpson rule integration routine before convergence checking is to begin. JMAX must be greater than JSTART. See discussion in Section 3.2. MIN:6 MAX:14
18	—	JMAX	INTEGER	Maximum number of iterations to perform for the Simpson rule integration routine. The maximum number of point evaluations = $[2^{j_{max}-1}]$. See discussion in Section 3.2. MIN:7 MAX:15
18	—	EPS	REAL	Convergence criteria for Simpson rule integration. See discussion in Section 3.2. MIN:1.0E-6 MAX:1.0
19	—	NTIMES	INTEGER	Number of time periods to calculate concentration over. Read only if KFLAG is 0. MIN:1 MAX:9
20 ^c		T1(I)	REAL	Beginning time of the I th time period to calculate concentration as a function of time (y, I=1 to NTIMES) ^b
20 ^c		T2(I)	REAL	Ending time of the I th time period to calculate concentration as a function of time (y, I=1 to NTIMES) ^b
20 ^c		TP(I)	REAL	Print time step for the I th time period (y, I=1 to NTIMES) ^b
21 ^d		ATIME(J)	REAL	Time of the J th release for tabulated source function. Maximum of 1000 points allowed (y)
21 ^d		QREL(J)	REAL	Mass flux of J th release for the tabulated source function (Ci or mg y ⁻¹)

a. Only one variable is read on line 15. The variable read depends on the value of IMODE (line 13). If IMODE=1, then line 15 variable is DCF and units are in Ci. If IMODE=2, then line 15 variable is RCSF and units are in Ci. If IMODE=3, then line 15 variable is RADMAX and units are in Ci. If IMODE=4, then line 15 variable is ZRADMAX and units are in mg. If IMODE=5, then line 15 variable is SFACOR and units are in mg. If IMODE=6, then line 15 variable is RFD and units are in mg.

b. Time from waste emplacement.

c. Line 20 is repeated NTIMES-1 number of times. This data is only read if KFLAG=0 and may contain up to 9 sets of T1, T2, and TP points.

d. The data listed on line 21 begins on line (20 + NTIMES) and may contain up to 1000 pairs of ATIME and QREL points. This data is only read if IMODE=3.

3.2.1 Version 2.4 Input Files

Version 2.4 uses nearly the same input file as Versions 2.0 through 2.03 except for the following:

- Line 2, Record 2: The variable ITYPE was added. ITYPE determines whether a 2D vertically averaged solution (ITYPE=0), 3D solution, point concentration (ITYPE=1), or 3D vertically averaged solution is used (ITYPE=2). If ITYPE=1 or 2, then the variable THICK (mixing thickness) is read as the aquifer thickness.
- Line 11, Record 3: The variable AZ is read. This variable is the dispersivity in the vertical direction. The variable VX is read in position 4 on the line.
- Line 16, Position 3: The variable ZD is read. This variable is the distance from the surface of the aquifer to the receptor location. If ITYPE=1, the concentration is evaluated at the point XD,YD, ZD. If ITYPE=2, then the average concentration from the depth ZD to the aquifer surface is calculated.

3.2.2 Vertical Mixing Options

It is important to note that the variable THICK has different meanings in Version 2.4 and Version 2.03 and earlier. In Version 2.03 and earlier, the variable THICK is the aquifer mixing thickness (or well screen) in Equation (29) (variable "b"). In Version 2.4, the variable THICK is the aquifer thickness in Equation (30) when ITYPE=1 or 2. When ITYPE=0, the variable THICK is the aquifer mixing thickness, b, in Equation (29) (see Figure 6) and has the same meaning defined in Versions 2.03 or earlier. For example, suppose you want to calculate the concentration in groundwater at a point downgradient as described in sample problem 8 (Appendix A). Version 2.4 offers three choices for this calculation. These choices are:

1. 2D vertically averaged solution
2. 3D point concentration solution
3. 3D vertically averaged solution.

The 2D vertically averaged solution (ITYPE=0) is the same solution as employed in all previous versions of GWSCREEN. The maximum parent concentration using this option was $6.36\text{E-}17$ Ci/L. The 3D point concentration solution (ITYPE=1) gives the concentration at the point XD,YD,ZD in the aquifer. The variable THICK is the *aquifer thickness* when ITYPE=1 and 2. This variable was set equal to 76 m. The maximum parent concentration when ITYPE=1 and ZD=1m (1 m below the aquifer surface) and AZ=4m was $3.14\text{E-}17$ Ci/L. The 3D vertically averaged solution (ITYPE=2) gives the average concentration from the surface of the aquifer to the depth, ZD. The difference between this solution and the 2D vertically averaged solution is that in the 2D solution, the contaminant mass is not allowed to disperse deeper into the aquifer than the well screen thickness. In the 3D solution, the contaminant plume is allowed to disperse in the entire thickness of the aquifer. The amount of dispersion is a function of the downgradient distance of the receptor and the vertical dispersivity (α_z). The average concentration is calculated for the top interval defined by the surface of the aquifer and the variable ZD. The maximum parent concentration using this option was $2.94\text{E-}17$ Ci/L.

3.2.3 Integration Routine Options

In general, the Simpson's rule integration routine is a more robust solver and is recommended for the pond model and when a user-defined release function is used; however, the routine usually requires more computational time. The variables JMAX, JSTART, and EPS are used with the Simpson's rule integration routine. The routine evaluates the integral for a variable number of points and monitors the accuracy of the solution. The accuracy is checked by computing the integral using 2^n number of middle points plus the two end points and then adding 2^{n+1} number of middle points and comparing the result with the previous evaluation. A maximum of JMAX number of iterations is performed. On the first iteration, the crudest approximation to the integral is performed by evaluating the function at the upper and lower limits. On each successive iteration, the number of middle points (points between the upper and lower limits of integration) evaluated are increased by a factor of 2 starting with one middle point added during the second iteration. The number of additional middle points is given by 2^{n-2} where n =the iteration number. The routine evaluates the integral for at least JSTART number iterations before the " $n-1$ " solution is checked for convergence with the n^{th} solution. For example, if the variable JSTART is set equal to 6 (its minimum allowable value) then 6 iterations are performed before convergence checking occurs. The number of middle points added on the 6th iteration is $2^{6-2} = 16$. Convergence is checked by calculating the EPS value and comparing it to the user input EPS value. The EPS variable is given by

$$EPS = \frac{|f_p - f_c|}{f_c} \quad (49)$$

where

f_p = previous evaluation of the integral [Equation (30)]
 f_c = current evaluation of the integral.

If the calculated EPS is less than the user input EPS, then the routine is terminated and the current evaluation of the integral is returned. If the calculated EPS is greater than the user input EPS, then 2^{n+1} number of middle points are added and a new value of the integral is calculated and checked. If convergence is not achieved in JMAX number of iterations, then the routine is terminated and the current value of the integral is returned. A message warns the user of non-convergence and the current EPS value is also printed. An adequate solution does not necessarily require convergence to be met and depends on the values of the integration variables JMAX, JSTART, and EPS. Unacceptable solutions are usually detected by observing the concentration verses time output. If there are *significant* fluctuations in the curve, then the EPS value should be set lower and JMAX increased. In the samples problems presented in Appendix A, adequate solutions were obtained using an EPS value of 5.0×10^{-3} and a JMAX value of 12. The JSTART variable, which must be less than JMAX, was set equal to 6. Decreasing the EPS value and increasing JMAX is not without cost, however, since computational time is significantly increased when these values are changed.

When a tabulated source function is used, the release function, $F(\tau)$, in Equation (32) is linearly interpolated from the data provided by the user. Linear interpolation is performed in the subroutine LINT.

3.3 Code Execution and Output

To perform a GWSCREEN simulation, an input file must first be built. Section 3.2 describes the structure and data needs for the input file. An input file can be constructed in any text editor and assigned any legal file name. To start a GWSCREEN simulation, type GWSCREEN and press the return key. The user is then prompted for the name of the user-defined input file (Table 2) and the name of the file the output is to be written to. The default names for these files are **GWSCREEN.PAR** and **GWSCREEN.OUT**, and the user may select them by simply pressing the return key at the prompt. Overall program flow (Figure 7) is controlled by the user input variables **IMODE**, **IMODEL**, and **KFLAG**. These variables determine the regulatory option to use, units of the calculation, the release model to use, and whether concentration versus time or the limiting soil concentration is calculated. The variable **ITYPE** in Version 2.4 controls the type of solution to use (2D or 3D).

All input data are printed to the output file along with the date and time of the run. If the contaminant being modeled is radioactive with radioactive progeny, then the progeny half lives, aquifer sorption coefficients, dose conversion factors, and slope factors are printed to the right of the parent value beginning with the first decay chain member. Space has been provided for the input data to be checked and reviewed by additional personnel. Fixed parameter values calculated in the code, such as the leach rate constant (λ_L) and the retardation factor (R_d), are also printed in the output file. Aquifer retardation factors and decay rate constants for radioactive progeny are printed to the right of the parent values.

3.3.1 KFLAG, IMODEL, IMODE, INTIME, ITYPE

The variable **KFLAG** determines whether concentration versus time or limiting soil concentration are calculated. If **KFLAG** equals 0, then groundwater concentration and source flux are calculated as a function of time and printed to the output file. Up to nine separate time periods for output may be selected. For each time period, the concentration may be printed for unlimited number of specific times within that time period. If **KFLAG** equals 1, then the limiting soil concentration is calculated and, depending on the option selected, the maximum radiological dose, carcinogenic risk, or noncarcinogenic hazard quotient are calculated. Unlike GWSCREEN Version 1.3 through 1.5, the peak concentration reported is based on the mass (or activity) input as the **QI** variable and not a unit inventory.

In Version 2.03 and higher, a second file is also printed when **KFLAG**=0 and **IMODE**=1, 2, 5, or 6. This file, given the name **DOSE.OUT**, contains the health effects calculation (radiological dose or toxicity) for each print time step requested in the input file. Time is output in the first column, and health effects corresponding to each time period are tabulated in the subsequent columns. If radioactive decay products are being modeled, then the health effects for each decay product are listed in order. The last column reports the sum of the health effects for all reported decay chain members.

The **IMODEL** variable selects what type of release model is used. If **IMODEL** is equal to 1, then the surficial or buried source model is used. If **IMODEL**=2, then the pond model is used; if **IMODEL**=3, then the tabulated source function is used. The tabulated source function requires a time history of flux to the unsaturated zone be appended to the end of the input file. Each time

GWSCREEN VERSION 2.03-2.4 FLOWCHART

Figure 7. Flow chart for the GWSCREEN code (not all subroutines are shown in this figure).

the mass release rate (mg or Ci per year). The last time value in the release file should be greater than the last time period requested for printing (variable T2(NTIMES)). For example, if T2(NTIMES) is 100 years, then the last value for ATIME should be at least 100 years. A release value (QREL) of zero may be used if there are no releases at that time.

Appropriate units are selected automatically with the IMODE variable. If concentration versus time mode (KFLAG=0) has been selected, then the output file contains the contaminant fluxes and groundwater concentrations for the output times specified by the NTIMES, T1, T2, and TP variables. These output times are the time from waste emplacement. If KFLAG=1, then the limiting soil concentration and limiting contaminant mass are calculated and printed to the output file. The code also compares the limiting contaminant mass with the solubility limited mass (Q_s). If the limiting mass exceeds the solubility limited mass as given by Equation (13), then a warning is printed at the bottom of the output file. If the solubility limit is unknown, then the variable SL should be set to 1×10^6 mg/L or greater. This will basically eliminate a solubility limited release from being considered.

The INTIME variable controls the concentration averaging time when KFLAG=1. If INTIME is less than or equal to 1, then the maximum concentration is reported as the average concentration. When KFLAG equals zero (concentration versus time model) and INTIME is greater than zero, GWSCREEN calculates the average concentration over the output time period defined by the variables T1(I), T2(I). If INTIME equals zero, then average concentrations are not calculated when KFLAG=0.

The ITYPE variable controls the type of groundwater solution to be computed. See Section 3.2 for details.

3.3.2 Solubility Limited Releases

Limiting soil inventories for contaminants with relatively short half-lives, compared to their unsaturated transit times, are usually quite large, and often exceed the solubility limited mass [Equation (13)]. This situation may occur even when the solubility limit is set artificially high. The user should be aware that the limiting contaminant inventory calculated under these conditions is unreasonably high and sometimes not physically possible. For radionuclides, the specific activity of the nuclide is also computed and compared to the limiting soil concentration. The specific activity is given by

$$S_p = \frac{N_A \lambda_d 3.1536 \times 10^7 \text{ s/y}}{MW 3.7 \times 10^{10} \text{ dps/Ci}} \quad (50)$$

Limiting soil concentrations that exceed the specific activity of the nuclide are also noted in the output.

3.3.3 Radioactive Progeny

Groundwater concentrations for radioactive progeny (when KFLAG=0) are designated by columns labeled member #1, member #2, member #3, ...member n. If the limiting soil concentration is

Groundwater concentrations for radioactive progeny (when KFLAG=0) are designated by columns labeled member #1, member #2, member #3, ...member n. If the limiting soil concentration is selected, then the maximum parent groundwater concentration and the corresponding radiological dose or carcinogenic risk is printed to the output file. The concentration of each of the remaining members of the decay chain at the time of maximum concentration of the parent is also printed in the output file along with the corresponding radiological dose or carcinogenic risk for each member. The groundwater concentration, dose, and risk values are based on the user input activity (or mass) in the source volume as defined by the QI variable. Concentration of the progeny are reported at the time of the maximum parent concentration. In most cases, the maximum progeny concentration occurs at the same time as the parent; however, there are cases in which the maximum progeny concentration occurs at a different time than that of the parent's. This generally happens when "no equilibrium conditions" exist between parent and progeny and is illustrated in example problem #8 (Figure 8). In example problem #8, the maximum ^{241}Pu concentration (parent nuclide) occurs at 318 years (compare output for sample problem #8 with Figure 8), the maximum ^{241}Am concentration occurs at 376 years, and the maximum ^{237}Np concentration occurs at 388 years. In the output for limiting soil concentration, the maximum concentrations for ^{241}Am ($4.0 \times 10^{-13} \text{ Ci L}^{-1}$) and ^{237}Np ($3.2 \times 10^{-15} \text{ Ci L}^{-1}$) are calculated at 318 years, the time of maximum concentration for ^{241}Pu . Note that these concentrations are lower than the actual maximum concentration presented in Figure 8. Also note in the output that the average concentrations for the progeny are higher than the reported maximum concentration for the progeny. This indicates that the peak progeny concentration did not occur at the same time as the peak parent concentration. The user should be aware when non-equilibrium conditions occur and run the code in both the limiting soil concentration and concentration versus time modes to ensure that a conservative answer has been calculated.

The ^{241}Pu flux to the aquifer and the unsaturated transit time (251 years) are also shown in Figure 8. Since the unsaturated transit time exceeds 10 times the half-life (14.4 years), then, as suggested in Section 2.2, the thickness in the unsaturated zone may be decreased such that $[10 \times T_{1/2}] \leq T_{\text{unsat}}$ for conservatism. In this problem, however, the limiting soil concentration is driven by ^{241}Am and ^{237}Np since the carcinogenic slope factors for these nuclides are about two orders of magnitude greater than ^{241}Pu , and their groundwater concentrations at the receptor are higher. Longer unsaturated transit times allow for more radioactive progeny ingrowth and, therefore, higher progeny groundwater concentrations and greater risk. Therefore, it is more conservative in this particular case to use the longer unsaturated transit time.

Figure 8. Concentration as a function of time for sample problem #8.

4. REFERENCES

- Baca, R. G., S. O. Magnuson, H. D. Nguyen, and P. Martin, 1992, *A Modeling Study of Waterflow in the Vadose Zone Beneath the Radioactive Waste Management Complex, Idaho National Engineering Laboratory*, EGG-GEO-10068, Idaho Falls, ID, January.
- Baes, C. F. III and R. D. Sharp, 1983, "A Proposal for Estimation of Soil Leaching and Leaching Constants for Use in Assessment Models," *Journal of Environmental Quality*, 12, 1, pp. 17-28.
- Bishop, C. W., 1991, "Hydrologic Properties of Vesicular Basalt," MS Thesis, University of Arizona, Tucson, AZ.
- Code of Federal Regulations, 40 CFR 141, Title 40, "Protection of the Environment," Part 141, National Primary Drinking Water Regulations, Amended by 56 FR 32113, July 15, 1991.
- Codell, R. B., K. T. Key, and G. Whelan, 1982, *A Collection of Mathematical Models for Dispersion in Surface Water and Groundwater*, NUREG-0868.
- DOE (U.S. Department of Energy), 1992, *Track 1 Sites: Guidance for Assessing Low Probability Hazard Sites at INEL*, DOE/ID-10340(92), Revision 1, July.
- DOE, 1994, *Track 2 Sites: Guidance for Assessing Low Probability Hazard Sites at INEL*, DOE/ID-10389, Revision 6, July.
- EPA (U.S. Environmental Protection Agency), 1989, *Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part A)*, EPA/540/1-89/002, December.
- Gilbert, T. L., C. Yo, Y. C. Yuan, A. J. Zielen, M. J. Jusko, and A. Wallo III, 1989, *A Manual for Implementing Residual Radioactive Material Guidelines*, ANL/ES-160, Argonne National Laboratory.
- Killogh, G. G., R. E. Moore, and J. E. Till, 1991, "DECHEM Version 3.02: An All Pathway Assessment Procedure for Determining Acceptable Concentrations of Chemicals in Soil of Waste Sites," Radiological Assessment Corporation, Rt 2 Box 122, Neeses, SC 29107.
- Kozak, M. W., M. S. Y. Chu, and C. P. Harlan, 1990, *Performance Assessment Methodology for Low-Level Waste Facilities*, NUREG/CR-5532.
- McElroy, D. L. and J. M. Hubbell, 1990, *Hydrologic and Physical Properties of Sediments at the Radioactive Waste Management Complex*, EGG-BG-9147, Idaho National Engineering Laboratory, EG&G Idaho, Inc., Idaho Falls, ID.
- Press, W. H., B. P. Flannery, S. A. Teukolsky, and W. T. Vetterling, 1986, *Numerical Recipes: The Art of Scientific Computing*, Cambridge: Cambridge University Press.

- Robertson, J. B., 1974, *Digital Modeling of Radioactive and Chemical Waste Transport in the Snake River Plain Aquifer at the National Reactor Testing Station, Idaho*, U.S. Geological Survey Open File Report No. IDO-22054, Water Resources Division, Idaho Falls, ID.
- Rood, A. S., 1992, *GWSCREEN: A Semi-Analytical Model for Assessment of the Groundwater Pathway from Surface or Buried Contamination, Theory and User's Manual*, EGG-GEO-10158, March.
- Rood, A. S., R. C. Arnett, and J. T. Barraclough, 1989, *Contaminant Transport in the Snake River Plain Aquifer: Phase I, Part 1: Simple Analytical Models of Individual Plumes*, EGG-ER-8623, Idaho National Engineering Laboratory, EG&G Idaho, Inc., Idaho Falls, ID, May.
- Scrabble, K. W., C. S. French, G. Chabot, and A. Major, 1974, "A General Equation for the Kinetics of Linear First Order Phenomena and Suggested Applications," *Health Physics*, 27, pp. 155-157.
- Seitz, R. R., A. S. Rood, G. A. Haris, and M. Kotecki, 1991, *Sample Application of Sensitivity/Uncertainty Analysis Techniques to a Groundwater Transport Problem*, DOE/LLW-108, National Low Level Waste Management Program.
- van Genuchten, M. Th., 1978, *Calculating the Unsaturated Hydraulic Conductivity with a New Closed-Form Analytical Model*, 78-WR-08, Water Resources Program, Department of Civil Engineering, Princeton University, Princeton, NJ.
- Whelan, G., D. L. Streng, J. G. Droppo, B. L. Steelman, and J. W. Buck, 1987, *The Remedial Action Priority System (RAPS): Mathematical Formulations*, DOE/RL/87-09, Pacific Northwest Laboratories.

APPENDIX A: GWSCREEN SAMPLE PROBLEMS

APPENDIX A: GWSCREEN SAMPLE PROBLEMS

The input and output files for nine sample problems are presented in this appendix. Each sample problem was intended to demonstrate a different aspect of the GWSCREEN code. The sample problems were run on an IBM® PS/2 486 SX personal computer. Code execution time ranged from about 1 to 55 seconds. Version 2.4 was used in sample problems 4b and 7c. The remaining sample problems were run with version 2.03. A brief description of each problem follows.

Sample Problem 1:

Limiting soil concentration for ^{239}Pu in a 50 m x 50 m x 2.5 m source volume located in an environment similar to eastern Idaho and using the default transport parameters presented in DOE/ID-1-340(92), Revision 1. The maximum allowable groundwater concentration was based on a carcinogenic target risk of 1×10^{-6} and was given by

$$C_{\max} = \frac{1 \times 10^{-6}}{\text{SF} \times \text{I} \times \text{ED} \times \text{EF}}$$

where

$C_{\max}$ = maximum allowable groundwater concentration averaged over the consumption period (pCi L⁻¹)

SF = slope factor (pCi⁻¹)

I = intake rate (2 L d⁻¹)

ED = exposure duration (30 years)

EF = exposure frequency (350 d y⁻¹).

The slope factor for ^{239}Pu is 3.1×10^{-11} pCi⁻¹ therefore the maximum allowable groundwater concentration is

$$\frac{1 \times 10^{-6}}{(3.1 \times 10^{-11} \text{ pCi}^{-1}) (2 \text{ L/d}) (30 \text{ y}) (350 \text{ d/y})} = 1.5 \times 10^{-12} \text{ Ci L}^{-1}.$$

When performing these calculations for radionuclides that decay to other radionuclides (progeny), the risks due to the progeny must also be considered. Plutonium 239 decays to ^{235}U with a half-life of 2.41×10^4 years. Uranium 235 has a long half-life (7.04×10^8 years) and therefore little of this isotope will decay during the time period of interest. For this example, only the ^{235}U decay chain member will be considered. The maximum allowable groundwater concentration for ^{235}U based on carcinogenic risk (slope factor = 1.3×10^{-10} pCi⁻¹) was 0.37 pCi L⁻¹. The maximum parent groundwater concentration adjusted for n number of decay chain members is given by the following.

$$C_L = \frac{CA_{\text{parent}}}{\sum_{i=1}^n \frac{CA_i}{MCL_i}} \quad (\text{A-1})$$

where

MCL_i = maximum contaminant limit for i^{th} member of the decay chain ($Ci\ L^{-1}$)

CA_{parent} = maximum parent groundwater concentration averaged over the consumption period ($Ci\ L^{-1}$)

CA_i = maximum groundwater concentration for the i^{th} decay chain member averaged over the consumption period ($Ci\ L^{-1}$)

I = water intake rate ($L\ d^{-1}$)

C_L = maximum allowable *parent* groundwater concentration for progeny ($Ci\ L^{-1}$).

This value is printed in the output file under the heading, "RESULTS OF CALCULATION" and "MAXIMUM PARENT CONCENTRATION ADJUSTED FOR PROGENY". The ^{235}U progeny had little impact on the results since very little activity was ingrown during the period of transit from the source to receptor.

Sample Problem 2: Maximum Permissible Concentration .

Limiting soil concentration for Sr-90 in a 25 m x 25 m x 1.0 m source volume located in an environment similar to eastern Idaho and using the default parameters presented in DOE/ID-1-340(92), Revision 1. The limiting soil concentration was based on the maximum permissible concentration in a community drinking water systems described in 40 CFR 141, Subpart B, Table A, of 8 pCi L^{-1} .

Sample Problem 3a.

Limiting soil concentration for a mercury carbonate (Hg_2CO_3) source in a 25 m x 25 m x 1.0 m source volume located in an environment similar to eastern Idaho and using the default parameters presented in DOE/ID-1-340(92), Revision 1. The limiting soil concentration was based on subchronic noncarcinogenic toxicity (1 year exposure period) using an RfD value of 3.0E4 mg/kg/day. Sample problem 3 illustrate the solubility release model in GWSCREEN. In this example, the solubility limit was provided as input. This value was based on the carbonate form of mercury and was obtained from the CRC Handbook of Chemistry and Physics. Also, an estimate of the source mass was provided as input. GWSCREEN was run in the "backwards" direction for this problem (Example problems 1 and 2 were also run in the backwards direction). That is, the limiting soil concentration and limiting contaminant mass were calculated. "Backward" calculations are performed in GWSCREEN by setting the KFLAG variable to 1.

A limiting soil contaminant mass of 2.4×10^8 and a limiting soil concentration of 256 mg kg^{-1} were calculated for this example. This mass was less than the estimated contaminant mass in the source volume of 2.81×10^8 mg (equivalent to 300 ppm soil concentration) and therefore the site would require further evaluation or cleanup. However, at the bottom of the output, a warning statement was printed stating that the limiting soil mass exceeded the solubility limited source mass. This statement indicates the following:

- The initial concentration of the leachate exceeds the solubility limit of the contaminant.
- Release of the contaminant from the source volume is controlled by the solubility limit of the contaminant.

At this point in the analysis, a forward calculation should be performed and the maximum groundwater concentration should be evaluated for risk. The forward calculation and risk calculation are illustrated in Example 3b.

Sample Problem 3b.

Concentration verses time for the 281 kg mercury carbonate source described in problem 3a. Note that the contaminant mass, QI, exceeds the solubility limited mass calculated in sample problem 3a and therefore, the release is solubility limited. Contaminant flux to the unsaturated zone is constant until the source mass is depleted to the solubility limited mass of 4.23×10^6 mg. After that, release from the source volume occurs by first order leaching. The solubility limited release time was 9841 years.

In this example, concentration as a function of time is printed to the output file following the output of the input parameter values and values calculated in the SOURCE subroutine. The first column lists the time from the start of waste emplacement. In the second and third columns, cumulative source flux and cumulative aquifer flux from the time of waste emplacement are printed. The forth and fifth columns contain the instantaneous aquifer flux and the groundwater concentration. The "DOSE.OUT" file is also output. In this file, the health effects (hazard quotients in this case) are output for each time period specified by the input file.

Sample Problem 4a.

Limiting soil concentration for 2,3,7,8-tetrachlorodibenzo-p-dioxine (TCDD) in a remediated storage site in Biloxi, Mississippi. The limiting soil concentration was based on a carcinogenic slope factor of $1.5E5$ (mg/kg/day)⁻¹. In this example, the optional loss rate constant for the source was employed. Data from the literature (Schaum, 1984) indicate that TCDD degrades in soil with a half life of around 100 years and near the surface with a half life of 12 years. Degradation rates of TCDD in groundwater were unknown. Since degradation only affects TCDD in the source compartment (soil), the half life of TCDD in soil (100 years) was converted to a first order rate constant using Equation 4. This value was set equal to the code variable, RC2 and the contaminant half life was set equal to infinity (by setting THALF=0.0). The K_d value used in the example was based on an organic partitioning coefficient (K_{oc}) of 3.3×10^6 mL g⁻¹ and a fraction of organic carbon of 5.0×10^{-4} . A well screen thickness of 5 m was selected.

Sample Problem 4b

Limiting soil concentration for 2,3,7,8-tetrachlorodibenzo-p-dioxine (TCDD) in a remediated storage site in Biloxi, Mississippi for a 5 m well screen thickness in a 25 m thick aquifer. Version 2.4 is used in this simulation, setting ITYPE=2 for the vertically averaged 3D solution. Note that average concentration is less than what was calculated in problem 4a because the contaminant is allowed to disperse in the *total* thickness of the aquifer. In problem 4a, the contaminant is only allowed to disperse in the first 5 m of the aquifer.

Sample Problem 5

Limiting ²²⁶Ra soil concentration for a hypothetical uranium mill tailings pile containing an

average ^{226}Ra concentration of 500 pCi g^{-1} . The limiting soil concentration was based on a maximum proposed groundwater concentration limit of 20 pCi L^{-1} for ^{226}Ra and (40 CRF 141) and 1.0 pCi L^{-1} for ^{210}Pb (proposed). Note that the maximum ^{226}Ra concentration in groundwater was adjusted for the ^{210}Pb progeny and is lower than 20 pCi/L (see Equation A-1).

Sample Problem 6a

Limiting soil concentration for a Ni-59 source at a hypothetical site. The limiting soil mass exceeds the solubility limit of Ni-59 therefore, a warning statement is printed to the output file. Limiting soil concentration was based on an annual committed dose equivalent of 4 mrem/y .

Sample Problem 6b

Concentration versus time for a 1000 Ci inventory (11 nCi/g) Ni-59 source at a hypothetical site. The release is solubility limited for a time period given by Equation 14. The maximum dose can be computed from the maximum concentration ($6.5\text{E-}9 \text{ Ci L}^{-1}$) by multiplying by an annual water ingestion rate and dose conversion factor.

$$\text{Dose} = 6.5\text{E-}9 \text{ Ci/L} \times 730 \text{ L/y} \times 200 \text{ rem/Ci} \times 1000 \text{ mrem/rem} = 0.95 \text{ mrem/y}.$$

This value is computed and printed in the DOSE.OUT file. Since this value is below the 4 mrem y^{-1} criteria, then the hypothetical inventory would be considered acceptable in terms of groundwater protection.

Sample Problem 7a

Limiting pond effluent concentration for a hypothetical percolation pond receiving $4000 \text{ m}^3 \text{ y}^{-1}$ liquid effluent containing $0.25 \mu\text{Ci L}^{-1}$ of ^{90}Sr . The output for the pond model includes the limiting pond effluent concentration and the contaminant mass in the pond sediments at the end of the operational lifetime of the pond. In this example, the unsaturated thickness was set very thin so that transit time from the base of the pond sediments to the top of the aquifer was insignificant. Since residence time in the unsaturated zone is low, the flux leaving the source compartment is essentially equal to the flux to the aquifer.

Sample Problem 7b

Concentration as a function of time for the pond described in problem 7a. In this example, the tabulated source function was used. The mass flux from the pond as a function of time was calculated using Equation 19 for time periods less than 30 years and Equation 9 for time periods > 30 years. These data were calculated on a spreadsheet and exported to an ASCII file. This file was then appended to the end of the GWSCREEN input file. Note that the flux to the aquifer after 32 years (95.7 Ci y^{-1}) does not equal the mass input rate to the pond (100 Ci y^{-1}) indicating that the pond sediment compartment has not equilibrated during the 30 year operational period. The aquifer flux after 30 years (0.62 Ci y^{-1}) is significantly lower than the flux at 30 years and is a result of the lower percolation rate after the operation of the pond is terminated.

Sample Problem 7c

Limiting pond effluent concentration for a hypothetical percolation pond receiving $4000 \text{ m}^3 \text{ y}^{-1}$ liquid effluent containing $0.25 \text{ } \mu\text{Ci L}^{-1}$ of ^{90}Sr . This is basically the same problem as described in problem 7a however, the limiting pond effluent concentration was based on carcinogenic risk instead of radiological dose and the vertically averaged 3D solution in Version 2.4 was used instead of the 2D solution employed in Version 2.03. In this example, the aquifer thickness and the well screen thickness were set equal to one another. Under these conditions, the concentration calculated with the vertically averaged 3D solution should be the same as the concentration calculated using the 2D vertically averaged solution. The GWSCREEN output reports maximum concentrations and average concentrations. Average concentrations were not comparable because the averaging times used in sample problem 7a and 7c were different. Maximum concentrations are comparable and these values were the same for problem 7a and 7c.

Sample Problem 8

Limiting soil concentration for a ^{241}Pu source in an environment similar to eastern Idaho. The limiting soil concentration is based carcinogenic risk. This example shows the importance of including radioactive progeny in the assessment. The risk resulting from ^{241}Pu alone is insignificant ($6.0\text{E-}12$). However the risk from the progeny, ^{241}Am ($2.4\text{E-}6$), is significant and the site may be in need of further evaluation. Also note the discussion in Section 3.3.3 of this document concerning this example.

Sample Problem 9

Limiting soil concentration for a $25 \text{ m} \times 15 \text{ m}$ hydrocarbon spill containing benzene. The optional loss rate constant (λ_o) was used to model volatilization losses from the source volume. Volatilization loss from groundwater was not accounted for. The volatilization rate constant ($1.13\text{E-}2 \text{ y}^{-1}$) and the degradation half life (0.95 years) were calculated using a methodology and data obtained in Ünlü (1992). Limiting soil concentration was based the carcinogenic risk associated with benzene exposure and sorption coefficients were based on a K_{oc} value of 83 mL g^{-1} and a foc of 0.003. Note: The volatilization rate constant is dependent on the geometry of the source and the type of hydrocarbon spilled. The volatilization rate constant should not be used with other problems since it is a site and scenario specific value.

REFERENCES

- DOE (U.S. Department of Energy), 1992, *Track 1 Sites: Guidance for Assessing Low Probability Hazard Sites at INEL*, DOE/ID-10340(92), Revision 1, July.
- Schaum, J., 1984, *Risk Analysis of TCDD Contaminated Soil*. Office of Research and Development, U. S. Environmental Protection Agency, Washington DC PB85-145704.
- Ünlü, K., M.W. Kemblowski, J.C. Parker, D. Stevent, P.K. Chong, and I. Kamil. 1992, " A Screening Model for Effects of Land-Disposed Wastes on Groundwater Quality". *Journal of Contaminant Hydrology* 11:27-49.

Sample Problem 1: Input File

```
EXAMPLE PROBLEM #1; Pu-239 for GWSCREEN Ver 2.03. INCLUDE U-235 PROGENY
1 1 KFLAG NPROG
1 INTIME
50.0 50.0 2.50 AL WA THICKS
1.0 0.35 0.090 PERC THETAS THETAU
1.5 22.0 0.0 RHOS zKDS RC2
1.9 22.0 RHOU zKDU
2.41E+04 7.04E8 THALF(1)
1.00 239.0 7.11E6 QI ZMW SL
1.9 0.10 22.0 6.0 RHOA PHI zKDA
1.0E-3 5.0E-4 570.0 AX AY VX
15.0 50.0 THICK DEPTH
3 1 IMODE IMODEL
1. 1. 1. 1. 1. RMI TOPER PNDFLX THETAP EVAP WAEFF
1.5E-12 3.7E-13 DCF-crad-radmax-NRADMAX-SFACTOR-RFD
0.0, 0. XD YD
70.0 2.555E+04 2.0 350. 70. 0.004 1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
1 6 11 1.0E-2 ISOLVE,JMAX,EPS
2 NTIMES
```

Output File

```
TIME OF RUN 16:10:50.5
DATE OF RUN 06/10/94
INPUT FILE NAME: pb-1.par
OUTPUT FILE NAME: pb-1.out
```

===== ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of Energy, Office of Environmental Restoration and Waste Management, DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570. This material is subject to a limited government license: Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory, all rights reserved. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe on privately owned rights. Subroutines GOLDEN, QSIMP, QGAUS, and TRAPZD are Copyright (C) 1992, Numerical Recipes Software. Reproduced by permission from the book, Numerical Recipes, Cambridge University Press.

```
*****
*
* This output was produced by the model: *
*
* GWSCREEN *
* Version Control Copy, Version 2.03 *
* A semi-analytical model for the assessment *
* of the groundwater pathway from the leaching *
* of surficial and buried contamination and *
* release of contaminants from percolation ponds *
* 03-08-94 *
* Arthur S. Rood *
* Idaho National Engineering Laboratory *
* EG&G Idaho Inc. *
* Subsurface and Environmental Modeling Unit *
* PO Box 1625 *
* Idaho Falls, Idaho 83415 *
*****
```

```
>>> TITLE OF PROJECT:
EXAMPLE PROBLEM #1; Pu-239 for GWSCREEN Ver 2.0. INCLUDE U-235 PROGENY
```

```
GAUSSIAN QUADRATURE SOLUTION
MODEL OPTIONS
IMODE: 3
KFLAG: 1 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC
```

IMODEL:1 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION

>>> INPUT DATA

NUMBER OF RADIOACTIVE PROGENY	1
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)	5.00E+01
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)	5.00E+01
THICKNESS OF SOURCE (m)	2.50E+00
PERCOLATION RATE (darcy vel m/y)	1.00E+00
VOLUMETRIC WATER CONTENT IN SOURCE	3.50E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE	9.00E-02
BULK DENSITY AT SOURCE (g/cm**3)	1.50E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)	2.20E+01
BULK DENSITY IN UNSAT ZONE (g/cm**3)	1.90E+00
UNSATURATED ZONE THICKNESS (m)	5.00E+01
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)	2.20E+01
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1)	0.00E+00
INITIAL MASS OR ACTIVITY (mg or Ci)	1.00E+00
MOLECULAR WEIGHT (g/mole)	2.39E+02
SOLUBILITY LIMIT (mg/L)	7.11E+06
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)	2.41E+04 7.04E+08
BULK DENSITY OF AQUIFER (g/cm**3)	1.90E+00
POROSITY OF AQUIFER	1.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)	2.20E+01 6.00E+00
DISPERSIVITY X DIRECTION (m)	1.00E-03
DISPERSIVITY Y DIRECTION (m)	5.00E-04
PORE VELOCITY (m/y)	5.70E+02
WELL SCREEN THICKNESS (m)	1.50E+01
DISTANCE TO RECEPTOR ALONG X AXIS (m)	0.00E+00
DISTANCE TO RECEPTOR ALONG Y AXIS (m)	0.00E+00
LIMITING RADIONUCLIDE GW CONCENTRATION (Ci/L)	1.50E-12 3.70E-13
UNITS OF CONTAMINANT	Ci

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

LIMITING SOIL CONCENTRATION CALCULATION

>>> INITIAL ACTIVITY CONVERTED TO MASS (mg) 1.61E+04

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

LEACH RATE CONSTANT (1/y)	1.1994E-02
UNSATURATED PORE VELOCITY (m/y)	1.1111E+01
DECAY CONSTANT(S) (1/y)	2.8761E-05 9.8458E-10
RETARDATION FACTOR(S) (SATURATED)	4.1900E+02 1.1500E+02
RETARDATION FACTOR (UNSATURATED)	4.6544E+02
SOLUBILITY LIMITED MASS (mg)	1.4820E+15
SOLUBILITY LIMITED ACTIVITY (Ci)	9.2058E+10
TRANSIT TIME IN UNSAT ZONE (years)	2.0945E+03
FRACTION DECAYED DURING UNSAT TRANSPORT	5.8462E-02

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

INTEGRATION TIME (years)	1
BODY WEIGHT (kg)	7.000E+01
AVERAGING TIME (days)	2.555E+04
WATER INTAKE RATE (L/d)	2.000E+00
EXPOSURE FREQUENCY (days/year)	3.500E+02
EXPOSURE DURATION (years)	7.000E+01
RADIOLOGICAL DOSE LIMIT (rem/y)	4.000E-03
CARCINOGENIC RISK CRITERIA	1.000E-06
HAZARD QUOTIENT	1.000E+00

>>> RESULTS OF CALCULATIONS

MAXIMUM RADIONUCLIDE CONCENTRATION LIMIT CALCULATION

DECAY-INGROWTH FACTORS 9.4104E-01 2.0185E-06

LIMITING PARENT GW CONCENTRATION ADJUSTED FOR PROGENY = 1.50E-12 Ci/L

NOTE: PROGENY CONCENTRATIONS ARE REPORTED AT THE TIME OF THE MAXIMUM PARENT CONCENTRATION

MAXIMUM GW CONCENTRATION FOR MBR #1: 1.18E-10 Ci/L

AVERAGE GW CONCENTRATION FOR MBR #1: 1.18E-10 Ci/L

MAXIMUM GW CONCENTRATION FOR MBR #2: 9.23E-16 Ci/L

AVERAGE GW CONCENTRATION FOR MBR #2: 9.23E-16 Ci/L

PEAK TIME (y): 2.113015E+03
 LIMITING SOIL CONCENTRATION (Ci/m**3): 2.031E-06
 LIMITING SOIL CONCENTRATION (Ci/kg): 1.354E-09
 LIMITING INVENTORY IN SOIL (Ci): 1.270E-02
 LIMITING INVENTORY IN SOIL (mg): 2.044E+02
 SPECIFIC ACTIVITY (Ci/g): 6.212E-02
 EXECUTION TIME (seconds) 0

Sample Problem 2: Input File

EXAMPLE PROBLEM #2; Sr-90 limit based on MCL of 8 pCi/L in 40 CFR 141 Ver 2.03

1 0	KFLAG
30	INTIME
25.0 25.0 1.00	AL WA THICKS
1.0 0.35 0.090	PERC THETAS THETAU
1.5 24.0 0.0	RHOS zKDS RC2
1.9 24.0	RHOJ zKDU
28.5	THALF
1.0 90.0 1.0e6	QI ZMW SL
2.0 0.10 24.0	RHOA PHI zKDA
1.0e-3 5.0e-4 570.	AX AY VX
15.0 5.0	THICK DEPTH
3 1	IMODE IMODEL
1. 1. 1. 1. 25.	RMI TOPER PNDFLX THETAP EVAP
1.44e-12	DCF-RADMAX-NRADMAX-SFACTOR-RFD
0.0, 0.	XD YD
70.0 2.555E+04 2.0 350. 30. 0.004	1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
1 6 11 1.0E-2	ISOLVE JMAX EPS

Output File

TIME OF RUN 14:17:13.6

DATE OF RUN 06/13/94

INPUT FILE NAME: pb-2.par

OUTPUT FILE NAME: pb-2.out

===== ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of Energy, Office of Environmental Restoration and Waste Management, DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570. This material is subject to a limited government license: Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory, all rights reserved. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe on privately owned rights. Subroutines GOLDEN, QSIMP, QGAUS, and TRAPZD are Copyright (C) 1992, Numerical Recipes Software. Reproduced by permission from the book, Numerical Recipes, Cambridge University Press.

 * This output was produced by the model: *
 * *
 * GWSCREEN *
 * Version Control Copy, Version 2.03 *
 * A semi-analytical model for the assessment *
 * of the groundwater pathway from the leaching *
 * of surficial and buried contamination and *
 * release of contaminants from percolation ponds *
 * 03-08-94 *
 * Arthur S. Rood *
 * Idaho National Engineering Laboratory *
 * EG&G Idaho Inc. *
 * Subsurface and Environmental Modeling Unit *
 * PO Box 1625 *
 * Idaho Falls, Idaho 83415 *

>>> TITLE OF PROJECT:
EXAMPLE PROBLEM #2; Sr-90 limit based on MCL of 8 pCi/L in 40 CFR 141 Ver 2.03

GAUSSIAN QUADRATURE SOLUTION

MODEL OPTIONS

IMODE: 3

KFLAG: 1 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC

IMODEL:1 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION

>>> INPUT DATA

NUMBER OF RADIOACTIVE PROGENY	0
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)	2.50E+01
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)	2.50E+01
THICKNESS OF SOURCE (m)	1.00E+00
PERCOLATION RATE (darcy vel m/y)	1.00E+00
VOLUMETRIC WATER CONTENT IN SOURCE	3.50E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE	9.00E-02
BULK DENSITY AT SOURCE (g/cm**3)	1.50E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)	2.40E+01
BULK DENSITY IN UNSAT ZONE (g/cm**3)	1.90E+00
UNSATURATED ZONE THICKNESS (m)	5.00E+00
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)	2.40E+01
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1)	0.00E+00
INITIAL MASS OR ACTIVITY (mg or Ci)	1.00E+00
MOLECULAR WEIGHT (g/mole)	9.00E+01
SOLUBILITY LIMIT (mg/L)	1.00E+06
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)	2.85E+01
BULK DENSITY OF AQUIFER (g/cm**3)	2.00E+00
POROSITY OF AQUIFER	1.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)	2.40E+01
DISPERSIVITY X DIRECTION (m)	1.00E-03
DISPERSIVITY Y DIRECTION (m)	5.00E-04
PORE VELOCITY (m/y)	5.70E+02
WELL SCREEN THICKNESS (m)	1.50E+01
DISTANCE TO RECEPTOR ALONG X AXIS (m)	0.00E+00
DISTANCE TO RECEPTOR ALONG Y AXIS (m)	0.00E+00
LIMITING RADIONUCLIDE GW CONCENTRATION (Ci/L)	1.44E-12
UNITS OF CONTAMINANT	Ci

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

LIMITING SOIL CONCENTRATION CALCULATION

>>> INITIAL ACTIVITY CONVERTED TO MASS (mg) 7.17E+00

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

LEACH RATE CONSTANT (1/y)	2.7510E-02
UNSATURATED PORE VELOCITY (m/y)	1.1111E+01
DECAY CONSTANT(S) (1/y)	2.4321E-02
RETARDATION FACTOR(S) (SATURATED)	4.8100E+02
RETARDATION FACTOR (UNSATURATED)	5.0767E+02
SOLUBILITY LIMITED MASS (mg)	2.2719E+13
SOLUBILITY LIMITED ACTIVITY (Ci)	3.1690E+12
TRANSIT TIME IN UNSAT ZONE (years)	2.2845E+02
FRACTION DECAYED DURING UNSAT TRANSPORT	9.9614E-01

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

INTEGRATION TIME (years)	30
BODY WEIGHT (kg)	7.000E+01
AVERAGING TIME (days)	2.555E+04
WATER INTAKE RATE (L/d)	2.000E+00
EXPOSURE FREQUENCY (days/year)	3.500E+02
EXPOSURE DURATION (years)	3.000E+01
RADIOLOGICAL DOSE LIMIT (rem/y)	4.000E-03
CARCINOGENIC RISK CRITERIA	1.000E-06
HAZARD QUOTIENT	1.000E+00

>>> RESULTS OF CALCULATIONS

MAXIMUM RADIONUCLIDE CONCENTRATION LIMIT CALCULATION

LIMITING PARENT GW CONCENTRATION ADJUSTED FOR PROGENY = 1.44E-12 Ci/L
 MAXIMUM GW CONCENTRATION FOR MBR #1: 1.66E-12 Ci/L
 AVERAGE GW CONCENTRATION FOR MBR #1: 1.02E-12 Ci/L
 PEAK TIME (y): 2.390082E+02
 LIMITING SOIL CONCENTRATION (Ci/m**3): 2.258E-03
 LIMITING SOIL CONCENTRATION (Ci/kg): 1.505E-06
 LIMITING INVENTORY IN SOIL (Ci): 1.411E+00
 LIMITING INVENTORY IN SOIL (mg): 1.012E+01
 SPECIFIC ACTIVITY (Ci/g): 1.395E+02
 EXECUTION TIME (seconds) 0

Sample Problem 3a: Input File

EXAMPLE #3A, Hg (Hg2CO3);30 year chronic exposure;50 m interbeds;Flood Scenario
 1 0 KFLAG NPROG
 30 INTIME
 25.0 25.0 1.00 AL WA THICKS
 1.0 0.40 0.40 PERC THETAS THETAU
 1.5 100.0 0.0 RHOS zKDS RC2
 1.9 100.0 RHOU zKDU
 0.0E00 THALF
 2.81e8 461.0 4.5E-02 QI ZMW SL (based on Hg2CO3 form) 1.125e8
 1.9 0.10 100.0 RHOA PHI zKDA
 9.00 4.000 570. AX AY VX
 15.0 50.0 THICK DEPTH
 6 1 IMODE IMODEL
 1. 1. 1. 1. 1. 25. RMI TOPER PNDFLX THETAP EVAP
 3.0e-04 DCF-RADMAX-NRADMAX-SFACTOR-RFD
 12.5, 0. XD YD
 70.0 25550. 2.0 350. 30.0 0.004 1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
 1 6 11 1.0E-2 ISOLVE,JMAX,EPS

Output File

TIME OF RUN 14:17:15.0
 DATE OF RUN 06/13/94
 INPUT FILE NAME: pb-3a.par
 OUTPUT FILE NAME: pb-3a.out

ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of Energy, Office of Environmental Restoration and Waste Management, DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.
 This material is subject to a limited government license:
 Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory, all rights reserved. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe on privately owned rights. Subroutines GOLDEN, QSIMP, QGAUS, and TRAP2D are Copyright (C) 1992, Numerical Recipes Software. Reproduced by permission from the book, Numerical Recipes, Cambridge University Press.

 *
 * This output was produced by the model: *
 *
 * GWSCREEN *
 * Version Control Copy, Version 2.03 *
 * A semi-analytical model for the assessment *
 * of the groundwater pathway from the leaching *
 * of surficial and buried contamination and *
 * release of contaminants from percolation ponds *
 * 03-08-94 *
 * Arthur S. Rood *
 * Idaho National Engineering Laboratory *
 * EG&G Idaho Inc. *
 * Subsurface and Environmental Modeling Unit *

* PO Box 1625 *
 * Idaho Falls, Idaho 83415 *

>>> TITLE OF PROJECT:
 EXAMPLE #3A, Hg (Hg2CO3);30 year chronic exposure;50 m interbeds;Flood Scenari

GAUSSIAN QUADRATURE SOLUTION

MODEL OPTIONS

IMODE: 6

KFLAG: 1 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC

IMODEL:1 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION

>>> INPUT DATA

NUMBER OF RADIOACTIVE PROGENY	0
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)	2.50E+01
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)	2.50E+01
THICKNESS OF SOURCE (m)	1.00E+00
PERCOLATION RATE (darcy vel m/y)	1.00E+00
VOLUMETRIC WATER CONTENT IN SOURCE	4.00E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE	4.00E-01
BULK DENSITY AT SOURCE (g/cm**3)	1.50E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)	1.00E+02
BULK DENSITY IN UNSAT ZONE (g/cm**3)	1.90E+00
UNSATURATED ZONE THICKNESS (m)	5.00E+01
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)	1.00E+02
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1)	0.00E+00
INITIAL MASS OR ACTIVITY (mg or Ci)	2.81E+08
MOLECULAR WEIGHT (g/mole)	4.61E+02
SOLUBILITY LIMIT (mg/L)	4.50E-02
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)	1.00E+38
BULK DENSITY OF AQUIFER (g/cm**3)	1.90E+00
POROSITY OF AQUIFER	1.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)	1.00E+02
DISPERSIVITY X DIRECTION (m)	9.00E+00
DISPERSIVITY Y DIRECTION (m)	4.00E+00
PORE VELOCITY (m/y)	5.70E+02
WELL SCREEN THICKNESS (m)	1.50E+01
DISTANCE TO RECEPTOR ALONG X AXIS (m)	1.25E+01
DISTANCE TO RECEPTOR ALONG Y AXIS (m)	0.00E+00
NON-CARCINOGENIC REFERENCE DOSE Rfd (mg/kg/d)	3.00E-04
UNITS OF CONTAMINANT	mg

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

LIMITING SOIL CONCENTRATION CALCULATION

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

LEACH RATE CONSTANT (1/y)	6.6489E-03
UNSATURATED PORE VELOCITY (m/y)	2.5000E+00
DECAY CONSTANT(S) (1/y)	0.0000E+00
RETARDATION FACTOR(S) (SATURATED)	1.9010E+03
RETARDATION FACTOR (UNSATURATED)	4.7600E+02
SOLUBILITY LIMITED MASS (mg)	4.2300E+06
SOLUBILITY LIMITED ACTIVITY (Ci)	0.0000E+00
TRANSIT TIME IN UNSAT ZONE (years)	9.5200E+03
FRACTION DECAYED DURING UNSAT TRANSPORT	0.0000E+00

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

INTEGRATION TIME (years)	30
BODY WEIGHT (kg)	7.000E+01
AVERAGING TIME (days)	2.555E+04
WATER INTAKE RATE (L/d)	2.000E+00
EXPOSURE FREQUENCY (days/year)	3.500E+02
EXPOSURE DURATION (years)	3.000E+01
RADIOLOGICAL DOSE LIMIT (rem/y)	4.000E-03
CARCINOGENIC RISK CRITERIA	1.000E-06
HAZARD QUOTIENT	1.000E+00

>>> RESULTS OF CALCULATIONS

```

*****
LIMITING GROUNDWATER CONCENTRATION (mg/L): 2.55E-02
MAXIMUM GROUNDWATER CONCENTRATION (mg/L): 3.01E-02
AVERAGE GROUNDWATER CONCENTRATION (mg/L): 3.00E-02
HAZARD QUOTIENT FOR INPUT MASS: 1.17E+00
PEAK TIME (y): 9.617575E+03
LIMITING SOIL CONCENTRATION (mg/m**3): 3.835E+05
LIMITING SOIL CONCENTRATION (mg/kg): 2.557E+02
LIMITING INVENTORY IN SOIL (mg): 2.397E+08
WARNING !!! THE LIMITING SOIL MASS OF 2.397E+08 mg
EXCEEDS THE SOLUBILITY LIMITED SOURCE MASS OF 4.230E+06 mg
EXECUTION TIME (seconds) 1

```

Sample Problem 3b: Input File

```

EXAMPLE #3b, Hg (Hg2CO3);30 year chronic exposure;50 m interbeds;Flood Scenario
0 0 KFLAG NPROG
30 INTIME
25.0 25.0 1.00 AL WA THICKS
1.0 0.40 0.40 PERC THETAS THETAU
1.5 100.0 0.0 RHOS zKDS RC2
1.9 100.0 RHOu zKDU
0.0E00 THALF
2.81e8 461.0 4.5E-02 QI ZMW SL (based on Hg2CO3 form) 1.125e8
1.9 0.10 100.0 RHOA PHI zKDA
9.00 4.000 570. AX AY VX
15.0 50.0 THICK DEPTH
6 1 IMODE IMODEL
1. 1. 1. 1. 1. 25. RMI TOPER PNDFLX THETAP EVAP
3.0e-04 DCF-RADMAX-RRADMAX-SFACTOR-RFD
12.5, 0. XD YD
70.0 25550. 2.0 350. 30.0 0.004 1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
1 6 11 1.0E-2 ISOLVE,JMAX,EPS
1 ntimes
19000.,1.952e4 ,10. t1 t2 tp

```

Output File

```

TIME OF RUN 14:17:17.6
DATE OF RUN 06/13/94
INPUT FILE NAME: pb-3b.par
OUTPUT FILE NAME: pb-3b.out

```

ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of Energy, Office of Environmental Restoration and Waste Management, DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570. This material is subject to a limited government license: Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory, all rights reserved. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe on privately owned rights. Subroutines GOLDEN, QSIMP, QGAUS, and TRAPZD are Copyright (C) 1992, Numerical Recipes Software. Reproduced by permission from the book, Numerical Recipes, Cambridge University Press.

```

*****
*
*   This output was produced by the model:
*
*   GWScreen
*   Version Control Copy, Version 2.03
*   A semi-analytical model for the assessment
*   of the groundwater pathway from the leaching
*   of surficial and buried contamination and
*   release of contaminants from percolation ponds
*   03-08-94
*

```

```

*           Arthur S. Rood           *
*       Idaho National Engineering Laboratory   •
*           EG&G Idaho Inc.           •
*       Subsurface and Environmental Modeling Unit •
*           PO Box 1625               •
*       Idaho Falls, Idaho 83415       •
*****

```

>>> TITLE OF PROJECT:

EXAMPLE #3b, Hg (Hg2CO3);30 year chronic exposure;50 m interbeds;Flood Scenari

GAUSSIAN QUADRATURE SOLUTION

MODEL OPTIONS

IMODE: 6

KFLAG: 0 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC

IMODEL:1 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION

>>> INPUT DATA

NUMBER OF RADIOACTIVE PROGENY	0
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)	2.50E+01
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)	2.50E+01
THICKNESS OF SOURCE (m)	1.00E+00
PERCOLATION RATE (darcy vel m/y)	1.00E+00
VOLUMETRIC WATER CONTENT IN SOURCE	4.00E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE	4.00E-01
BULK DENSITY AT SOURCE (g/cm**3)	1.50E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)	1.00E+02
BULK DENSITY IN UNSAT ZONE (g/cm**3)	1.90E+00
UNSATURATED ZONE THICKNESS (m)	5.00E+01
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)	1.00E+02
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1)	0.00E+00
INITIAL MASS OR ACTIVITY (mg or Ci)	2.81E+08
MOLECULAR WEIGHT (g/mole)	4.61E+02
SOLUBILITY LIMIT (mg/L)	4.50E-02
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)	1.00E+38
BULK DENSITY OF AQUIFER (g/cm**3)	1.90E+00
POROSITY OF AQUIFER	1.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)	1.00E+02
DISPERSIVITY X DIRECTION (m)	9.00E+00
DISPERSIVITY Y DIRECTION (m)	4.00E+00
PORE VELOCITY (m/y)	5.70E+02
WELL SCREEN THICKNESS (m)	1.50E+01
DISTANCE TO RECEPTOR ALONG X AXIS (m)	1.25E+01
DISTANCE TO RECEPTOR ALONG Y AXIS (m)	0.00E+00
NON-CARCINOGENIC REFERENCE DOSE RfD (mg/kg/d)	3.00E-04
UNITS OF CONTAMINANT	mg

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

LEACH RATE CONSTANT (1/y)	6.6489E-03
UNSATURATED PORE VELOCITY (m/y)	2.5000E+00
DECAY CONSTANT(S) (1/y)	0.0000E+00
RETARDATION FACTOR(S) (SATURATED)	1.9010E+03
RETARDATION FACTOR (UNSATURATED)	4.7600E+02
SOLUBILITY LIMITED MASS (mg)	4.2300E+06
SOLUBILITY LIMITED ACTIVITY (Ci)	0.0000E+00
TRANSIT TIME IN UNSAT ZONE (years)	9.5200E+03
FRACTION DECAYED DURING UNSAT TRANSPORT	0.0000E+00

>>> SOLUBILITY LIMITED RELEASE FOR 9.8407E+03 YEARS

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

INTEGRATION TIME (years)	30
BODY WEIGHT (kg)	7.000E+01
AVERAGING TIME (days)	2.555E+04
WATER INTAKE RATE (L/d)	2.000E+00
EXPOSURE FREQUENCY (days/year)	3.500E+02
EXPOSURE DURATION (years)	3.000E+01
RADIOLOGICAL DOSE LIMIT (rem/y)	4.000E-03

CARCINOGENIC RISK CRITERIA 1.000E-06
HAZARD QUOTIENT 1.000E+00

>>> RESULTS OF CALCULATIONS

>>> CONCENTRATION VS TIME MODE

TIME (years)	CUMULATIVE SOURCE FLUX (mg)	CUMULATIVE AQUIFER FLUX (mg)	AQUIFER FLUX (mg/year)	GW CONC ... member #1 (mg/m**3)
1.9000E+04	2.8100E+08	2.6663E+08	2.8125E+04	8.8504E-01
1.9010E+04	2.8100E+08	2.6691E+08	2.8125E+04	8.8504E-01
1.9020E+04	2.8100E+08	2.6719E+08	2.8125E+04	8.8504E-01
1.9030E+04	2.8100E+08	2.6747E+08	2.8125E+04	8.8504E-01
1.9040E+04	2.8100E+08	2.6775E+08	2.8125E+04	8.8504E-01
1.9050E+04	2.8100E+08	2.6803E+08	2.8125E+04	8.8504E-01
1.9060E+04	2.8100E+08	2.6831E+08	2.8125E+04	8.8504E-01
1.9070E+04	2.8100E+08	2.6859E+08	2.8125E+04	8.8504E-01
1.9080E+04	2.8100E+08	2.6888E+08	2.8125E+04	8.8504E-01
1.9090E+04	2.8100E+08	2.6916E+08	2.8125E+04	8.8504E-01
1.9100E+04	2.8100E+08	2.6944E+08	2.8125E+04	8.8504E-01
1.9110E+04	2.8100E+08	2.6972E+08	2.8125E+04	8.8504E-01
1.9120E+04	2.8100E+08	2.7000E+08	2.8125E+04	8.8504E-01
1.9130E+04	2.8100E+08	2.7028E+08	2.8125E+04	8.8504E-01
1.9140E+04	2.8100E+08	2.7056E+08	2.8125E+04	8.8504E-01
1.9150E+04	2.8100E+08	2.7084E+08	2.8125E+04	8.8504E-01
1.9160E+04	2.8100E+08	2.7113E+08	2.8125E+04	8.8504E-01
1.9170E+04	2.8100E+08	2.7141E+08	2.8125E+04	8.8504E-01
1.9180E+04	2.8100E+08	2.7169E+08	2.8125E+04	8.8504E-01
1.9190E+04	2.8100E+08	2.7197E+08	2.8125E+04	8.8504E-01
1.9200E+04	2.8100E+08	2.7225E+08	2.8125E+04	8.8504E-01
1.9210E+04	2.8100E+08	2.7253E+08	2.8125E+04	8.8504E-01
1.9220E+04	2.8100E+08	2.7281E+08	2.8125E+04	8.8504E-01
1.9230E+04	2.8100E+08	2.7309E+08	2.8125E+04	8.8504E-01
1.9240E+04	2.8100E+08	2.7338E+08	2.8125E+04	8.8504E-01
1.9250E+04	2.8100E+08	2.7366E+08	2.8125E+04	8.8504E-01
1.9260E+04	2.8100E+08	2.7394E+08	2.8125E+04	8.8504E-01
1.9270E+04	2.8100E+08	2.7422E+08	2.8125E+04	8.8504E-01
1.9280E+04	2.8100E+08	2.7450E+08	2.8125E+04	8.8504E-01
1.9290E+04	2.8100E+08	2.7478E+08	2.8125E+04	8.8504E-01
1.9300E+04	2.8100E+08	2.7506E+08	2.8125E+04	8.8504E-01
1.9310E+04	2.8100E+08	2.7534E+08	2.8125E+04	8.8504E-01
1.9320E+04	2.8100E+08	2.7563E+08	2.8125E+04	8.8504E-01
1.9330E+04	2.8100E+08	2.7591E+08	2.8125E+04	8.8504E-01
1.9340E+04	2.8100E+08	2.7619E+08	2.8125E+04	8.8504E-01
1.9350E+04	2.8100E+08	2.7647E+08	2.8125E+04	8.8504E-01
1.9360E+04	2.8100E+08	2.7675E+08	2.8125E+04	8.8504E-01
1.9370E+04	2.8100E+08	2.7702E+08	2.6441E+04	8.8275E-01
1.9380E+04	2.8100E+08	2.7728E+08	2.4740E+04	8.7049E-01
1.9390E+04	2.8100E+08	2.7752E+08	2.3148E+04	8.5902E-01
1.9400E+04	2.8100E+08	2.7774E+08	2.1659E+04	8.4829E-01
1.9410E+04	2.8100E+08	2.7795E+08	2.0266E+04	8.1644E-01
1.9420E+04	2.8100E+08	2.7815E+08	1.8962E+04	7.8640E-01
1.9430E+04	2.8100E+08	2.7833E+08	1.7742E+04	7.5829E-01
1.9440E+04	2.8100E+08	2.7850E+08	1.6601E+04	7.3198E-01
1.9450E+04	2.8100E+08	2.7866E+08	1.5533E+04	7.0737E-01
1.9460E+04	2.8100E+08	2.7881E+08	1.4534E+04	6.8048E-01
1.9470E+04	2.8100E+08	2.7895E+08	1.3599E+04	6.4551E-01
1.9480E+04	2.8100E+08	2.7909E+08	1.2724E+04	6.1278E-01
1.9490E+04	2.8100E+08	2.7921E+08	1.1906E+04	5.8215E-01
1.9500E+04	2.8100E+08	2.7932E+08	1.1140E+04	5.5350E-01
1.9510E+04	2.8100E+08	2.7943E+08	1.0423E+04	5.2669E-01
1.9520E+04	2.8100E+08	2.7953E+08	9.7528E+03	5.0160E-01

AVERAGE INTEGRATED CONCENTRATION FROM 1.9000E+04 TO 1.9520E+04 YEARS = 8.35E-01 mg/m**3
MAXIMUM CONCENTRATION(S) mg/m**3
8.85E-01
TIME(S) OF MAXIMUM CONCENTRATIONS (years)
1.90E+04
EXECUTION TIME (seconds) 3

Sample problem 4a: Input File

EXAMPLE PROBLEM #4a TCDD dioxin storage at Biloxi Mississippi Ver 2.03 TITLE

1 0	KFLAG
30	INTIME
250.0 250.0 0.61	AL WA THICKS
0.58 0.125 0.125	PERC THETAS THETAU
2.0 1.65E+03 0.00693	RHOS zKDS RC2
2.0 1.65E+03	RHOU zKDU
0.0E+00	THALF
7.6e4 322.0 2.0E-04	QI ZMW SL
2.0 0.25 1.65E+03	RHOA PHI zKDA
30.9 9.0 50.6	AX AY VX
5.0 1.0	THICK DEPTH
5 1	IMODE IMODEL
1. 1. 1. 1. 1. 250.	RMI TOPER PNDFLX THETAP EVAP
1.50e5	DCF-RADMAX-NRADMAX-SFACTOR-RFD
152.0, 0.	XD YD
70.0 2.555E+04 2.0 350. 30. 0.004 1.0E-6 1.0	BW AT WI EF ED DLIM CRISK HQ
1 6 10 1.0E-2	ISOLVE,JMAX,EPS

Degradation rate of TCDD in soil based on 100 year half time. No degradation assumed for groundwater.
Kd based on Koc of 3.3E6 ml/g and foc of 5E-4

Output File

TIME OF RUN 14:17:21.6
DATE OF RUN 06/13/94
INPUT FILE NAME: pb-4a.par
OUTPUT FILE NAME: pb-4a.out

ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of Energy, Office of Environmental Restoration and Waste Management, DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570. This material is subject to a limited government license: Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory, all rights reserved. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe on privately owned rights. Subroutines GOLDEN, QSIMP, QGAUS, and TRAPZD are Copyright (C) 1992, Numerical Recipes Software. Reproduced by permission from the book, Numerical Recipes, Cambridge University Press.

```

*****
*
*   This output was produced by the model:
*
*           GWSCREEN
*   Version Control Copy, Version 2.03
*   A semi-analytical model for the assessment
*   of the groundwater pathway from the leaching
*   of surficial and buried contamination and
*   release of contaminants from percolation ponds
*           03-08-94
*           Arthur S. Rood
*   Idaho National Engineering Laboratory
*           EG&G Idaho Inc.
*   Subsurface and Environmental Modeling Unit
*           PO Box 1625
*           Idaho Falls, Idaho 83415
*****

```

>>> TITLE OF PROJECT:
EXAMPLE PROBLEM #4a TCDD dioxin storage at Biloxi Mississippi Ver 2.03 TITLE

GAUSSIAN QUADRATURE SOLUTION
MODEL OPTIONS
IMODE: 5
KFLAG: 1 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC

IMODEL:1 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION

>>> INPUT DATA

NUMBER OF RADIOACTIVE PROGENY	0
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)	2.50E+02
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)	2.50E+02
THICKNESS OF SOURCE (m)	6.10E-01
PERCOLATION RATE (darcy vel m/y)	5.80E-01
VOLUMETRIC WATER CONTENT IN SOURCE	1.25E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE	1.25E-01
BULK DENSITY AT SOURCE (g/cm**3)	2.00E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)	1.65E+03
BULK DENSITY IN UNSAT ZONE (g/cm**3)	2.00E+00
UNSATURATED ZONE THICKNESS (m)	1.00E+00
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)	1.65E+03
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1)	6.93E-03
INITIAL MASS OR ACTIVITY (mg or Ci)	7.60E+04
MOLECULAR WEIGHT (g/mole)	3.22E+02
SOLUBILITY LIMIT (mg/L)	2.00E-04
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)	1.00E+38
BULK DENSITY OF AQUIFER (g/cm**3)	2.00E+00
POROSITY OF AQUIFER	2.50E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)	1.65E+03
DISPERSIVITY X DIRECTION (m)	3.09E+01
DISPERSIVITY Y DIRECTION (m)	9.00E+00
PORE VELOCITY (m/y)	5.06E+01
WELL SCREEN THICKNESS (m)	5.00E+00
DISTANCE TO RECEPTOR ALONG X AXIS (m)	1.52E+02
DISTANCE TO RECEPTOR ALONG Y AXIS (m)	0.00E+00
CARCINOGENIC SLOPE FACTOR (mg/kg/d)**-1	1.50E+05
UNITS OF CONTAMINANT	mg

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

LIMITING SOIL CONCENTRATION CALCULATION

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

LEACH RATE CONSTANT (1/y)	2.8812E-04
UNSATURATED PORE VELOCITY (m/y)	4.6400E+00
DECAY CONSTANT(S) (1/y)	0.0000E+00
RETARDATION FACTOR(S) (SATURATED)	1.3201E+04
RETARDATION FACTOR (UNSATURATED)	2.6401E+04
SOLUBILITY LIMITED MASS (mg)	2.5163E+07
SOLUBILITY LIMITED ACTIVITY (Ci)	0.0000E+00
TRANSIT TIME IN UNSAT ZONE (years)	5.6899E+03
FRACTION DECAYED DURING UNSAT TRANSPORT	0.0000E+00

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

INTEGRATION TIME (years)	30
BODY WEIGHT (kg)	7.000E+01
AVERAGING TIME (days)	2.555E+04
WATER INTAKE RATE (L/d)	2.000E+00
EXPOSURE FREQUENCY (days/year)	3.500E+02
EXPOSURE DURATION (years)	3.000E+01
RADIOLOGICAL DOSE LIMIT (rem/y)	4.000E-03
CARCINOGENIC RISK CRITERIA	1.000E-06
HAZARD QUOTIENT	1.000E+00

>>> RESULTS OF CALCULATIONS

CARCINOGENIC RISK CALCULATION

LIMITING GROUNDWATER CONCENTRATION (mg/L):	5.68E-10
MAXIMUM GROUNDWATER CONCENTRATION (mg/L):	2.41E-09
AVERAGE GROUNDWATER CONCENTRATION (mg/L):	2.41E-09
CARCINOGENIC RISK FOR USER INPUT MASS:	4.25E-06
PEAK TIME (y):	3.682666E+04
LIMITING SOIL CONCENTRATION (mg/m**3):	4.693E-01
LIMITING SOIL CONCENTRATION (mg/kg):	2.347E-04
LIMITING INVENTORY IN SOIL (mg):	1.789E+04

EXECUTION TIME (seconds) 1

Sample Problem 4b: Input File

EXAMPLE PROBLEM #4 TCDD dioxin storage at Biloxi Mississippi Ver 2.4 TITLE
0 0 KFLAG
30 INTIME
250.0 250.0 0.61 AL WA THICKS
0.58 0.125 0.125 PERC THETAS THETAU
2.0 1.65E+03 0.00693 RHOS zKDS RC2
2.0 1.65E+03 RHOU zKDU
0.0E+00 THALF
7.6e4 322.0 2.0E-04 QI ZMW SL
2.0 0.25 1.65E+03 RHOA PHI zKDA
30.9 9.0 50.6 AX AY VX
5.0 1.0 THICK DEPTH
5 1 IMODE IMODEL
1. 1. 1. 1. 250. RMI TOPER PNDFLX THETAP EVAP
1.50e5 DCF-RADMAX-NRADMAX-SFACTOR-RFD
152.0, 0. XD YD
70.0 2.555E+04 2.0 350. 30. 0.004 1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
1 6 10 1.0E-2 ISOLVE,JMAX,EPS
1
3.68116E+04 3.68416E+04 2.
Degredation rate of TCDD in soil based on 100 year half time. No degradation
assumed for groundwater.
Kd based on Koc of 3.3E6 ml/g and foc of 5E-4

Output File

TIME OF RUN 08:18:41.2
DATE OF RUN 06/14/94
INPUT FILE NAME: pb-4b.par
OUTPUT FILE NAME: pb-4b.out

=====

ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND
LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of
Energy, Office of Environmental Restoration and Waste Management,
DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.
This material is subject to a limited government license:
Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory,
all rights reserved. Neither the United States nor the United States
Department of Energy, nor any of their employees, makes any warranty
expressed or implied, or assumes any legal liability or
responsibility for the accuracy, completeness, or usefulness of any
information, apparatus, product or process disclosed, or represents that
its use would not infringe on privately owned rights. Subroutines GOLDEN,
QSIMP, QGAUS, and TRAPZD are Copyright (C) 1992, Numerical Recipes
Software. Reproduced by permission from the book, Numerical Recipes,
Cambridge University Press.

=====

* This output was produced by the model: *

* GWSCREEN *

* Version Control Copy, Version 2.4 *

* A semi-analytical model for the assessment *

* of the groundwater pathway from the leaching *

* of surficial and buried contamination and *

* release of contaminants from percolation ponds *

* 03-10-94 *

* Arthur S. Rood *

* Idaho National Engineering Laboratory *

* EG&G Idaho Inc. *

* Subsurface and Environmental Modeling Unit *

* PO Box 1625 *

* Idaho Falls, Idaho 83415 *

>>> TITLE OF PROJECT:

'EXAMPLE PROBLEM #4 TCDD dioxin storage at Biloxi Mississippi GWS V 2.4' TIT

GAUSSIAN QUADRATURE SOLUTION

MODEL OPTIONS

IMODE: 5

KFLAG: 1 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC

IMODEL:1 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION

ITYPE:2 (0) VERT AVG; (1) NON-VERT AVG; (2) AVG FROM 0 TO ZD

>>> INPUT DATA

NUMBER OF RADIOACTIVE PROGENY	0
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)	2.50E+02
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)	2.50E+02
THICKNESS OF SOURCE (m)	6.10E-01
PERCOLATION RATE (darcy vel m/y)	5.80E-01
VOLUMETRIC WATER CONTENT IN SOURCE	1.25E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE	1.25E-01
BULK DENSITY AT SOURCE (g/cm**3)	2.00E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)	1.65E+03
BULK DENSITY IN UNSAT ZONE (g/cm**3)	2.00E+00
UNSATURATED ZONE THICKNESS (m)	1.00E+00
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)	1.65E+03
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1)	6.93E-03
INITIAL MASS OR ACTIVITY (mg or Ci)	7.60E+04
MOLECULAR WEIGHT (g/mole)	3.22E+02
SOLUBILITY LIMIT (mg/L)	2.00E-04
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)	1.00E+38
BULK DENSITY OF AQUIFER (g/cm**3)	2.00E+00
POROSITY OF AQUIFER	2.50E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)	1.65E+03
DISPERSIVITY X DIRECTION (m)	3.09E+01
DISPERSIVITY Y DIRECTION (m)	9.00E+00
DISPERSIVITY Z DIRECTION (m)	9.00E+00
PORE VELOCITY (m/y)	5.06E+01
AQUIFER THICKNESS (m)	2.50E+01
DISTANCE TO RECEPTOR ALONG X AXIS (m)	1.52E+02
DISTANCE TO RECEPTOR ALONG Y AXIS (m)	0.00E+00
WELL SCREEN THICKNESS (m)	5.00E+00
CARCINOGENIC SLOPE FACTOR (mg/kg/d)**-1	1.50E+05
UNITS OF CONTAMINANT	mg

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

LIMITING SOIL CONCENTRATION CALCULATION

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

LEACH RATE CONSTANT (1/y)	2.8812E-04
UNSATURATED PORE VELOCITY (m/y)	4.6400E+00
DECAY CONSTANT(S) (1/y)	0.0000E+00
RETARDATION FACTOR(S) (SATURATED)	1.3201E+04
RETARDATION FACTOR (UNSATURATED)	2.6401E+04
SOLUBILITY LIMITED MASS (mg)	2.5163E+07
SOLUBILITY LIMITED ACTIVITY (Ci)	0.0000E+00
TRANSIT TIME IN UNSAT ZONE (years)	5.6899E+03
FRACTION DECAYED DURING UNSAT TRANSPORT	0.0000E+00

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

INTEGRATION TIME (years)	30
BODY WEIGHT (kg)	7.000E+01
AVERAGING TIME (days)	2.555E+04
WATER INTAKE RATE (L/d)	2.000E+00
EXPOSURE FREQUENCY (days/year)	3.500E+02
EXPOSURE DURATION (years)	3.000E+01
RADIOLOGICAL DOSE LIMIT (rem/y)	4.000E-03
CARCINOGENIC RISK CRITERIA	1.000E-06
HAZARD QUOTIENT	1.000E+00

>>> RESULTS OF CALCULATIONS

CARCINOGENIC RISK CALCULATION
 LIMITING GROUNDWATER CONCENTRATION (mg/L): 5.68E-10
 MAXIMUM GROUNDWATER CONCENTRATION (mg/L): 4.82E-10
 AVERAGE GROUNDWATER CONCENTRATION (mg/L): 4.82E-10
 CARCINOGENIC RISK FOR USER INPUT MASS: 8.49E-07
 PEAK TIME (y): 3.682666E+04
 LIMITING SOIL CONCENTRATION (mg/m**3): 2.347E+00
 LIMITING SOIL CONCENTRATION (mg/kg): 1.173E-03
 LIMITING INVENTORY IN SOIL (mg): 8.947E+04
 EXECUTION TIME (seconds) 6

Sample Problem 5: Input File

EXAMPLE PROBLEM #5	Ra-226 limiting soil conc INCLUDING Pb-210	Ver 2.03	TITLE
1 1	KFLAG NPROG		
1	INTIME		
100.0 100.0 5.0	AL WA THICKS		
0.10 0.10 0.15	PERC THETAS THETAU		
1.8 1.0E+02 0.0	RHOS zKDS RC2		
2.0 1.0E+01	RHOU zKDU		
1.60E+03 21.0	THALF(I)		
9.00 226. 1.0	QI ZMW SL		
2.0 0.30 10.0 20	RHOA PHI zKDA(I)		
10.0 1.0 300	AX AY VX		
5.0 25.0	THICK DEPTH		
3 1	IMODE IMODEL		
1. 1. 1. 1. 1. 100.	RMI TOPER PNDFLX THETAP EVAP		
20.0E-12 1.0E-12	DCF-RADMAX-NRADMAX-SFACTOR-RFD		
50.0, 0.	XD YD		
70.0 2.555E+04 2.0 350. 70. 0.004	1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ		
1 6 11 1.0E-2	ISOLVE,JMAX,EPS		
1			
5095. 5097. 1.			

Output File

TIME OF RUN 14:17:26.0
 DATE OF RUN 06/13/94
 INPUT FILE NAME: pb-5.par
 OUTPUT FILE NAME: pb-5.out

ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of Energy, Office of Environmental Restoration and Waste Management, DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570. This material is subject to a limited government license: Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory, all rights reserved. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe on privately owned rights. Subroutines GOLDEN, QSIMP, QGAUS, and TRAPZD are Copyright (C) 1992, Numerical Recipes Software. Reproduced by permission from the book, Numerical Recipes, Cambridge University Press.

```

*****
*
*   This output was produced by the model:
*
*   GWSCREEN
*   Version Control Copy, Version 2.03
*   A semi-analytical model for the assessment
*   of the groundwater pathway from the leaching
*   of surficial and buried contamination and
*   release of contaminants from percolation ponds
*   03-08-94
*   Arthur S. Rood
*   Idaho National Engineering Laboratory
*

```

```

*           EG&G Idaho Inc.           *
*   Subsurface and Environmental Modeling Unit   *
*           PO Box 1625               *
*           Idaho Falls, Idaho 83415        *
*****

```

```

>>> TITLE OF PROJECT:
EXAMPLE PROBLEM #5 Ra-226 limiting soil conc INCLUDING Pb-210 Ver 2.03
-----

```

GAUSSIAN QUADRATURE SOLUTION

MODEL OPTIONS

IMODE: 3

KFLAG: 1 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC

IMODEL:1 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION

>>> INPUT DATA

```

*****
NUMBER OF RADIOACTIVE PROGENY              1
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)  1.00E+02
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m) 1.00E+02
THICKNESS OF SOURCE (m)                   5.00E+00
PERCOLATION RATE (darcy vel m/y)          1.00E-01
VOLUMETRIC WATER CONTENT IN SOURCE        1.00E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE 1.50E-01
BULK DENSITY AT SOURCE (g/cm**3)          1.80E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)      1.00E+02
BULK DENSITY IN UNSAT ZONE (g/cm**3)       2.00E+00
UNSATURATED ZONE THICKNESS (m)            2.50E+01
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)  1.00E+01
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1) 0.00E+00
INITIAL MASS OR ACTIVITY (mg or Ci)        9.00E+00
MOLECULAR WEIGHT (g/mole)                 2.26E+02
SOLUBILITY LIMIT (mg/L)                   1.00E+00
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y) 1.60E+03 2.10E+01
BULK DENSITY OF AQUIFER (g/cm**3)         2.00E+00
POROSITY OF AQUIFER                      3.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)  1.00E+01 2.00E+01
DISPERSIVITY X DIRECTION (m)              1.00E+01
DISPERSIVITY Y DIRECTION (m)              1.00E+00
PORE VELOCITY (m/y)                      3.00E+02
WELL SCREEN THICKNESS (m)                 5.00E+00
DISTANCE TO RECEPTOR ALONG X AXIS (m)    5.00E+01
DISTANCE TO RECEPTOR ALONG Y AXIS (m)    0.00E+00
LIMITING RADIONUCLIDE GW CONCENTRATION (Ci/L) 2.00E-11 1.00E-12
UNITS OF CONTAMINANT                      Ci

```

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

LIMITING SOIL CONCENTRATION CALCULATION

>>> INITIAL ACTIVITY CONVERTED TO MASS (mg) 9.10E+03

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

```

*****
LEACH RATE CONSTANT (1/y)                 1.1105E-04
UNSATURATED PORE VELOCITY (m/y)           6.6667E-01
DECAY CONSTANT(S) (1/y)                   4.3322E-04 3.3007E-02
RETARDATION FACTOR(S) (SATURATED)         6.7667E+01 1.3433E+02
RETARDATION FACTOR (UNSATURATED)          1.3433E+02
SOLUBILITY LIMITED MASS (mg)              9.0050E+09
SOLUBILITY LIMITED ACTIVITY (Ci)          8.9102E+06
TRANSIT TIME IN UNSAT ZONE (years)        5.0375E+03
FRACTION DECAYED DURING UNSAT TRANSPORT  8.8722E-01
-----

```

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

```

*****
INTEGRATION TIME (years)                  1
BODY WEIGHT (kg)                          7.000E+01
AVERAGING TIME (days)                    2.555E+04
WATER INTAKE RATE (L/d)                   2.000E+00
EXPOSURE FREQUENCY (days/year)           3.500E+02
EXPOSURE DURATION (years)                 7.000E+01
RADIOLOGICAL DOSE LIMIT (rem/y)           4.000E-03
CARCINOGENIC RISK CRITERIA                1.000E-06

```

HAZARD QUOTIENT 1.000E+00

>>> RESULTS OF CALCULATIONS

MAXIMUM RADIONUCLIDE CONCENTRATION LIMIT CALCULATION

DECAY-INGROWTH FACTORS 1.0994E-01 1.1141E-01

LIMITING PARENT GW CONCENTRATION ADJUSTED FOR PROGENY = 1.78E-12 Ci/L

NOTE: PROGENY CONCENTRATIONS ARE REPORTED AT THE TIME OF THE MAXIMUM PARENT CONCENTRATION

MAXIMUM GW CONCENTRATION FOR MBR #1: 2.42E-12 Ci/L

AVERAGE GW CONCENTRATION FOR MBR #1: 2.42E-12 Ci/L

MAXIMUM GW CONCENTRATION FOR MBR #2: 1.23E-12 Ci/L

AVERAGE GW CONCENTRATION FOR MBR #2: 1.23E-12 Ci/L

PEAK TIME (y): 5.096234E+03

LIMITING SOIL CONCENTRATION (Ci/m**3): 1.330E-04

LIMITING SOIL CONCENTRATION (Ci/kg): 7.388E-08

LIMITING INVENTORY IN SOIL (Ci): 6.649E+00

LIMITING INVENTORY IN SOIL (mg): 6.720E+03

SPECIFIC ACTIVITY (Ci/g): 9.895E-01

EXECUTION TIME (seconds) 1

Sample Problem 6a: Input File

EXAMPLE PROBLEM #6a for users manual Ni-59 solubility limited release Ver 2.03

TITLE

```
1 0 KFLAG NPROG
1 INTIME
100.0 100.0 5.0 AL WA THICKS
0.10 0.10 0.15 PERC THETAS THETAU
1.8 2.0E-1 0.0 RHOS zKDS RC2
2.0 8.0 RHOU zKDU
7.5E+04 THALF(I)
1000.0 59. 3.6E-3 QI ZHW SL
2.0 0.30 10.0 RHQA PHI zKDA
10.0 1.0 300 AX AY VX
5.0 0.5 THICK DEPTH
1 1 IMODE IMODEL
1. 1. 1. 1. 1. 100 RMI TOPER PNDFLX THETAP EVAP
2.0E+02 DCF- value includes Th-234 contribution
50.0, 0. XD YD
70.0 2.555E+04 2.0 350. 70. 0.004 1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
1 6 11 1.0E-2 ISOLVE,JMAX,EPS
```

Output File

TIME OF RUN 14:17:28.1

DATE OF RUN 06/13/94

INPUT FILE NAME: pb-6a.par

OUTPUT FILE NAME: pb-6a.out

=====

ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND
LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of
Energy, Office of Environmental Restoration and Waste Management,
DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.

This material is subject to a limited government license:

Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory,
all rights reserved. Neither the United States nor the United States
Department of Energy, nor any of their employees, makes any warranty
expressed or implied, or assumes any legal liability or
responsibility for the accuracy, completeness, or usefulness of any
information, apparatus, product or process disclosed, or represents that
its use would not infringe on privately owned rights. Subroutines GOLDEN,
QSIMP, QGAUS, and TRAPZD are Copyright (C) 1992, Numerical Recipes
Software. Reproduced by permission from the book, Numerical Recipes,
Cambridge University Press.

=====

```
*****
*
* This output was produced by the model:
*
* GWScreen
* Version Control Copy, Version 2.03
*
```

```

*   A semi-analytical model for the assessment   *
*   of the groundwater pathway from the leaching *
*   of surficial and buried contamination and    *
*   release of contaminants from percolation ponds *
*   03-08-94                                     *
*   Arthur S. Rood                               *
*   Idaho National Engineering Laboratory         *
*   EG&G Idaho Inc.                             *
*   Subsurface and Environmental Modeling Unit    *
*   PO Box 1625                                  *
*   Idaho Falls, Idaho 83415                     *
*****

```

```

>>> TITLE OF PROJECT:
EXAMPLE PROBLEM #6a for users manual Ni-59 solubility limited release Ver 2.03
*****

```

GAUSSIAN QUADRATURE SOLUTION

MODEL OPTIONS

IMODE: 1

KFLAG: 1 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC

IMODEL:1 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION

>>> INPUT DATA

```

NUMBER OF RADIOACTIVE PROGENY                0
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)      1.00E+02
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)  1.00E+02
THICKNESS OF SOURCE (m)                      5.00E+00
PERCOLATION RATE (darcy vel m/y)             1.00E-01
VOLUMETRIC WATER CONTENT IN SOURCE            1.00E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE  1.50E-01
BULK DENSITY AT SOURCE (g/cm**3)             1.80E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)         2.00E-01
BULK DENSITY IN UNSAT ZONE (g/cm**3)          2.00E+00
UNSATURATED ZONE THICKNESS (m)                5.00E-01
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)      8.00E+00
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1) 0.00E+00
INITIAL MASS OR ACTIVITY (mg or Ci)           1.00E+03
MOLECULAR WEIGHT (g/mole)                     5.90E+01
SOLUBILITY LIMIT (mg/L)                       3.60E-03
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)   7.50E+04
BULK DENSITY OF AQUIFER (g/cm**3)             2.00E+00
POROSITY OF AQUIFER                          3.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)     1.00E+01
DISPERSIVITY X DIRECTION (m)                  1.00E+01
DISPERSIVITY Y DIRECTION (m)                  1.00E+00
PORE VELOCITY (m/y)                          3.00E+02
WELL SCREEN THICKNESS (m)                     5.00E+00
DISTANCE TO RECEPTOR ALONG X AXIS (m)        5.00E+01
DISTANCE TO RECEPTOR ALONG Y AXIS (m)        0.00E+00
RADIOLOGICAL DOSE CONVERSION FACTOR (rem/Ci)  2.00E+02
UNITS OF CONTAMINANT                          Ci

```

INPUT DATA FILE CREATED BY:_____ DATE / /

INPUT DATA CHECKED BY:_____ DATE / /

LIMITING SOIL CONCENTRATION CALCULATION

>>> INITIAL ACTIVITY CONVERTED TO MASS (mg) 1.24E+07

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

```

LEACH RATE CONSTANT (1/y)                    4.3478E-02
UNSATURATED PORE VELOCITY (m/y)              6.6667E-01
DECAY CONSTANT(S) (1/y)                     9.2420E-06
RETARDATION FACTOR(S) (SATURATED)            6.7667E+01
RETARDATION FACTOR (UNSATURATED)            1.0767E+02
SOLUBILITY LIMITED MASS (mg)                 8.2800E+04
SOLUBILITY LIMITED ACTIVITY (Ci)             6.6949E+00
TRANSIT TIME IN UNSAT ZONE (years)           8.0750E+01
FRACTION DECAYED DURING UNSAT TRANSPORT      7.4601E-04

```

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

INTEGRATION TIME (years) 1

BODY WEIGHT (kg) 7.000E+01
 AVERAGING TIME (days) 2.555E+04
 WATER INTAKE RATE (L/d) 2.000E+00
 EXPOSURE FREQUENCY (days/year) 3.500E+02
 EXPOSURE DURATION (years) 7.000E+01
 RADIOLOGICAL DOSE LIMIT (rem/y) 4.000E-03
 CARCINOGENIC RISK CRITERIA 1.000E-06
 HAZARD QUOTIENT 1.000E+00
 =====

>>> RESULTS OF CALCULATIONS

COMMITTED EFFECTIVE DOSE EQUIVALENT CALCULATION

COMPOSITE DOSE CONVERSION FACTOR (rem/Ci): 2.00E+02
 LIMITING GROUNDWATER CONCENTRATION (Ci/L): 2.86E-08
 MAXIMUM GW CONCENTRATION FOR MBR #1: 4.59E-07 Ci/L CEDE = 6.43E-02 rem
 MAXIMUM CEDE 6.43E-02 rem
 PEAK TIME (y): 1.038572E+02
 LIMITING SOIL CONCENTRATION (Ci/m**3): 1.245E-03
 LIMITING SOIL CONCENTRATION (Ci/kg): 6.915E-07
 LIMITING INVENTORY IN SOIL (Ci): 6.223E+01
 LIMITING INVENTORY IN SOIL (mg): 7.696E+05
 SPECIFIC ACTIVITY (Ci/g): 8.086E-02
 WARNING !!! THE LIMITING SOIL MASS OF 7.696E+05 mg
 EXCEEDS THE SOLUBILITY LIMITED SOURCE MASS OF 8.280E+04 mg
 EXECUTION TIME (seconds) 1

Sample Problem 6b: Input File

EXAMPLE PROBLEM #6b for users manual Ni-59 solubility limited release Ver 2.03
 0 0 KFLAG NPROG
 1 INTIME
 100.0 100.0 5.0 AL WA THICKS
 0.10 0.10 0.15 PERC THETAS THETAU
 1.8 2.0E-1 0.0 RHOS zKDS RC2
 2.0 8.0 RHOU zKDU
 7.5E+04 THALF
 1000.0 59. 3.6E-3 QI ZMW SL
 2.0 0.30 10.0 RHOA PHI zKDA
 10.0 1.0 300 AX AY VX
 5.0 0.5 THICK DEPTH
 1 1 IMODE IMODEL
 1. 1. 1. 1. 1. 100. RMI TOPER PNDFLX THETAP EVAP
 2.0E+02 DCF- value includes Th-234 contribution
 50.0, 0. XD YD
 70.0 2.555E+04 2.0 350. 70. 0.004 1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
 1 6 11 1.0E-2 ISOLVE,JMAX,EPS
 5 NTIMES
 100. 130. 3. T1 T2 TP
 130. 160. 3. T1 T2 TP
 160. 190. 3. T1 T2 TP
 210. 3000. 200. T1 T2 TP
 3075. 5000. 75. T1 T2 TP

Output File

TIME OF RUN 14:17:30.1
 DATE OF RUN 06/13/94
 INPUT FILE NAME: pb-6b.par
 OUTPUT FILE NAME: pb-6b.out

===== ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of
 Energy, Office of Environmental Restoration and Waste Management,
 DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.
 This material is subject to a limited government license:
 Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory,
 all rights reserved. Neither the United States nor the United States
 Department of Energy, nor any of their employees, makes any warranty
 expressed or implied, or assumes any legal liability or
 responsibility for the accuracy, completeness, or usefulness of any
 information, apparatus, product or process disclosed, or represents that

its use would not infringe on privately owned rights. Subroutines GOLDEN, QSIMP, QGAUS, and TRAP2D are Copyright (C) 1992, Numerical Recipes Software. Reproduced by permission from the book, Numerical Recipes, Cambridge University Press.

```

=====
*****
*
*   This output was produced by the model:
*
*   GWScreen
*   Version Control Copy, Version 2.03
*   A semi-analytical model for the assessment
*   of the groundwater pathway from the leaching
*   of surficial and buried contamination and
*   release of contaminants from percolation ponds
*   03-08-94
*   Arthur S. Rood
*   Idaho National Engineering Laboratory
*   EG&G Idaho Inc.
*   Subsurface and Environmental Modeling Unit
*   PO Box 1625
*   Idaho Falls, Idaho 83415
*****

>>> TITLE OF PROJECT:
EXAMPLE PROBLEM #6b for users manual Ni-59 solubility limited release Ver 2.03
=====

GAUSSIAN QUADRATURE SOLUTION
MODEL OPTIONS
IMODE: 1
KFLAG: 0 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC
IMODEL:1 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION
>>> INPUT DATA
*****
NUMBER OF RADIOACTIVE PROGENY                0
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)      1.00E+02
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)   1.00E+02
THICKNESS OF SOURCE (m)                       5.00E+00
PERCOLATION RATE (darcy vel m/y)              1.00E-01
VOLUMETRIC WATER CONTENT IN SOURCE            1.00E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE   1.50E-01
BULK DENSITY AT SOURCE (g/cm**3)              1.80E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)          2.00E-01
BULK DENSITY IN UNSAT ZONE (g/cm**3)          2.00E+00
UNSATURATED ZONE THICKNESS (m)                5.00E-01
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)      8.00E+00
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1) 0.00E+00
INITIAL MASS OR ACTIVITY (mg or Ci)            1.00E+03
MOLECULAR WEIGHT (g/mole)                     5.90E+01
SOLUBILITY LIMIT (mg/L)                       3.60E-03
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)    7.50E+04
BULK DENSITY OF AQUIFER (g/cm**3)             2.00E+00
POROSITY OF AQUIFER                           3.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)      1.00E+01
DISPERSIVITY X DIRECTION (m)                  1.00E+01
DISPERSIVITY Y DIRECTION (m)                  1.00E+00
PORE VELOCITY (m/y)                           3.00E+02
WELL SCREEN THICKNESS (m)                     5.00E+00
DISTANCE TO RECEPTOR ALONG X AXIS (m)        5.00E+01
DISTANCE TO RECEPTOR ALONG Y AXIS (m)        0.00E+00
RADIOLOGICAL DOSE CONVERSION FACTOR (rem/Ci)   2.00E+02
UNITS OF CONTAMINANT                           Ci

INPUT DATA FILE CREATED BY: _____ DATE / /
INPUT DATA CHECKED BY: _____ DATE / /
=====

>>> INITIAL ACTIVITY CONVERTED TO MASS (mg) 1.24E+07
>>> VALUES CALCULATED IN SOURCE SUBROUTINE
*****
LEACH RATE CONSTANT (1/y)                     4.3478E-02
UNSATURATED PORE VELOCITY (m/y)               6.6667E-01

```

DECAY CONSTANT(S) (1/y) 9.2420E-06
 RETARDATION FACTOR(S) (SATURATED) 6.7667E+01
 RETARDATION FACTOR (UNSATURATED) 1.0767E+02
 SOLUBILITY LIMITED MASS (mg) 8.2800E+04
 SOLUBILITY LIMITED ACTIVITY (Ci) 6.6949E+00
 TRANSIT TIME IN UNSAT ZONE (years) 8.0750E+01
 FRACTION DECAYED DURING UNSAT TRANSPORT 7.4601E-04

>>> SOLUBILITY LIMITED RELEASE FOR 3.3590E+03 YEARS
 >>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

 INTEGRATION TIME (years) 1
 BODY WEIGHT (kg) 7.000E+01
 AVERAGING TIME (days) 2.555E+04
 WATER INTAKE RATE (L/d) 2.000E+00
 EXPOSURE FREQUENCY (days/year) 3.500E+02
 EXPOSURE DURATION (years) 7.000E+01
 RADIOLOGICAL DOSE LIMIT (rem/y) 4.000E-03
 CARCINOGENIC RISK CRITERIA 1.000E-06
 HAZARD QUOTIENT 1.000E+00

>>> RESULTS OF CALCULATIONS

>>> CONCENTRATION VS TIME MODE

TIME (years)	CUMULATIVE SOURCE FLUX (Ci)	CUMULATIVE AQUIFER FLUX (Ci)	AQUIFER FLUX (Ci/year)	GW CONC ... member #1 (Ci/m**3)
1.0000E+02	2.9108E+01	5.5992E+00	2.9087E-01	4.4372E-06
1.0300E+02	2.9982E+01	6.4718E+00	2.9087E-01	4.9170E-06
1.0600E+02	3.0855E+01	7.3444E+00	2.9087E-01	5.2983E-06
1.0900E+02	3.1728E+01	8.2170E+00	2.9087E-01	5.5942E-06
1.1200E+02	3.2601E+01	9.0896E+00	2.9087E-01	5.8197E-06
1.1500E+02	3.3475E+01	9.9622E+00	2.9087E-01	5.9891E-06
1.1800E+02	3.4348E+01	1.0835E+01	2.9087E-01	6.1155E-06
1.2100E+02	3.5221E+01	1.1707E+01	2.9087E-01	6.2085E-06
1.2400E+02	3.6094E+01	1.2580E+01	2.9087E-01	6.2768E-06
1.2700E+02	3.6968E+01	1.3453E+01	2.9087E-01	6.3266E-06
1.3000E+02	3.7841E+01	1.4325E+01	2.9087E-01	6.3628E-06
1.3000E+02	3.7841E+01	1.4325E+01	2.9087E-01	6.3628E-06
1.3300E+02	3.8714E+01	1.5198E+01	2.9087E-01	6.3887E-06
1.3600E+02	3.9588E+01	1.6070E+01	2.9087E-01	6.4076E-06
1.3900E+02	4.0461E+01	1.6943E+01	2.9087E-01	6.4213E-06
1.4200E+02	4.1334E+01	1.7816E+01	2.9087E-01	6.4311E-06
1.4500E+02	4.2207E+01	1.8688E+01	2.9087E-01	6.4379E-06
1.4800E+02	4.3081E+01	1.9561E+01	2.9087E-01	6.4431E-06
1.5100E+02	4.3954E+01	2.0433E+01	2.9087E-01	6.4463E-06
1.5400E+02	4.4827E+01	2.1306E+01	2.9087E-01	6.4489E-06
1.5700E+02	4.5700E+01	2.2179E+01	2.9087E-01	6.4511E-06
1.6000E+02	4.6574E+01	2.3051E+01	2.9087E-01	6.4521E-06
1.6000E+02	4.6574E+01	2.3051E+01	2.9087E-01	6.4521E-06
1.6300E+02	4.7447E+01	2.3924E+01	2.9087E-01	6.4531E-06
1.6600E+02	4.8320E+01	2.4796E+01	2.9087E-01	6.4536E-06
1.6900E+02	4.9193E+01	2.5669E+01	2.9087E-01	6.4540E-06
1.7200E+02	5.0067E+01	2.6542E+01	2.9087E-01	6.4547E-06
1.7500E+02	5.0940E+01	2.7414E+01	2.9087E-01	6.4547E-06
1.7800E+02	5.1813E+01	2.8287E+01	2.9087E-01	6.4549E-06
1.8100E+02	5.2686E+01	2.9159E+01	2.9087E-01	6.4553E-06
1.8400E+02	5.3560E+01	3.0032E+01	2.9087E-01	6.4549E-06
1.8700E+02	5.4433E+01	3.0905E+01	2.9087E-01	6.4552E-06
1.9000E+02	5.5306E+01	3.1777E+01	2.9087E-01	6.4554E-06
2.1000E+02	6.1128E+01	3.7595E+01	2.9087E-01	6.4550E-06
4.1000E+02	1.1934E+02	9.5768E+01	2.9087E-01	6.4559E-06
6.1000E+02	1.7756E+02	1.5394E+02	2.9087E-01	6.4567E-06
8.1000E+02	2.3578E+02	2.1212E+02	2.9087E-01	6.4567E-06
1.0100E+03	2.9400E+02	2.7029E+02	2.9087E-01	6.4567E-06
1.2100E+03	3.5221E+02	3.2846E+02	2.9087E-01	6.4567E-06
1.4100E+03	4.1043E+02	3.8664E+02	2.9087E-01	6.4567E-06
1.6100E+03	4.6865E+02	4.4481E+02	2.9087E-01	6.4567E-06
1.8100E+03	5.2686E+02	5.0298E+02	2.9087E-01	6.4567E-06
2.0100E+03	5.8508E+02	5.6116E+02	2.9087E-01	6.4567E-06
2.2100E+03	6.4330E+02	6.1933E+02	2.9087E-01	6.4567E-06

2.4100E+03	7.0151E+02	6.7750E+02	2.9087E-01	6.4567E-06
2.6100E+03	7.5973E+02	7.3568E+02	2.9087E-01	6.4567E-06
2.8100E+03	8.1795E+02	7.9385E+02	2.9087E-01	6.4567E-06
3.0750E+03	8.9509E+02	8.7093E+02	2.9087E-01	6.4567E-06
3.1500E+03	9.1692E+02	8.9274E+02	2.9087E-01	6.4567E-06
3.2250E+03	9.3875E+02	9.1456E+02	2.9087E-01	6.4567E-06
3.3000E+03	9.6058E+02	9.3638E+02	2.9087E-01	6.4567E-06
3.3750E+03	9.8111E+02	9.5819E+02	2.9087E-01	6.4567E-06
3.4500E+03	9.8432E+02	9.7943E+02	1.8642E-01	5.9956E-06
3.5250E+03	9.8445E+02	9.8355E+02	7.1451E-03	3.6871E-07
3.6000E+03	9.8445E+02	9.8371E+02	2.7386E-04	1.4174E-08
3.6750E+03	9.8445E+02	9.8372E+02	1.0497E-05	5.4326E-10
3.7500E+03	9.8445E+02	9.8372E+02	4.0232E-07	2.0822E-11
3.8250E+03	9.8445E+02	9.8372E+02	1.5420E-08	7.9808E-13
3.9000E+03	9.8445E+02	9.8372E+02	5.9103E-10	3.0589E-14
3.9750E+03	9.8445E+02	9.8372E+02	2.2653E-11	1.1724E-15
4.0500E+03	9.8445E+02	9.8372E+02	8.6827E-13	4.4938E-17
4.1250E+03	9.8445E+02	9.8372E+02	3.3280E-14	1.7224E-18
4.2000E+03	9.8445E+02	9.8372E+02	1.2756E-15	6.6017E-20
4.2750E+03	9.8445E+02	9.8372E+02	4.8890E-17	2.5303E-21
4.3500E+03	9.8445E+02	9.8372E+02	1.8739E-18	9.6983E-23
4.4250E+03	9.8445E+02	9.8372E+02	7.1823E-20	3.7172E-24
4.5000E+03	9.8445E+02	9.8372E+02	2.7529E-21	1.4248E-25
4.5750E+03	9.8445E+02	9.8372E+02	1.0551E-22	5.4609E-27
4.6500E+03	9.8445E+02	9.8372E+02	4.0441E-24	2.0931E-28
4.7250E+03	9.8445E+02	9.8372E+02	1.5501E-25	8.0224E-30
4.8000E+03	9.8445E+02	9.8372E+02	5.9411E-27	3.0749E-31
4.8750E+03	9.8445E+02	9.8372E+02	2.2771E-28	1.1785E-32
4.9500E+03	9.8445E+02	9.8372E+02	8.7279E-30	4.5172E-34
AVERAGE INTEGRATED CONCENTRATION FROM 1.0000E+02 TO 1.3000E+02 YEARS = 5.80E-06 Ci/m**3				
AVERAGE INTEGRATED CONCENTRATION FROM 1.3000E+02 TO 1.6000E+02 YEARS = 6.43E-06 Ci/m**3				
AVERAGE INTEGRATED CONCENTRATION FROM 1.6000E+02 TO 1.9000E+02 YEARS = 6.45E-06 Ci/m**3				
AVERAGE INTEGRATED CONCENTRATION FROM 2.1000E+02 TO 3.0000E+03 YEARS = 6.46E-06 Ci/m**3				
AVERAGE INTEGRATED CONCENTRATION FROM 3.0750E+03 TO 5.0000E+03 YEARS = 1.48E-06 Ci/m**3				
MAXIMUM CONCENTRATION(S) Ci/m**3				
6.46E-06				
TIME(S) OF MAXIMUM CONCENTRATIONS (years)				
1.21E+03				
EXECUTION TIME (seconds) 7				

Sample Problem 7a: Input File

```

EXAMPLE PROBLEM #7a; Sr-90 release to a pond LIMITING CONC CALC Ver 2.03
1 0 KFLAG NPROG
1 INTIME
20.0 20.0 0.50 AL WA THICKS
0.20 0.36 0.120 PERC THETAS THETAU
1.5 24.0 0.0 RHOS zKDS
1.9 24.0 RHOU zKDU
2.85E1 THALF(1)
0.0 90.0 1.0 QI ZMW SL
1.9 0.10 22.0 24.0 RHOA PHI zKDA
9.0 4.0 570.0 AX AY VX
15.0 0.00001 THICK DEPTH
1 2 IMODE IMODEL
1. 30. 4000. 0.4 0.0 20. RMI TOPER PNDFLX THETAP EVAP WAEFF
1.3E5 DCF-RADMAX-NRADMAX-SFACTOR-RFD
100.0, 0. XD YD
70.0 2.555E+04 2.0 365. 30. 0.004 1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
2 6 12 1.0E-3 ISOLVE,JSTART,JMAX,EPS

```

Output File

TIME OF RUN 14:17:38.9
 DATE OF RUN 06/13/94
 INPUT FILE NAME: PB-7A.PAR
 OUTPUT FILE NAME: PB-7A.OUT

=====
 ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND
 LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of

Energy, Office of Environmental Restoration and Waste Management,
DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.
This material is subject to a limited government license:
Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory,
all rights reserved. Neither the United States nor the United States
Department of Energy, nor any of their employees, makes any warranty
expressed or implied, or assumes any legal liability or
responsibility for the accuracy, completeness, or usefulness of any
information, apparatus, product or process disclosed, or represents that
its use would not infringe on privately owned rights. Subroutines GOLDEN,
QSIMP, QGAUS, and TRAP2D are Copyright (C) 1992, Numerical Recipes
Software. Reproduced by permission from the book, Numerical Recipes,
Cambridge University Press.

=====

```

*****
*
*   This output was produced by the model:
*
*   GWSCREEN
*   Version Control Copy, Version 2.03
*   A semi-analytical model for the assessment
*   of the groundwater pathway from the leaching
*   of surficial and buried contamination and
*   release of contaminants from percolation ponds
*   03-08-94
*   Arthur S. Rood
*   Idaho National Engineering Laboratory
*   EG&G Idaho Inc.
*   Subsurface and Environmental Modeling Unit
*   PO Box 1625
*   Idaho Falls, Idaho 83415
*****

>>> TITLE OF PROJECT:
EXAMPLE PROBLEM #7a; Sr-90 release to a pond LIMITING CONC CALC Ver 2.03
-----

SIMPSON RULE SOLUTION
JSTART = 6
JMAX = 12
EPS = 1.0000E-03
MODEL OPTIONS
IMODE: 1
KFLAG: 1 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC
IMODEL:2 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION
>>> INPUT DATA
*****
NUMBER OF RADIOACTIVE PROGENY          0
LENGTH OF SOURCE PARALLEL TO GW FLOW (m) 2.00E+01
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m) 2.00E+01
THICKNESS OF SOURCE (m) 5.00E-01
PERCOLATION RATE (darcy vel m/y) 2.00E-01
VOLUMETRIC WATER CONTENT IN SOURCE 3.60E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE 1.20E-01
BULK DENSITY AT SOURCE (g/cm**3) 1.50E+00
SORPTION COEFFICIENT AT SOURCE (ml/g) 2.40E+01
BULK DENSITY IN UNSAT ZONE (g/cm**3) 1.90E+00
UNSATURATED ZONE THICKNESS (m) 1.00E-05
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g) 2.40E+01
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1) 0.00E+00
INITIAL MASS OR ACTIVITY (mg or Ci) 0.00E+00
MOLECULAR WEIGHT (g/mole) 9.00E+01
SOLUBILITY LIMIT (mg/L) 1.00E+00
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y) 2.85E+01
BULK DENSITY OF AQUIFER (g/cm**3) 1.90E+00
POROSITY OF AQUIFER 1.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g) 2.20E+01
DISPERSIVITY X DIRECTION (m) 9.00E+00
DISPERSIVITY Y DIRECTION (m) 4.00E+00
PORE VELOCITY (m/y) 5.70E+02
WELL SCREEN THICKNESS (m) 1.50E+01
DISTANCE TO RECEPTOR ALONG X AXIS (m) 1.00E+02
DISTANCE TO RECEPTOR ALONG Y AXIS (m) 0.00E+00
RADIOLOGICAL DOSE CONVERSION FACTOR (rem/Ci) 1.30E+05

```

MASS RELEASE RATE TO POND (mg or Ci per y) 1.00E+00
 OPERATION TIME OF POND (years) 3.00E+01
 LIQUID EFFLUENT FLOW RATE TO POND (m**3/y) 4.00E+03
 MOISTURE CONTENT OF UNDERLYING SEDIMENTS 4.00E-01
 EVAPORATION RATE CONSTANT FROM POND (y**-1) 0.00E+00
 EFFECTIVE WIDTH OF POND AT AQUIFER (m) 2.00E+01
 UNITS OF CONTAMINANT Ci

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

 LIMITING SOIL CONCENTRATION CALCULATION

>>> INITIAL ACTIVITY CONVERTED TO MASS (mg) 0.00E+00

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

LEACH RATE CONSTANT (1/y) 1.1001E-02
 UNSATURATED PORE VELOCITY (m/y) 8.3333E+01
 DECAY CONSTANT(S) (1/y) 2.4321E-02
 RETARDATION FACTOR(S) (SATURATED) 4.1900E+02
 LEACH RATE CONSTANT FROM POND SEDIMENTS 5.4945E-01
 RETARDATION FACTOR (UNSATURATED) 3.8100E+02
 SOLUBILITY LIMITED MASS (mg) 7.2800E+06
 SOLUBILITY LIMITED ACTIVITY (Ci) 1.0155E+06
 TRANSIT TIME IN UNSAT ZONE (years) 4.5720E-05
 FRACTION DECAYED DURING UNSAT TRANSPORT 1.1120E-06

POND SEDIMENT INVENTORY AT END OF OPERATIONS: 1.74E+00 Ci

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

INTEGRATION TIME (years) 1
 BODY WEIGHT (kg) 7.000E+01
 AVERAGING TIME (days) 2.555E+04
 WATER INTAKE RATE (L/d) 2.000E+00
 EXPOSURE FREQUENCY (days/year) 3.650E+02
 EXPOSURE DURATION (years) 3.000E+01
 RADIOLOGICAL DOSE LIMIT (rem/y) 4.000E-03
 CARCINOGENIC RISK CRITERIA 1.000E-06
 HAZARD QUOTIENT 1.000E+00

>>> RESULTS OF CALCULATIONS

COMMITTED EFFECTIVE DOSE EQUIVALENT CALCULATION

COMPOSITE DOSE CONVERSION FACTOR (rem/Ci): 1.30E+05

LIMITING GROUNDWATER CONCENTRATION (Ci/L): 4.21E-11

MAXIMUM GW CONCENTRATION FOR MBR #1: 1.46E-09 Ci/L CEDE = 1.38E-01 rem

MAXIMUM CEDE 1.38E-01 rem

PEAK TIME (y): 6.773253E+01

LIMITING POND EFFLUENT CONCENTRATION (Ci/L): 7.239E-09

EXECUTION TIME (seconds) 36

Sample Problem 7b: Input File

EXAMPLE PROBLEM #7b; Sr-90 release to a pond CONC VS TIME Ver 2.03

0 0	KFLAG NPROG
1	INTIME
20.0 20.0 0.50	AL WA THICKS
0.20 0.36 0.12	PERC THETAS THETAU
1.5 24.0 0.0	RHOS zKDS
1.9 24.0	RHOU zKDU
2.85E1	THALF(I)
0.00 90.0 1.0	QI ZMW SL
1.9 0.10 22.0 24.0	RHOA PHI zKDA
9.0 4.0 570.0	AX AY VX
15.0 0.00001	THICK DEPTH
1 3	IMODE IMODEL
1. 30. 4000. 0.4 0.0 20.	RMI TOPER PNDFLX THETAP EVAP WAEFF
1.3e5	DCF-RADMAX-RRADMAX-SFACTOR-RFD
100.0, 0.	XD YD
70.0 2.555E+04 2.0 365. 30. 0.004	1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
2 6 12 5.0E-3	ISOLVE,JSTART JMAX,EPS
3	NTIMES

0.0	30.0	2.0	
32.	62.0	2.0	
64.	94.0	1.0	
0.0000E+00			0.0000E+00
1.0000E+00			4.1808E+01
2.0000E+00			6.5364E+01
3.0000E+00			7.8636E+01
4.0000E+00			8.6113E+01
5.0000E+00			9.0325E+01
6.0000E+00			9.2699E+01
7.0000E+00			9.4036E+01
8.0000E+00			9.4789E+01
9.0000E+00			9.5213E+01
1.0000E+01			9.5453E+01
1.1000E+01			9.5587E+01
1.2000E+01			9.5663E+01
1.3000E+01			9.5706E+01
1.4000E+01			9.5730E+01
1.5000E+01			9.5744E+01
1.6000E+01			9.5751E+01
1.7000E+01			9.5756E+01
1.8000E+01			9.5758E+01
1.9000E+01			9.5759E+01
2.0000E+01			9.5760E+01
2.1000E+01			9.5761E+01
2.2000E+01			9.5761E+01
2.3000E+01			9.5761E+01
2.4000E+01			9.5761E+01
2.5000E+01			9.5761E+01
2.6000E+01			9.5761E+01
2.7000E+01			9.5761E+01
2.8000E+01			9.5761E+01
2.9000E+01			9.5761E+01
3.0000E+01			9.5761E+01
3.2000E+01			1.7866E+00
3.3000E+01			1.7246E+00
3.4000E+01			1.6647E+00
3.5000E+01			1.6069E+00
3.6000E+01			1.5512E+00
3.7000E+01			1.4973E+00
3.8000E+01			1.4454E+00
3.9000E+01			1.3952E+00
4.0000E+01			1.3468E+00
4.1000E+01			1.3000E+00
4.2000E+01			1.2549E+00
4.3000E+01			1.2114E+00
4.4000E+01			1.1693E+00
4.5000E+01			1.1287E+00
4.6000E+01			1.0896E+00
4.7000E+01			1.0518E+00
4.8000E+01			1.0153E+00
4.9000E+01			9.8002E-01
5.0000E+01			9.4601E-01
5.1000E+01			9.1317E-01
5.2000E+01			8.8148E-01
5.3000E+01			8.5089E-01
5.4000E+01			8.2136E-01
5.5000E+01			7.9285E-01
5.6000E+01			7.6534E-01
5.7000E+01			7.3878E-01
5.8000E+01			7.1314E-01
5.9000E+01			6.8839E-01
6.0000E+01			6.6450E-01
6.1000E+01			6.4143E-01
6.2000E+01			6.1917E-01
6.4000E+01			5.7694E-01
6.6000E+01			5.3759E-01
6.8000E+01			5.0092E-01
7.0000E+01			4.6676E-01
7.2000E+01			4.3492E-01
7.4000E+01			4.0526E-01
7.6000E+01			3.7762E-01
7.8000E+01			3.5186E-01

8.0000E+01	3.2786E-01
8.2000E+01	3.0550E-01
8.4000E+01	2.8466E-01
8.6000E+01	2.6525E-01
8.8000E+01	2.4715E-01
9.0000E+01	2.3030E-01
9.2000E+01	2.1459E-01
9.4000E+01	1.9995E-01

Output File

TIME OF RUN 14:18:16.4
 DATE OF RUN 06/13/94
 INPUT FILE NAME: PB-7B.PAR
 OUTPUT FILE NAME: PB-7B.out

ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of Energy, Office of Environmental Restoration and Waste Management, DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570. This material is subject to a limited government license: Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory, all rights reserved. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe on privately owned rights. Subroutines GOLDEN, QSIMP, QGAUS, and TRAP2D are Copyright (C) 1992, Numerical Recipes Software. Reproduced by permission from the book, Numerical Recipes, Cambridge University Press.

```

*****
*
*   This output was produced by the model:
*
*           GWSCREEN
*   Version Control Copy, Version 2.03
*   A semi-analytical model for the assessment
*   of the groundwater pathway from the leaching
*   of surficial and buried contamination and
*   release of contaminants from percolation ponds
*   03-08-94
*   Arthur S. Rood
*   Idaho National Engineering Laboratory
*   EG&G Idaho Inc.
*   Subsurface and Environmental Modeling Unit
*   PO Box 1625
*   Idaho Falls, Idaho 83415
*****
  
```

>>> TITLE OF PROJECT:
 EXAMPLE PROBLEM #7b; Sr-90 release to a pond CONC VS TIME Ver 2.03

SIMPSON RULE SOLUTION

JSTART = 6
 JMAX = 12
 EPS = 5.0000E-03

MODEL OPTIONS

IMODE: 1
 KFLAG: 0 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC
 IMODEL:3 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION

>>> INPUT DATA

NUMBER OF RADIOACTIVE PROGENY	0
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)	2.00E+01
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)	2.00E+01
THICKNESS OF SOURCE (m)	5.00E-01
PERCOLATION RATE (darcy vel m/y)	2.00E-01
VOLUMETRIC WATER CONTENT IN SOURCE	3.60E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE	1.20E-01

BULK DENSITY AT SOURCE (g/cm**3)	1.50E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)	2.40E+01
BULK DENSITY IN UNSAT ZONE (g/cm**3)	1.90E+00
UNSATURATED ZONE THICKNESS (m)	1.00E-05
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)	2.40E+01
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1)	0.00E+00
INITIAL MASS OR ACTIVITY (mg or Ci)	0.00E+00
MOLECULAR WEIGHT (g/mole)	9.00E+01
SOLUBILITY LIMIT (mg/L)	1.00E+00
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)	2.85E+01
BULK DENSITY OF AQUIFER (g/cm**3)	1.90E+00
POROSITY OF AQUIFER	1.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)	2.20E+01
DISPERSIVITY X DIRECTION (m)	9.00E+00
DISPERSIVITY Y DIRECTION (m)	4.00E+00
PORE VELOCITY (m/y)	5.70E+02
WELL SCREEN THICKNESS (m)	1.50E+01
DISTANCE TO RECEPTOR ALONG X AXIS (m)	1.00E+02
DISTANCE TO RECEPTOR ALONG Y AXIS (m)	0.00E+00
RADIOLOGICAL DOSE CONVERSION FACTOR (rem/Ci)	1.30E+05
UNITS OF CONTAMINANT	Ci

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

LEACH RATE CONSTANT (1/y)	0.0000E+00
UNSATURATED PORE VELOCITY (m/y)	1.6667E+00
DECAY CONSTANT(S) (1/y)	2.4321E-02
RETARDATION FACTOR(S) (SATURATED)	4.1900E+02
RETARDATION FACTOR (UNSATURATED)	3.8100E+02
SOLUBILITY LIMITED MASS (mg)	0.0000E+00
SOLUBILITY LIMITED ACTIVITY (Ci)	0.0000E+00
TRANSIT TIME IN UNSAT ZONE (years)	2.2860E-03
FRACTION DECAYED DURING UNSAT TRANSPORT	5.5596E-05

TABULATED SOURCE FUNCTION

TIME (years)	SOURCE FLUX Ci/year
0.0000E+00	0.0000E+00
1.0000E+00	4.1808E+01
2.0000E+00	6.5364E+01
3.0000E+00	7.8636E+01
4.0000E+00	8.6113E+01
5.0000E+00	9.0325E+01
6.0000E+00	9.2699E+01
7.0000E+00	9.4036E+01
8.0000E+00	9.4789E+01
9.0000E+00	9.5213E+01
1.0000E+01	9.5453E+01
1.1000E+01	9.5587E+01
1.2000E+01	9.5663E+01
1.3000E+01	9.5706E+01
1.4000E+01	9.5730E+01
1.5000E+01	9.5744E+01
1.6000E+01	9.5751E+01
1.7000E+01	9.5756E+01
1.8000E+01	9.5758E+01
1.9000E+01	9.5759E+01
2.0000E+01	9.5760E+01
2.1000E+01	9.5761E+01
2.2000E+01	9.5761E+01
2.3000E+01	9.5761E+01
2.4000E+01	9.5761E+01
2.5000E+01	9.5761E+01
2.6000E+01	9.5761E+01
2.7000E+01	9.5761E+01

2.8000E+01	9.5761E+01
2.9000E+01	9.5761E+01
3.0000E+01	9.5761E+01
3.2000E+01	1.7866E+00
3.3000E+01	1.7246E+00
3.4000E+01	1.6647E+00
3.5000E+01	1.6069E+00
3.6000E+01	1.5512E+00
3.7000E+01	1.4973E+00
3.8000E+01	1.4454E+00
3.9000E+01	1.3952E+00
4.0000E+01	1.3468E+00
4.1000E+01	1.3000E+00
4.2000E+01	1.2549E+00
4.3000E+01	1.2114E+00
4.4000E+01	1.1693E+00
4.5000E+01	1.1287E+00
4.6000E+01	1.0896E+00
4.7000E+01	1.0518E+00
4.8000E+01	1.0153E+00
4.9000E+01	9.8002E-01
5.0000E+01	9.4601E-01
5.1000E+01	9.1317E-01
5.2000E+01	8.8148E-01
5.3000E+01	8.5089E-01
5.4000E+01	8.2136E-01
5.5000E+01	7.9285E-01
5.6000E+01	7.6534E-01
5.7000E+01	7.3878E-01
5.8000E+01	7.1314E-01
5.9000E+01	6.8839E-01
6.0000E+01	6.6450E-01
6.1000E+01	6.4143E-01
6.2000E+01	6.1917E-01
6.4000E+01	5.7694E-01
6.6000E+01	5.3759E-01
6.8000E+01	5.0092E-01
7.0000E+01	4.6676E-01
7.2000E+01	4.3492E-01
7.4000E+01	4.0526E-01
7.6000E+01	3.7762E-01
7.8000E+01	3.5186E-01
8.0000E+01	3.2786E-01
8.2000E+01	3.0550E-01
8.4000E+01	2.8466E-01
8.6000E+01	2.6525E-01
8.8000E+01	2.4715E-01
9.0000E+01	2.3030E-01
9.2000E+01	2.1459E-01
9.4000E+01	1.9995E-01

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

INTEGRATION TIME (years)	1
BODY WEIGHT (kg)	7.000E+01
AVERAGING TIME (days)	2.555E+04
WATER INTAKE RATE (L/d)	2.000E+00
EXPOSURE FREQUENCY (days/year)	3.650E+02
EXPOSURE DURATION (years)	3.000E+01
RADIOLOGICAL DOSE LIMIT (rem/y)	4.000E-03
CARCINOGENIC RISK CRITERIA	1.000E-06
HAZARD QUOTIENT	1.000E+00

>>> RESULTS OF CALCULATIONS

>>> CONCENTRATION VS TIME MODE

TIME (years)	GW CONC. member #1 Ci/m**3
0.0000E+00	0.0000E+00
2.0000E+00	0.0000E+00
4.0000E+00	0.0000E+00

6.0000E+00 3.1743E-17
 8.0000E+00 8.9224E-14
 1.0000E+01 1.1816E-11
 1.2000E+01 3.2641E-10
 1.4000E+01 3.6036E-09
 1.6000E+01 2.2194E-08
 1.8000E+01 9.1885E-08
 2.0000E+01 2.8695E-07
 2.2000E+01 7.2733E-07
 2.4000E+01 1.5703E-06
 2.6000E+01 2.9987E-06
 2.8000E+01 5.1887E-06
 3.0000E+01 8.3007E-06
 3.2000E+01 1.2444E-05
 3.4000E+01 1.7672E-05
 3.6000E+01 2.4012E-05
 3.8000E+01 3.1409E-05
 4.0000E+01 3.9755E-05
 4.2000E+01 4.8945E-05
 4.4000E+01 5.8810E-05
 4.6000E+01 6.9216E-05
 4.8000E+01 7.9949E-05
 5.0000E+01 9.0762E-05
 5.2000E+01 1.0144E-04
 5.4000E+01 1.1159E-04
 5.6000E+01 1.2096E-04
 5.8000E+01 1.2937E-04
 6.0000E+01 1.3641E-04
 6.2000E+01 1.4208E-04
 6.4000E+01 1.4593E-04
 6.5000E+01 1.4753E-04
 6.6000E+01 1.4854E-04
 6.7000E+01 1.4903E-04
 6.8000E+01 1.4938E-04
 6.9000E+01 1.4930E-04
 7.0000E+01 1.4888E-04
 7.1000E+01 1.4849E-04
 7.2000E+01 1.4741E-04
 7.3000E+01 1.4589E-04
 7.4000E+01 1.4429E-04
 7.5000E+01 1.4255E-04
 7.6000E+01 1.4008E-04
 7.7000E+01 1.3811E-04
 7.8000E+01 1.3583E-04
 7.9000E+01 1.3317E-04
 8.0000E+01 1.3035E-04
 8.1000E+01 1.2723E-04
 8.2000E+01 1.2378E-04
 8.3000E+01 1.2188E-04
 8.4000E+01 1.1900E-04
 8.5000E+01 1.1520E-04
 8.6000E+01 1.1199E-04
 8.7000E+01 1.0847E-04
 8.8000E+01 1.0535E-04
 8.9000E+01 1.0208E-04
 9.0000E+01 9.8873E-05
 9.1000E+01 9.5546E-05
 9.2000E+01 9.2272E-05
 9.3000E+01 8.9160E-05
 9.4000E+01 8.6129E-05

AVERAGE INTEGRATED CONCENTRATION FROM 0.0000E+00 TO 3.0000E+01 YEARS = 9.83E-07 Ci/m**3

AVERAGE INTEGRATED CONCENTRATION FROM 3.2000E+01 TO 6.2000E+01 YEARS = 7.58E-05 Ci/m**3

AVERAGE INTEGRATED CONCENTRATION FROM 6.4000E+01 TO 9.4000E+01 YEARS = 1.28E-04 Ci/m**3

MAXIMUM CONCENTRATION(S) Ci/m**3

1.49E-04

TIME(S) OF MAXIMUM CONCENTRATIONS (years)

6.80E+01

EXECUTION TIME (seconds) 12

Sample Problem 7c: Input File

Example Pb-7c Limiting Conc based on carcinogenic; risk vert avg solution Ver 2.4

1 0

KFLAG NPROG

```

30 2          INTIME ITYPE
20.0 20.0 0.50 AL WA THICKS
0.20 0.36 0.120 PERC THETAS THETAU
1.5 24.0 0.0   RHOS zKDS
1.9 24.0       RHOU zKDU
2.85E1        THALF(I)
0.0 90.0 1.0   QI ZMW SL
1.9 0.10 22.0 24.0 RHOA PHI zKDA
9.0 4.0 4.0 570.0 AX AY AZ VX
15.0 0.00001    THICK DEPTH
2 2            IMODE IMODEL
1. 30. 4000. 0.4 0.0 20. RMI TOPER PNDFLX THETAP EVAP WAEFF
36.0          DCF-RADMAX-NRADMAX-SFACTOR-RFD
100.0, 0. 14.9999      XD YD ZD
70.0 2.555E+04 2.0 365. 30. 0.004 1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
2 6 11 1.0E-2        ISOLVE,JSTART,JMAX,EPS

```

Output File

```

TIME OF RUN 14:18:30.6
DATE OF RUN 06/13/94
INPUT FILE NAME: PB-7c.PAR
OUTPUT FILE NAME: PB-7c.out

```

=====

ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of Energy, Office of Environmental Restoration and Waste Management, DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570. This material is subject to a limited government license: Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory, all rights reserved. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe on privately owned rights. Subroutines GOLDEN, QSIMP, QGAUS, and TRAPZD are Copyright (C) 1992, Numerical Recipes Software. Reproduced by permission from the book, Numerical Recipes, Cambridge University Press.

```

*****
*
*   This output was produced by the model:
*
*   GWSCREEN
*   Version Control Copy, Version 2.4
*   A semi-analytical model for the assessment
*   of the groundwater pathway from the leaching
*   of surficial and buried contamination and
*   release of contaminants from percolation ponds
*   03-10-94
*   Arthur S. Rood
*   Idaho National Engineering Laboratory
*   EG&G Idaho Inc.
*   Subsurface and Environmental Modeling Unit
*   PO Box 1625
*   Idaho Falls, Idaho 83415
*****

```

```

>>> TITLE OF PROJECT:
Example Pb-7c Limiting Conc based on carcinogenic; risk vert avg solution Ver

```

SIMPSON RULE SOLUTION

```

JSTART = 6
JMAX = 11
EPS = 1.0000E-02
MODEL OPTIONS
IMODE: 2
KFLAG: 1 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC
IMODEL:2 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION
ITYPE:2 (0) VERT AVG; (1) NON-VERT AVG; (2) AVG FROM 0 TO ZD

```

>>> INPUT DATA

NUMBER OF RADIOACTIVE PROGENY	0
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)	2.00E+01
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)	2.00E+01
THICKNESS OF SOURCE (m)	5.00E-01
PERCOLATION RATE (darcy vel m/y)	2.00E-01
VOLUMETRIC WATER CONTENT IN SOURCE	3.60E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE	1.20E-01
BULK DENSITY AT SOURCE (g/cm**3)	1.50E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)	2.40E+01
BULK DENSITY IN UNSAT ZONE (g/cm**3)	1.90E+00
UNSATURATED ZONE THICKNESS (m)	1.00E-05
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)	2.40E+01
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1)	0.00E+00
INITIAL MASS OR ACTIVITY (mg or Ci)	0.00E+00
MOLECULAR WEIGHT (g/mole)	9.00E+01
SOLUBILITY LIMIT (mg/L)	1.00E+00
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)	2.85E+01
BULK DENSITY OF AQUIFER (g/cm**3)	1.90E+00
POROSITY OF AQUIFER	1.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)	2.20E+01
DISPERSIVITY X DIRECTION (m)	9.00E+00
DISPERSIVITY Y DIRECTION (m)	4.00E+00
DISPERSIVITY Z DIRECTION (m)	4.00E+00
PORE VELOCITY (m/y)	5.70E+02
AQUIFER THICKNESS (m)	1.50E+01
DISTANCE TO RECEPTOR ALONG X AXIS (m)	1.00E+02
DISTANCE TO RECEPTOR ALONG Y AXIS (m)	0.00E+00
WELL SCREEN THICKNESS (m)	1.50E+01
RADIOLOGICAL CARCINOGENIC SLOPE FACTOR (1/Ci)	3.60E+01
MASS RELEASE RATE TO POND (mg or Ci per y)	1.00E+00
OPERATION TIME OF POND (years)	3.00E+01
LIQUID EFFLUENT FLOW RATE TO POND (m**3/y)	4.00E+03
MOISTURE CONTENT OF UNDERLYING SEDIMENTS	4.00E-01
EVAPORATION RATE CONSTANT FROM POND (y**-1)	0.00E+00
EFFECTIVE WIDTH OF POND AT AQUIFER (m)	2.00E+01
UNITS OF CONTAMINANT	Ci

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

LIMITING SOIL CONCENTRATION CALCULATION

>>> INITIAL ACTIVITY CONVERTED TO MASS (mg) 0.00E+00

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

LEACH RATE CONSTANT (1/y)	1.1001E-02
UNSATURATED PORE VELOCITY (m/y)	8.3333E+01
DECAY CONSTANT(S) (1/y)	2.4321E-02
RETARDATION FACTOR(S) (SATURATED)	4.1900E+02
LEACH RATE CONSTANT FROM POND SEDIMENTS	5.4945E-01
RETARDATION FACTOR (UNSATURATED)	3.8100E+02
SOLUBILITY LIMITED MASS (mg)	7.2800E+06
SOLUBILITY LIMITED ACTIVITY (Ci)	1.0155E+06
TRANSIT TIME IN UNSAT ZONE (years)	4.5720E-05
FRACTION DECAYED DURING UNSAT TRANSPORT	1.1120E-06

POND SEDIMENT INVENTORY AT END OF OPERATIONS: 1.74E+00 Ci

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

INTEGRATION TIME (years)	30
BODY WEIGHT (kg)	7.000E+01
AVERAGING TIME (days)	2.555E+04
WATER INTAKE RATE (L/d)	2.000E+00
EXPOSURE FREQUENCY (days/year)	3.650E+02
EXPOSURE DURATION (years)	3.000E+01
RADIOLOGICAL DOSE LIMIT (rem/y)	4.000E-03
CARCINOGENIC RISK CRITERIA	1.000E-06
HAZARD QUOTIENT	1.000E+00

>>> RESULTS OF CALCULATIONS

```

*****
MAXIMUM AVERAGE GW CONCENTRATION BETWEEN YEARS 5.23E+01 AND 8.23E+01
CARCINOGENIC RISK CALCULATION FOR RADIONUCLIDES
MAXIMUM GW CONCENTRATION FOR MBR #1: 1.46E-09 Ci/L
AVERAGE GW CONCENTRATION FOR MBR #1: 1.33E-09 Ci/L RISK = 1.05E-03
MAXIMUM CARCINOGENIC RISK: 1.05E-03
LIMITING PARENT GROUNDWATER CONC. (Ci/L): 1.27E-12
PEAK TIME (y): 6.800890E+01
LIMITING POND EFFLUENT CONCENTRATION (Ci/L): 2.384E-10
EXECUTION TIME (seconds) 54

```

Sample Problem 8: Input File

```

EXAMPLE PROBLEM #8; Pu-241 Am-241 AND NP-237 PROG CARCIN RISK CALC Ver 2.03
1 2 KFLAG NPROG
30 INTIME
70.0 30.0 2.0 AL WA THICKS
1.0 0.35 0.090 PERC THETAS THETAU
1.5 22.0 0.0 RHOS zKDS
1.9 22.0 RHOU zKDU
14.4 432.2 2.1E6 THALF(I)
10.00 239.0 7.11E6 QI ZMW SL
1.9 0.10 22.0 340.0 5.0 RHOA PHI zKDA
9.0E-0 4.0E-0 570.0 AX AY VX
15.0 6.0 THICK DEPTH
2 1 IMODE IMODEL
1. 1. 1. 1. 1. 30. RMI TOPER PNDFLX THETAP EVAP WAEFF
4.8 310. 270 DCF-RCSF-RADMAX-NRADMAX-SFACTOR-RFD
135.0, 0. XD YD
70.0 2.555E+04 2.0 350. 30. 0.004 1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
1 6 11 1.0E-2 ISOLVE,JMAX,EPS
2 NTIMES
300.0, 400.0 2. T1 T2 TP
400. 500. 5. T1 T2 TP

```

Output File

```

TIME OF RUN 14:19:25.8
DATE OF RUN 06/13/94
INPUT FILE NAME: pb-8.par
OUTPUT FILE NAME: pb-8.out

```

ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND LIMITATION OF LIABILITY

```

This material resulted from work developed under U.S. Department of
Energy, Office of Environmental Restoration and Waste Management,
DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.
This material is subject to a limited government license:
Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory,
all rights reserved. Neither the United States nor the United States
Department of Energy, nor any of their employees, makes any warranty
expressed or implied, or assumes any legal liability or
responsibility for the accuracy, completeness, or usefulness of any
information, apparatus, product or process disclosed, or represents that
its use would not infringe on privately owned rights. Subroutines GOLDEN,
QSIMP, QGAUS, and TRAPZD are Copyright (C) 1992, Numerical Recipes
Software. Reproduced by permission from the book, Numerical Recipes,
Cambridge University Press.

```

```

*****
* This output was produced by the model: *
* *
* GWSCREEN *
* Version Control Copy, Version 2.03 *
* A semi-analytical model for the assessment *
* of the groundwater pathway from the leaching *
* of surficial and buried contamination and *
* release of contaminants from percolation ponds *

```

```

*          03-08-94          *
*      Arthur S. Rood        *
*  Idaho National Engineering Laboratory *
*      EG&G Idaho Inc.      *
*  Subsurface and Environmental Modeling Unit *
*      PO Box 1625          *
*      Idaho Falls, Idaho 83415      *
*****

```

```

>>> TITLE OF PROJECT:
EXAMPLE PROBLEM #8; Pu-241 Am-241 AND NP-237 PROG CARCIN RISK CALC Ver 2.03

```

GAUSSIAN QUADRATURE SOLUTION

MODEL OPTIONS

IMODE: 2

KFLAG: 1 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC

IMODEL:1 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION

>>> INPUT DATA

```

NUMBER OF RADIOACTIVE PROGENY          2
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)  7.00E+01
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)  3.00E+01
THICKNESS OF SOURCE (m)                2.00E+00
PERCOLATION RATE (darcy vel m/y)        1.00E+00
VOLUMETRIC WATER CONTENT IN SOURCE      3.50E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE  9.00E-02
BULK DENSITY AT SOURCE (g/cm**3)        1.50E+00
SORPTION COEFFICIENT AT SOURCE (ml/g)    2.20E+01
BULK DENSITY IN UNSAT ZONE (g/cm**3)    1.90E+00
UNSATURATED ZONE THICKNESS (m)          6.00E+00
SORPTION COEFFICIENT IN UNSAT ZONE (ml/g)  2.20E+01
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1) 0.00E+00
INITIAL MASS OR ACTIVITY (mg or Ci)      1.00E+01
MOLECULAR WEIGHT (g/mole)                2.39E+02
SOLUBILITY LIMIT (mg/L)                  7.11E+06
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)  1.44E+01  4.32E+02  2.10E+06
BULK DENSITY OF AQUIFER (g/cm**3)        1.90E+00
POROSITY OF AQUIFER                     1.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (ml/g)  2.20E+01  3.40E+02  5.00E+00
DISPERSIVITY X DIRECTION (m)             9.00E+00
DISPERSIVITY Y DIRECTION (m)             4.00E+00
PORE VELOCITY (m/y)                     5.70E+02
WELL SCREEN THICKNESS (m)                1.50E+01
DISTANCE TO RECEPTOR ALONG X AXIS (m)   1.35E+02
DISTANCE TO RECEPTOR ALONG Y AXIS (m)   0.00E+00
RADIOLOGICAL CARCINOGENIC SLOPE FACTOR (1/Ci)  4.80E+00  3.10E+02  2.70E+02
UNITS OF CONTAMINANT                     Ci

```

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

LIMITING SOIL CONCENTRATION CALCULATION

>>> INITIAL ACTIVITY CONVERTED TO MASS (mg) 9.62E+01

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

```

LEACH RATE CONSTANT (1/y)              1.4993E-02
UNSATURATED PORE VELOCITY (m/y)        1.1111E+01
DECAY CONSTANT(S) (1/y)                4.8135E-02  1.6038E-03  3.3007E-07
RETARDATION FACTOR(S) (SATURATED)      4.1900E+02  6.4610E+03  9.6000E+01
RETARDATION FACTOR (UNSATURATED)       4.6544E+02
SOLUBILITY LIMITED MASS (mg)            9.9590E+14
SOLUBILITY LIMITED ACTIVITY (Ci)        1.0353E+14
TRANSIT TIME IN UNSAT ZONE (years)      2.5134E+02
FRACTION DECAYED DURING UNSAT TRANSPORT  9.9999E-01

```

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

```

INTEGRATION TIME (years)                30
BODY WEIGHT (kg)                         7.000E+01
AVERAGING TIME (days)                   2.555E+04
WATER INTAKE RATE (L/d)                  2.000E+00
EXPOSURE FREQUENCY (days/year)          3.500E+02

```

EXPOSURE DURATION (years)	3.000E+01
RADIOLOGICAL DOSE LIMIT (rem/y)	4.000E-03
CARCINOGENIC RISK CRITERIA	1.000E-06
HAZARD QUOTIENT	1.000E+00

>>> RESULTS OF CALCULATIONS

CARCINOGENIC RISK CALCULATION FOR RADIONUCLIDES

DECAY-INGROWTH FACTORS: 2.1285E-07 2.0659E-02 2.6053E-06

NOTE: PROGENY CONCENTRATIONS ARE REPORTED AT THE TIME OF THE MAXIMUM PARENT CONCENTRATION

MAXIMUM GW CONCENTRATION FOR MBR #1: 6.36E-17 Ci/L

AVERAGE GW CONCENTRATION FOR MBR #1: 5.95E-17 Ci/L RISK = 6.00E-12

MAXIMUM GW CONCENTRATION FOR MBR #2: 4.00E-13 Ci/L

AVERAGE GW CONCENTRATION FOR MBR #2: 4.06E-13 Ci/L RISK = 2.64E-06

MAXIMUM GW CONCENTRATION FOR MBR #3: 3.40E-15 Ci/L

AVERAGE GW CONCENTRATION FOR MBR #3: 3.50E-15 Ci/L RISK = 1.98E-08

MAXIMUM CARCINOGENIC RISK: 2.66E-06

LIMITING PARENT GROUNDWATER CONC. (Ci/L): 2.23E-17

PEAK TIME (y): 3.191569E+02

LIMITING SOIL CONCENTRATION (Ci/m**3): 8.937E-04

LIMITING SOIL CONCENTRATION (Ci/kg): 5.958E-07

LIMITING INVENTORY IN SOIL (Ci): 3.754E+00

LIMITING INVENTORY IN SOIL (mg): 3.611E+01

SPECIFIC ACTIVITY (Ci/g): 1.040E+02

EXECUTION TIME (seconds) 3

Sample Problem 9: Input File

EXAMPLE PROBLEM #9; hydrocarbon benzene spill with vapor diffusion loss Ver 2.03

1 0	KFLAG NPROG
30	INTIME
15.0 25.0 2.00	AL WA THICKS
0.10 0.30 0.090	PERC THETAS THETAU
1.5 0.25 1.13e-2	RHOS zKDS RC2
1.9 0.25	RHOU zKDU
0.95	THALF(I)
5.625e8 78.11 1780.	QI ZMW SL
1.9 0.10 0.25	RHOA PHI zKDA
9.0 4.0 570.0	AX AY VX
15.0 0.1	THICK DEPTH
5 1	IMODE IMODEL
100. 30. 4000. 0.4 0.0 25	RMI TOPER PNDPLX THETAP EVAP WAEFF
5.2e-2	DCF-RADMAX-NRADMAX-SFACTOR-RFD
25.0, 0.	XD YD
70.0 2.555E+04 2.0 350. 30. 0.004	1.0E-6 1.0 BW AT WI EF ED DLIM CRISK HQ
1 6 12 5.0E-3	ISOLVE,JMAX,EPS

Output File

TIME OF RUN 14:19:29.9

DATE OF RUN 06/13/94

INPUT FILE NAME: PB-9.PAR

OUTPUT FILE NAME: PB-9.OUT

===== ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND LIMITATION OF LIABILITY

This material resulted from work developed under U.S. Department of Energy, Office of Environmental Restoration and Waste Management, DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.

This material is subject to a limited government license:

Copyright 1993, EG&G Idaho Inc., Idaho National Engineering Laboratory, all rights reserved. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe on privately owned rights. Subroutines GOLDEN, QSIMP, QGAUS, and TRAPZD are Copyright (C) 1992, Numerical Recipes Software. Reproduced by permission from the book, Numerical Recipes, Cambridge University Press.

```

*****
*
*   This output was produced by the model:
*
*   GWScreen
*   Version Control Copy, Version 2.03
*   A semi-analytical model for the assessment
*   of the groundwater pathway from the leaching
*   of surficial and buried contamination and
*   release of contaminants from percolation ponds
*   03-08-94
*   Arthur S. Rood
*   Idaho National Engineering Laboratory
*   EG&G Idaho Inc.
*   Subsurface and Environmental Modeling Unit
*   PO Box 1625
*   Idaho Falls, Idaho 83415
*****

```

>>> TITLE OF PROJECT:
 EXAMPLE PROBLEM #9: hydrocarbon benzene spill with vapor diffusion loss Ver 2.

GAUSSIAN QUADRATURE SOLUTION

MODEL OPTIONS

IMODE: 5

KFLAG: 1 (0)CONC VS TIME; (1)PEAK CONC AND LIMITING SOIL CONC

IMODEL:1 (1) SURF OR BURIED SOURCE; (2)POND SOURCE; (3) TABULATED SOURCE FUNCTION

>>> INPUT DATA

NUMBER OF RADIOACTIVE PROGENY	0
LENGTH OF SOURCE PARALLEL TO GW FLOW (m)	1.50E+01
WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m)	2.50E+01
THICKNESS OF SOURCE (m)	2.00E+00
PERCOLATION RATE (darcy vel m/y)	1.00E-01
VOLUMETRIC WATER CONTENT IN SOURCE	3.00E-01
VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE	9.00E-02
BULK DENSITY AT SOURCE (g/cm**3)	1.50E+00
SORPTION COEFFICIENT AT SOURCE (mL/g)	2.50E-01
BULK DENSITY IN UNSAT ZONE (g/cm**3)	1.90E+00
UNSATURATED ZONE THICKNESS (m)	1.00E-01
SORPTION COEFFICIENT IN UNSAT ZONE (mL/g)	2.50E-01
OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1)	1.13E-02
INITIAL MASS OR ACTIVITY (mg or Ci)	5.62E+08
MOLECULAR WEIGHT (g/mole)	7.81E+01
SOLUBILITY LIMIT (mg/L)	1.78E+03
HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y)	9.50E-01
BULK DENSITY OF AQUIFER (g/cm**3)	1.90E+00
POROSITY OF AQUIFER	1.00E-01
SORPTION COEFFICIENT(S) IN AQUIFER (mL/g)	2.50E-01
DISPERSIVITY X DIRECTION (m)	9.00E+00
DISPERSIVITY Y DIRECTION (m)	4.00E+00
PORE VELOCITY (m/y)	5.70E+02
WELL SCREEN THICKNESS (m)	1.50E+01
DISTANCE TO RECEPTOR ALONG X AXIS (m)	2.50E+01
DISTANCE TO RECEPTOR ALONG Y AXIS (m)	0.00E+00
CARCINOGENIC SLOPE FACTOR (mg/kg/d)**-1	5.20E-02
UNITS OF CONTAMINANT	mg

INPUT DATA FILE CREATED BY: _____ DATE / /

INPUT DATA CHECKED BY: _____ DATE / /

LIMITING SOIL CONCENTRATION CALCULATION

>>> VALUES CALCULATED IN SOURCE SUBROUTINE

LEACH RATE CONSTANT (1/y)	7.4074E-02
UNSATURATED PORE VELOCITY (m/y)	1.1111E+00
DECAY CONSTANT(S) (1/y)	7.2963E-01
RETARDATION FACTOR(S) (SATURATED)	5.7500E+00
RETARDATION FACTOR (UNSATURATED)	6.2778E+00
SOLUBILITY LIMITED MASS (mg)	9.0112E+08
SOLUBILITY LIMITED ACTIVITY (Ci)	0.0000E+00
TRANSIT TIME IN UNSAT ZONE (years)	5.6500E-01

FRACTION DECAYED DURING UNSAT TRANSPORT 3.3783E-01

>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION

INTEGRATION TIME (years)	30
BODY WEIGHT (kg)	7.000E+01
AVERAGING TIME (days)	2.555E+04
WATER INTAKE RATE (L/d)	2.000E+00
EXPOSURE FREQUENCY (days/year)	3.500E+02
EXPOSURE DURATION (years)	3.000E+01
RADIOLOGICAL DOSE LIMIT (rem/y)	4.000E-03
CARCINOGENIC RISK CRITERIA	1.000E-06
HAZARD QUOTIENT	1.000E+00

>>> RESULTS OF CALCULATIONS

CARCINOGENIC RISK CALCULATION

LIMITING GROUNDWATER CONCENTRATION (mg/L):	1.64E-03
MAXIMUM GROUNDWATER CONCENTRATION (mg/L):	3.95E-01
AVERAGE GROUNDWATER CONCENTRATION (mg/L):	2.33E-02
CARCINOGENIC RISK FOR USER INPUT MASS:	1.42E-05
PEAK TIME (y):	1.110326E+00
LIMITING SOIL CONCENTRATION (mg/m**3):	5.268E+04
LIMITING SOIL CONCENTRATION (mg/kg):	3.512E+01
LIMITING INVENTORY IN SOIL (mg):	3.951E+07
EXECUTION TIME (seconds)	1

APPENDIX B: GWSCREEN Code Listing

APPENDIX B: GWSCREEN Code Listing

```
PROGRAM GWS6
***** Begin Prologue *****

*
* Identification
*
* Program Name: GWSCREEN
* Module Name: gws6.f Version: 1.9
* Date: 4/13/94 Time: 12:26:37
*
C
C AUTHOR A.S. ROOD
C APRIL, 1991

C ***** NOTE *****
C FOR COMPILATION ON INEL CRAY, THE FUNCTION DEFINITION MUST CHANGE
C FROM REAL*8 FUNCTION(xxxx) TO FUNCTION(xxxx). REAL*8 FUNCTION(xxxx)
C IS THE LAHEY FORMAT AND FUNCTION(xxxx) IS CRAY UNIX. THE FOLLOWING
C FUNCTIONS ARE AFFECTED; AREA, FUNC, ERF, GAMMP, GAMMLN
C *****

C This program is designed to calculate the concentration of a contaminant
C in the surface soil that results in a groundwater concentration that is
C at the acceptable regulatory standard for either maximum concentration,
C radiological dose or carcinogenic risk. The program also calculates the
C groundwater concentration as a function of time for an initial inventory.

C The program uses a three stage approach:
C First, the leach rate of the contaminant from the surface is
C calculated. Next the transit time from the surface to the aquifer is
C calculated. Any decay which occurs during transit is accounted for and plug
C flow is assumed. The contaminant is then assumed to dissolve in the aquifer
C and initially mix in an volume that is equivalent to the area of the source
C on the surface times the thickness of the well screen. The peak, or an
C average integrated concentration is then calculated and compared with the
C appropriate regulatory limit.

C This program uses equation 4.37 in NUREG CR/3332 to calculate groundwater
C concentrations. The leach rate from the source is determined using
C methodology in the RESRAD code (DOE/CH/8901).
C Solution for time variant releases
C are taken from the Gaussian Quad integration. Limits of integration are
C determined by Codell's method in NUREG-0868. Gaus Quad integration
C was used in two routines in the code. The convolution integral which
C describes groundwater concentration resulting from a non-steady state
C release is solved using a modified Gaus Quad routine found in Numerical
C Recipes (Press et al) and found in the QGAUS2 subroutine.
C
C A second integration routine was taken also from Numerical Recipes (Press et al
C 1987) and is used in the subroutine QGAUS. This routine calculates the
C average integrated concentration.

IMPLICIT REAL*8 (A-H,O-Z)

C INPUT VARIABLES:

C TITLE = TITLE OF PROJECT
C KFLAG (0) = CONCENTRATION VS TIME
C (1) = LIMITING SOIL CONCENTRATION
C INTIME = INTEGRATING TIME. INTIME MUST EQUAL THE EXPOSURE DURATION
C FOR CARCINOGENIC CALCULATIONS
```

C ITYPE = (0) FOR VERTICALLY AVERAGED (1) FOR NON VERTICALLY AVERAGED
 C AL = LENGTH OF SOURCE PARALLEL TO FLOW (m)
 C WA = WIDTH OF SOURCE PERPENDICULAR TO FLOW (m)
 C THICKS = THICKNESS OF CONTAMINATED ZONE (m)
 C PERC = PERCOLATION RATE (m/y)
 C THETAS = VOLUMETRIC MOISTURE CONTENT IN CONTAMINATED ZONE
 C THETAU = VOLUMETRIC MOISTURE CONTENT IN UNSATURATED ZONE
 C RHOS = DENSITY OF SURFACE SOIL (g/cm3)
 C zKDS = SORPTION COEFFICIENT IN SOURCE (cm3/g)
 C RC2 = ADDITIONAL RATE CONSTANT FOR SOURCE DEPLETION (y-1)
 C THALF = HALF LIFE (y)
 C QI = UNIT INITIAL MASS IN SOURCE COMPARTMENT (CI OR MG)
 C QX=INPUT INITIAL MASS IN SOURCE COMPARTMENT
 C ZMW = MOLECULAR WEIGHT (G/MOLE)
 C SL = SOLUBILITY LIMIT OF CONTAMINANT (MG/L)
 C RHOA = DENSITY OF AQUIFER (G/CM3)
 C PHI = POROSITY OF AQUIFER
 C zKDA = SORPTION COEFFICIENT IN AQUIFER
 C AX = DISPERSIVITY IN THE X DIRECTION (m)
 C AY = DISPERSIVITY IN THE Y DIRECTION (m)
 C AZ = DISPERSIVITY IN THE Z DIRECTION (m)
 C VX = PORE VELOCITY IN AQUIFER, (m/y)
 C THICK = THICKNESS OF WELL SCREEN (m)
 C DEPTH = DEPTH OF AQUIFER FROM BASE OF CONTAMINATED ZONE (m)
 C IMODE = (1) LIMIT BASED ON 4 MREM/Y
 C (2) LIMIT BASED ON REFERENCE DOSE
 C (3) LIMIT BASED ON MAXIMUM CONTAMINANT LIMIT FOR RADIONUCLIDES
 C (4) LIMIT BASED ON CARCINOGENIC RISK FOR RADIONUCLIDES
 C (5) LIMIT BASED ON MAXIMUM CONTAMINANT LIMIT FOR CHEMICALS
 C (6) LIMIT BASED ON CARCINOGENIC RISK (1.0E-6)
 C DCF = DOSE CONVERSION FACTOR (rem/Ci)
 C DSLOPE = SLOPE FACTOR FOR RADIONUCLIDES (1/pCi)
 C RADMAX = GROUNDWATER CRITERIA LIMIT FOR RADIONUCLIDES (Ci/L)
 C ZRADMAX = GROUNDWATER CRITERIA LIMIT FOR NON-RAD (mg/L)
 C SFACOR = SLOPE FACTOR FOR CARCINOGENIC RISK CALCULATION (MG/KG/D)**-1
 C RFD = REFERENCE DOSE FOR NON-CARCINOGENIC EFFECTS (MG/KG/D)
 C XD = RECEPTOR DISTANCE DOWNGRADE (m)
 C YD = RECEPTOR DISTANCE PERPENDICULAR TO GW FLOW (m)
 C ZD = RECEPTOR DISTANCE AT DEPTH IN AQUIFER (m)
 C T1 = START TIME FOR CALCULATIONS (KFLAG=0) (y)
 C T2 = END TIME FOR CALCULATIONS (KFLAG=0) (y)
 C TP = PRINT TIME STEP (y)
 C EXPOSURE DATA
 C BW = BODY WEIGHT (kg)
 C AT = AVERAGING TIME (days)
 C WI = WATER INTAKE RATE (L/d)
 C EF = EXPOSURE FREQUENCY (years)
 C ED = EXPOSURE DURATION THIS VALUE SHOULD BE THE SAME AS INTIME FOR
 * CARCINOGEN CALCULATIONS (years)
 C RCSF = RADIOLOGICAL CARCINOGENIC SLOPE FACTOR (1/Ci)
 C DLIM = RADIOLOGICAL DOSE LIMIT (rem/y)
 C CRISK = CARCINOGENIC RISK CRITERIA
 C HQ = HAZARD QUOTIENT
 C RMI = RATE OF MASS INPUT INTO PERCOLATION POND (MG OR CI PER YEAR)
 C TOPER = OPERATION TIME OF PERC POND FACILITY (YEARS)
 C PNDFLX = WATER FLUX INTO POND (M**3/Y)
 C EVAP = EVAPORATION RATE CONSTANT FOR POND (Y**-1)
 C WAEFF = EFFECTIVE WIDTH OF POND AT AQUIFER
 C FIXED VALUES
 C UNITS = MG OR CI
 C CALCULATED VARIABLES IN MAIN PROGRAM
 C QM = INITIAL SOURCE MASS FOR RADIONUCLIDES
 C TTIME = CHARACTER VARIABLE FOR HOLDING TIME OF RUN
 C DDATE = CHARACTER VARIABLE FOR HOLDING DATA OF RUN
 C CSD = LIMITING SOIL CONCENTRATION IN CI OR mg PER KG
 C QACT = SOLUBILITY LIMITED MASS CONVERTED TO ACTIVITY
 C QCS = LIMITING CONTAMINANT AMOUNT (CI OR MG)
 C QMCS = LIMITING CONTAMINANT MASS (MG)
 C DAIC = AVERAGE INTEGRATED CONC FOR PROGENY

```

C CHARACTER VALUES
  CHARACTER*2 UNITS
  CHARACTER*45 MODE
C COMMON STATEMENTS
  COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
  I QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW, RC2, IMODE,
  I ITYPE
  COMMON /SOURCE/ THETAS, THETAU, RHOS, THICKS, zKDS,
  I DEPTH, PERC, THALF, RHOA, zKDU, RHOU, QM
  COMMON /EXPOSURE/ BW, AT, WI, EF, ED, DLIM, CRISK, HQ
  COMMON /FILES/ FILEIN, FILEOU, TITLE
  CHARACTER*40 FILEIN, FILEOU
  CHARACTER*78 TITLE
  COMMON /POND/ RMI, TOPER, PNDFLX, THETAP, EVAP, PLEACH, WAEFF
  PARAMETER (NSPEC=9, SEC=3.1536E7, A=6.023E23)
  COMMON /DECAY/ ADCF, AKD, ATHALF, ARD, ARADMAX, RCSF
  DIMENSION ADCF(NSPEC), AKD(NSPEC), ATHALF(NSPEC), ARADMAX(NSPEC)
  I, ARD(NSPEC), RCSF(NSPEC)
  COMMON /TABLE/ ATIME, QREL, NP
  PARAMETER (NPOINTS=1000)
  DIMENSION ATIME(NPOINTS), QREL(NPOINTS)
  DIMENSION ADLR(NSPEC), DAIC(NSPEC)
  DIMENSION T1(NSPEC), T2(NSPEC), TP(NSPEC)
C ***** End prologue

  Character idkeyw*72
  Data idkeyw /'@(#)gws6.f 1.9 4/13/94 12:26:37\0'/
  idkeyw = idkeyw

C ***** READ DATA IN SUBROUTINE INPUT *****
  CALL INPUT(XDUMMY, T1, T2, TP, KFLAG, INTIME, IFLAG, IMODEL, ISOLVE, NN,
  INPROG, NTIMES)

  CALL TIMER(ITICK1)
c  TICK1 = SECOND() for INEL cray
  IF(IFLAG.EQ.1) THEN
    GOTO 999
  ENDIF
C USE SUBROUTINE "ASSIGN" TO ASSIGN A VALUE TO XDUMMY BASED ON THE
C VALUE OF IMODE
  CALL ASSIGN(XDUMMY, ZRADMAX, SFACTOR, RFD, INTIME, UNITS,
  IMODE)
C WRITE INPUT DATA TO OUTPUT FILE
  WRITE(*,*) TITLE
  WRITE(2,1000) IMODE, KFLAG, IMODEL, ITYPE
  WRITE(2,2000) NPROG, AL, WA
  WRITE(2,2050) THICKS, PERC, THETAS, THETAU, RHOS, zKDS, RHOU, DEPTH,
  I zKDU
  IF(IMODEL.EQ.2) THEN
    WRITE(2,2100) RC2, QI, ZMW, SL
  ELSE
    WRITE(2,2100) RC2, QX, ZMW, SL
  ENDIF
  WRITE(2,2075) (ATHALF(I), I=1, NN)
  WRITE(2,2150) RHOA, PHI, (AKD(I), I=1, NN)
  IF(ITYPE.LE.0) THEN
    WRITE(2,2200) AX, AY, AZ, VX, THICK, XD, YD, ZD
  ENDIF
  IF(ITYPE.EQ.1) THEN
    WRITE(2,2275) AX, AY, AZ, VX, THICK, XD, YD, ZD
  ENDIF
  IF(ITYPE.EQ.2) THEN
    WRITE(2,2250) AX, AY, AZ, VX, THICK, XD, YD, ZD
  ENDIF

  IF(IMODE.GT.3) THEN
    WRITE(2,2300) MODE, XDUMMY
  ELSE
    IF(IMODE.EQ.1) THEN

```

```

        WRITE(2,2400) MODE,(ADCF(I),I=1,NN)
    ENDIF
    IF(IMODE.EQ.2)THEN
        WRITE(2,2400) MODE,(RCSF(I),I=1,NN)
    ENDIF
    IF(IMODE.EQ.3)THEN
        WRITE(2,2400) MODE,(ARADMAX(I),I=1,NN)
    ENDIF
ENDIF

IF(IMODEL.EQ.2)THEN
    WRITE(2,2500) RMI,TOPEP,PNDFLX,THETAP,EVAP,WAEFF
ENDIF

WRITE(2,2550) UNITS
IF(KFLAG.GT.0)THEN
    WRITE(2,352)
ENDIF

C convert initial activity to mass if a radionuclide for solubility check
C CONVERT CI TO MG. USE THE CONVERSIONS 1 CI=3.7E10 DPS, 3.1536 S/Y
C 6.023E23 ATOMS/MOLE AND 1000 MG/G
IF(IMODEL.EQ.2)THEN
    QTEMP=QI
    ELSE
        QTEMP=QX
    ENDIF
IF(IMODEL.EQ.3.AND.IMODEL.LT.3)THEN
    QM=(((QTEMP*3.7E10)*SEC*ZMW)/(LOG(2.)/THALF))/A)*1000
    WRITE(2,2800) QM
    ELSE
        QM=QTEMP
    ENDIF
C .....
C ..... CALCULATE SOURCE .....
C ..... RELEASE AND FIXED .....
C ..... VALUES .....
C .....

CALL SOURCEX(UX,RDU,TSL,TRANSIT,ADLR,KFLAG,IMODEL,NN,UNITS)
C WRITE EXPOSURE DATA TO OUTPUT FILE
WRITE(2,400) INTIME,BW,AT,WI,EF,ED,DLIM,CRISK,HQ

C .....
C ..... CALCULATE CONCENTRATION AS A FUNCTION .....
C ..... OF TIME .....
C .....

IF(KFLAG.EQ.0.OR.IMODEL.EQ.3)THEN
    IF(IMODEL.NE.2)THEN
        QI=QX
    ENDIF
    CALL CTIME(UNITS,TSL,TRANSIT,ADLR,T1,T2,TP,SFACTOR,RFD,ISOLVE,
    IMODEL,NN,NTIMES,INTIME,KFLAG,IMODE)
    CALL TIMER(ITICK2)
    ITICK=(ITICK2-ITICK1)/100
    WRITE(*,*) ' Normal Termination'
    WRITE(2,2700) ITICK
    CLOSE(2,STATUS='KEEP')
    GOTO 999
ENDIF
C .....
C ..... CALCULATE LIMITING SOIL CONCENTRATION .....
C .....

C CHECK EXPOSURE DURATION TO MAKE SURE IT IS EQUAL TO INTEGRATION TIME
C FOR CARCINOGENIC CALCULATIONS
IF(IMODE.EQ.2.OR.IMODE.EQ.5)THEN
    IF(ED.NE.INTIME)THEN
        WRITE(*,13)
        WRITE(2,13)
        GOTO 999
    
```

```

        ENDIF
    ENDIF
C CALCULATE PEAK GROUNDWATER CONCENTRATION
    CALL PEAK(GWPEAK,PKTIME,TSL,IMODEL,ISOLVE)
    PKTIMEA = PKTIME + TRANSIT
    GWMAXI = GWPEAK * QX
C CALCULATE AVERAGE INTEGRATED CONC. (AIC) OR IF 1 YEAR INTEGRATION TIME
C IS USED THEN USE THE PEAK CONCENTRATION
    X1 = FLOAT(INTIME)
    CALL GWINT(X1,PKTIME,TRANSIT,TSL,AIC,DAIC,ADLR,GWPEAK,PKTIMEA,
    I IMODEL,ISOLVE,NN,KFLAG)
    AICI = AIC * QX
    DO 10,I = 1,NN
        DAIC(I) = DAIC(I) * QX
10    CONTINUE

    IF(AIC.LE.0.)THEN
        WRITE(2,201)
    C    WRITE(*,201)
        GOTO 999
    ENDIF
C ***** CALCULATE SOIL CONC FOR THE GIVEN CONTAMINANT *****
    VOL = THICKS * WA * AL
C IMODE = (1) LIMIT BASED ON 4 MREM/Y
C    (2) LIMIT BASED ON CARCINOGENIC RADIOLOGICAL RISK
C    (3) LIMIT BASED ON MAXIMUM CONTAMINANT LIMIT FOR RADIONUCLIDES
C    (4) LIMIT BASED ON MAXIMUM CONTAMINANT LIMIT FOR CHEMICALS
C    (5) LIMIT BASED ON CARCINOGENIC RISK (1.0E-6)
C    (6) LIMIT BASED ON REFERENCE DOSE
C ***** RADIOLOGICAL DOSE
C DAIC,GWMAXI,GWPEAK CONCENTRATION IN CI/M**3

    IF(IMODE.EQ.1)THEN
        CALL RAD(CS,CE,AIC,AICI,VOL,PKTIMEA,ADLR,NN,IMODEL)
    ENDIF

C ***** CARCINOGENIC RADIOLOGICAL RISK
    IF(IMODE.EQ.2)THEN
        CALL CRAD(CS,CE,AIC,DAIC,VOL,GWMAXI,PKTIMEA,ADLR,NN,IMODEL)
    ENDIF

C ***** RADIONUCLIDE CONCENTRATION IN GROUNDWATER
    IF(IMODE.EQ.3)THEN
        CALL MAXRAD(CS,CE,AIC,DAIC,VOL,GWMAXI,PKTIMEA,ADLR,NN,IMODEL)
    ENDIF
C ***** NON-RAD CONCENTRATION IN GROUNDWATER
    IF(IMODE.EQ.4)THEN
        CALL MAXNRAD(CS,CE,AIC,AICI,GWMAXI,VOL,ZRADMAX,IMODEL)
    ENDIF
C ***** CARCINOGENIC RISK
    IF(IMODE.EQ.5)THEN
        CALL CARCIN(CS,CE,AIC,VOL,SFACTOR,AICI,GWMAXI,IMODEL)
    ENDIF

C ***** NON CARCINOGENIC CHRONIC EXPOSURE
    IF(IMODE.EQ.6)THEN
        CALL NCARCIN(CS,CE,AIC,VOL,RFD,AICI,GWMAXI,IMODEL)
    ENDIF

    CALL WRITEO(PKTIMEA,CS,CE,UNITS,IMODEL)

    CALL TIMER(ITICK2)
    ITICK = (ITICK2-ITICK1)/100
    WRITE(*,*) '      Normal Termination'
    WRITE(2,2700) ITICK
    CLOSE(2,STATUS='KEEP')

13 FORMAT(' '
    1/,2X,'ERROR:EXPOSURE DURATION (ED) MUST EQUAL INTEGRATION TIME (IN

```

```

ITIME'
I/,2X,'FOR CARCINOGENIC CALCULATION')
201 FORMAT(2X,'NO SOIL CONCENTRATION LIMITS CALCULATED SINCE THE'
I/,2X,'AVERAGE INTEGRATED CONCENTRATION IS ZERO')
352 FORMAT(2X,'LIMITING SOIL CONCENTRATION CALCULATION')
400 FORMAT(2X,'>>> EXPOSURE DATA FOR LIMITING SOIL CONCENTRATION'
I/,2X,'.....'
I/,2X,'INTEGRATION TIME (years)          ',I3
I/,2X,'BODY WEIGHT (kg)                  ',1PE10.3
I/,2X,'AVERAGING TIME (days)           ',1PE10.3
I/,2X,'WATER INTAKE RATE (L/d)          ',1PE10.3
I/,2X,'EXPOSURE FREQUENCY (days/year)   ',1PE10.3
I/,2X,'EXPOSURE DURATION (years)        ',1PE10.3
I/,2X,'RADIOLOGICAL DOSE LIMIT (rem/y)   ',1PE10.3
I/,2X,'CARCINOGENIC RISK CRITERIA       ',1PE10.3
I/,2X,'HAZARD QUOTIENT                   ',1PE10.3
I/,2X,'-----'
I/,2X,'>>> RESULTS OF CALCULATIONS
I/,2X,'.....')
1000 FORMAT(2X,'MODEL OPTIONS'
I/,2X,'IMODE: ',I1
I/,2X,'KFLAG: ',I1,I1X,'(0)CONC VS TIME; (1)PEAK CONC AND LIMITING S
OIL CONC'
I/,2X,'IMODEL:',I1,I1X,'(1) SURF OR BURIED SOURCE; (2)POND SOURCE; (
13) TABULATED SOURCE FUNCTION'
I/,2X,'ITYPE:',I1,I1X,'(0) VERT AVG; (1) NON-VERT AVG; (2) AVG FROM
10 TO 2D')

2000 FORMAT(2X,'>>> INPUT DATA '
I/,2X,'.....'
I/,2X,'NUMBER OF RADIOACTIVE PROGENY          ',I2
I/,2X,'LENGTH OF SOURCE PARALLEL TO GW FLOW (m) ',1PE9.2
I/,2X,'WIDTH OF SOURCE PERPENDICULAR TO GW FLOW (m) ',1PE9.2)

2050 FORMAT(2X,'THICKNESS OF SOURCE (m)          ',1PE9.2
I/,2X,'PERCOLATION RATE (darcy vel m/y)         ',1PE9.2
I/,2X,'VOLUMETRIC WATER CONTENT IN SOURCE        ',1PE9.2
I/,2X,'VOLUMETRIC WATER CONTENT IN UNSATURATED ZONE ',1PE9.2
I/,2X,'BULK DENSITY AT SOURCE (g/cm**3)         ',1PE9.2
I/,2X,'SORPTION COEFFICIENT AT SOURCE (ml/g)     ',1PE9.2
I/,2X,'BULK DENSITY IN UNSAT ZONE (g/cm**3)     ',1PE9.2
I/,2X,'UNSATURATED ZONE THICKNESS (m)           ',1PE9.2
I/,2X,'SORPTION COEFFICIENT IN UNSAT ZONE (ml/g) ',1PE9.2)

2075 FORMAT(2X,'HALF-LIFE(S) OF CONTAMINANT AND PROGENY (y) ',1PE9.2
1,1PE9.2,1PE9.2,1PE9.2,1PE9.2,1PE9.2,1PE9.2,1PE9.2,1PE9.2)
2100 FORMAT(2X,'OPTIONAL LOSS RATE CONSTANT FOR SOURCE (y**-1)',1PE9.2
I/,2X,'INITIAL MASS OR ACTIVITY (mg or Ci)       ',1PE9.2
I/,2X,'MOLECULAR WEIGHT (g/mole)                ',1PE9.2
I/,2X,'SOLUBILITY LIMIT (mg/L)                  ',1PE9.2)

2150 FORMAT(2X,'BULK DENSITY OF AQUIFER (g/cm**3) ',1PE9.2
I/,2X,'POROSITY OF AQUIFER                      ',1PE9.2
I/,2X,'SORPTION COEFFICIENT(S) IN AQUIFER (ml/g) ',1PE9.2
1,1PE9.2,1PE9.2,1PE9.2,1PE9.2,1PE9.2,1PE9.2,1PE9.2,1PE9.2)
2200 FORMAT(2X,'DISPERSIVITY X DIRECTION (m)      ',1PE9.2
I/,2X,'DISPERSIVITY Y DIRECTION (m)              ',1PE9.2
I/,2X,'DISPERSIVITY Z DIRECTION (m)              ',1PE9.2
I/,2X,'PORE VELOCITY (m/y)                      ',1PE9.2
I/,2X,'WELL SCREEN THICKNESS (m)                ',1PE9.2
I/,2X,'DISTANCE TO RECEPTOR ALONG X AXIS      (m) ',1PE9.2
I/,2X,'DISTANCE TO RECEPTOR ALONG Y AXIS      (m) ',1PE9.2
I/,2X,'DISTANCE TO RECEPTOR ALONG Z AXIS      (m) ',1PE9.2)

2250 FORMAT(2X,'DISPERSIVITY X DIRECTION (m)      ',1PE9.2
I/,2X,'DISPERSIVITY Y DIRECTION (m)              ',1PE9.2
I/,2X,'DISPERSIVITY Z DIRECTION (m)              ',1PE9.2
I/,2X,'PORE VELOCITY (m/y)                      ',1PE9.2)

```



```

1/,2X,'AQUIFER THICKNESS (m) ',1PE9.2
1/,2X,'DISTANCE TO RECEPTOR ALONG X AXIS (m) ',1PE9.2
1/,2X,'DISTANCE TO RECEPTOR ALONG Y AXIS (m) ',1PE9.2
1/,2X,'WELL SCREEN THICKNESS (m) ',1PE9.2)
2275 FORMAT(2X,'DISPERSIVITY X DIRECTION (m) ',1PE9.2
1/,2X,'DISPERSIVITY Y DIRECTION (m) ',1PE9.2
1/,2X,'DISPERSIVITY Z DIRECTION (m) ',1PE9.2
1/,2X,'PORE VELOCITY (m/y) ',1PE9.2
1/,2X,'AQUIFER THICKNESS (m) ',1PE9.2
1/,2X,'DISTANCE TO RECEPTOR ALONG X AXIS (m) ',1PE9.2
1/,2X,'DISTANCE TO RECEPTOR ALONG Y AXIS (m) ',1PE9.2
1/,2X,'DISTANCE TO RECEPTOR ALONG Z AXIS (m) ',1PE9.2)

2300 FORMAT(2X,A45,1X,1PE9.2)
2400 FORMAT(2X,A45,1X,1PE9.2,1PE9.2,1PE9.2,1PE9.2,1PE9.2,1PE9.2,
11PE9.2,1PE9.2,1PE9.2)
2500 FORMAT(2X,'MASS RELEASE RATE TO POND (mg or Ci per y) ',1PE9.2
1/,2X,'OPERATION TIME OF POND (years) ',1PE9.2
1/,2X,'LIQUID EFFLUENT FLOW RATE TO POND (m**3/y) ',1PE9.2
1/,2X,'MOISTURE CONTENT OF UNDERLYING SEDIMENTS ',1PE9.2
1/,2X,'EVAPORATION RATE CONSTANT FROM POND (y**-1) ',1PE9.2
1/,2X,'EFFECTIVE WIDTH OF POND AT AQUIFER (m) ',1PE9.2)
2550 FORMAT(2X,'UNITS OF CONTAMINANT ',a2
1/,2X,'
1/,2X,'INPUT DATA FILE CREATED BY: _____ DATE / / '
1/,2X,'
1/,2X,'INPUT DATA CHECKED BY: _____ DATE / / '
1/,2X,'
1/,2X,'-----')
2600 FORMAT(2X,'>>> INITIAL ACTIVITY CONVERTED TO MASS (mg) ',1PE9.2)
2700 FORMAT(2X,'EXECUTION TIME (seconds) ',i6)
999 END
C .....
C SUBROUTINE INPUT
C .....
SUBROUTINE INPUT(XDUMMY,T1,T2,TP,KFLAG,INTIME,IFLAG,IMODEL,
IISOLVE,NN,NPROG,NTIMES)
implicit real*8 (a-h,o-z)
C THIS SUBROUTINE READS THE INPUT FILE

.
.
. Identification
.
. Program Name: GWSCREEN
. Module Name: input.f Version: 1.16
. Date: 3/10/94 Time: 10:12:13
.

COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
I QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW,RC2,IMODE,
I ITYPE
COMMON /SOURCE/ THETAS, THETAU, RHOS, THICKS, zKDS,
I DEPTH, PERC, THALF,RHOA, zKDU, RHOU, QM
COMMON /POND/ RMI,TOPE,PNDFLX,THETAP,EVAP,PLEACH,WAEFF
PARAMETER (NSPEC=9)
COMMON /DECAY/ ADCF,AKD,ATHALF,ARD,ARADMAX,RCSF
DIMENSION ADCF(NSPEC),AKD(NSPEC),ATHALF(NSPEC),ARADMAX(NSPEC)
I,ARD(NSPEC),RCSF(NSPEC)
COMMON /EXPOSURE/BW,AT,WI,EF,ED,DLIM,CRISK,HQ
COMMON /FILES/ FILEIN,FILEOU,TITLE
CHARACTER*40 FILEIN,FILEOU
CHARACTER*78 TITLE
COMMON /SIMP/ EPS,JMAX,JSTART
COMMON /TABLE/ ATIME,QREL,NP
PARAMETER (NPOINTS=1000)
DIMENSION ATIME(NPOINTS),QREL(NPOINTS)
DIMENSION T1(NSPEC),T2(NSPEC),TP(NSPEC)
CHARACTER*10 TTIME
CHARACTER*10 DDATE

```

```

Character idkeyw*72
Data idkeyw /'@(#)input.f1.16 3/10/84 10:12:13\0'/
idkeyw = idkeyw
IFLAG=0
C IFLAG CHECKS ERRORS IN INPUT DECK. IF AN ERROR IS DETECTED THEN
C IFLAG IS SET EQUAL TO 1 AND THE PROGRAM IS TERMINATED
C BL=THE MINIMUM ACCEPTABLE VALUE
C BH=MAXIMUM ACCEPTABLE VALUE
C KLINE=LINE NUMBER OF RECORD
C KREC=RECORD NUMBER

C .....
C .....
C ..... READ IN DATA .....
C .....
C .....

CALL TIME(TTIME)
CALL DATE(DDATE)
c CALL DATTIM(DDATE,TTIME,TIMNEW)
WRITE(*,1500)
write(*,*)
WRITE(*,1200)
1200 format(1x,'ENTER FILE WHICH CONTAINS INPUT DATA [GWSCREEN.PAR] >>>
! ')
READ(*,1201) FILEIN
IF(ICHAR(FILEIN(1:1)).EQ.32)THEN
FILEIN='GWSCREEN.PAR'
ENDIF
1201 format(a40)
3 WRITE(*,1202)
1202 format(1x,'ENTER FILE TO WRITE OUTPUT TO [GWSCREEN.OUT] >>>')
READ(*,1201) FILEOU
IF(ICHAR(FILEOU(1:1)).EQ.32)THEN
FILEOU='GWSCREEN.OUT'
ENDIF
IF(FILEIN.EQ.FILEOU)THEN
WRITE(*,*) '*** OUTPUT FILE WILL OVERWRITE INPUT FILE !!!!!!!!'
GOTO 3
ENDIF

OPEN(unit=1,file=FILEIN, STATUS='OLD')
OPEN(unit=2,file=FILEOU, STATUS='UNKNOWN')
WRITE(2,*) 'TIME OF RUN ',TTIME
WRITE(2,*) 'DATE OF RUN ',DDATE
WRITE(2,*) 'INPUT FILE NAME: ',FILEIN
WRITE(2,*) 'OUTPUT FILE NAME: ',FILEOU
CALL LICENSE
C .....TITLE
READ(1,1205) TITLE
1205 format(a78)
KLINE=2
KREC=1
C ..... KFLAG, NPROG
READ(1,*) KFLAG,NPROG
VI=FLOAT(KFLAG)
BL=0.0
BH=1.0
CALL CHECK(VI,KLINE,KREC,BL,BH,IFLAG)
VI=FLOAT(NPROG)
BL=0.0
BH=8.0
KREC=KREC+1
CALL CHECK(VI,KLINE,KREC,BL,BH,IFLAG)
NN=NPROG+1
C ..... INTIME,ITYPE
READ(1,*) INTIME,ITYPE
VI=FLOAT(INTIME)
BL=0.0

```

```

BH=1.0E3
KLINE=KLINE+1
KREC=1
CALL CHECK(VI,KLINE,KREC,BL,BH,IFLAG)
VI=FLOAT(ITYPE)
BL=0.0
BH=2.
KREC=2
CALL CHECK(VI,KLINE,KREC,BL,BH,IFLAG)
C ***** AL WA THICKS
KLINE=KLINE+1
KREC=1
READ(1,*) AL,WA,THICKS
BL=1.0
BH=1.0E4
CALL CHECK(AL,KLINE,KREC,BL,BH,IFLAG)
KREC=KREC+1
CALL CHECK(WA,KLINE,KREC,BL,BH,IFLAG)
KREC=KREC+1
BL=1.0E-3
CALL CHECK(THICKS,KLINE,KREC,BL,BH,IFLAG)

C ***** PERC THETAS THETAU
KLINE=KLINE+1
READ(1,*) PERC,THETAS,THETAU
KREC=1
BL=1.0E-4
BH=1.0E6
CALL CHECK(PERC,KLINE,KREC,BL,BH,IFLAG)
KREC=KREC+1
BL=1.0E-8
BH=9.999999E-1
CALL CHECK(THETAS,KLINE,KREC,BL,BH,IFLAG)
KREC=KREC+1
CALL CHECK(THETAU,KLINE,KREC,BL,BH,IFLAG)

C ***** RHOS ZKDS RC2
READ(1,*) RHOS,zKDS,RC2
KLINE=KLINE+1
KREC=1
BH=1.0E1
BL=1.0E-2
CALL CHECK(RHOS,KLINE,KREC,BL,BH,IFLAG)
KREC=KREC+1
BL=0.0
BH=1.0E18
CALL CHECK(ZKDS,KLINE,KREC,BL,BH,IFLAG)
KREC=KREC+1
CALL CHECK(RC2,KLINE,KREC,BL,BH,IFLAG)

C ***** RHOU ZKDU
READ(1,*) RHOU,zKDU
KLINE=KLINE+1
KREC=1
BH=1.0E1
BL=1.0E-2
CALL CHECK(RHOU,KLINE,KREC,BL,BH,IFLAG)
KREC=KREC+1
BL=0.0
BH=1.0E18
CALL CHECK(ZKDU,KLINE,KREC,BL,BH,IFLAG)

C ***** THALF
READ(1,*) (ATHALF(J),J=1,NN)
KLINE=KLINE+1
DO 20,I=1,NN
  IF(ATHALF(I).LE.0.0)THEN
    ATHALF(I)=1.0E38
  ENDIF

```

```

20 CONTINUE
  THALF=ATHALF(1)
C ***** QX ZMW SL
  KLINE=KLINE+1
  KREC=1
  BH=1.0E38
  BL=0.0
  READ(1,*) QX,ZMW,SL
  CALL CHECK(QX,KLINE,KREC,BL,BH,IFLAG)
  QI=1.0
  BL=1.0E-18
  KREC=KREC+1
  CALL CHECK(SL,KLINE,KREC,BL,BH,IFLAG)
  KREC=KREC+1
  CALL CHECK(ZMW,KLINE,KREC,BL,BH,IFLAG)
C ***** RHOA PHI AKD
  READ(1,*) RHOA,PHI,(AKD(I),I=1,NN)
  KLINE=KLINE+1
  KREC=1
  BL=0.01
  BH=10.
  CALL CHECK(RHOA,KLINE,KREC,BL,BH,IFLAG)
  KREC=2
  BL=1.0E-10
  BH=0.9999999999999999
  CALL CHECK(PHI,KLINE,KREC,BL,BH,IFLAG)
  BL=0.0
  BH=1E18
  KREC=3
  DO 30,J=1,NN
    CALL CHECK(AKD(J),KLINE,KREC,BL,BH,IFLAG)
    KREC=KREC+1
30 CONTINUE
C ***** AX AY VX
  READ(1,*) AX,AY,AZ,VX
  KLINE=KLINE+1
  KREC=1
  BL=1.0E-10
  BH=1.0E6
  CALL CHECK(AX,KLINE,KREC,BL,BH,IFLAG)
  KREC=KREC+1
  CALL CHECK(AY,KLINE,KREC,BL,BH,IFLAG)
  KREC=KREC+1
  CALL CHECK(AZ,KLINE,KREC,BL,BH,IFLAG)
  KREC=KREC+1
  CALL CHECK(VX,KLINE,KREC,BL,BH,IFLAG)

C ***** THICK DEPTH
  READ(1,*) THICK,DEPTH
  KLINE=KLINE+1
  KREC=1
  CALL CHECK(THICK,KLINE,KREC,BL,BH,IFLAG)
  KREC=KREC+1
  BL=0.0
  CALL CHECK(DEPTH,KLINE,KREC,BL,BH,IFLAG)
  KREC=KREC+1

C ***** IMODE IMODEL
  READ(1,*) IMODE,IMODEL
  KREC=1
  KLINE=KLINE+1
  VI=FLOAT(IMODE)
  BL=1.0
  BH=6.0
  CALL CHECK(VI,KLINE,KREC,BL,BH,IFLAG)
  IF(IMODE.GT.3.AND.NN.GT.1)THEN
    WRITE(*,*) 'ERROR: DECAY PRODUCTS ARE NOT CALCULATED FOR NON-
    IRADIOLOGICAL SPECIES'
    IFLAG=1

```

```

    RETURN
ENDIF
IF(IIMODEL.GT.2.AND.KFLAG.GT.0)THEN
    WRITE(*,*) 'ERROR: PEAK CONCENTRATION ROUTINE NOT ALLOWED WHEN
IIMODEL=3 (TABULATED SOURCE FUNCTION)'
    IFLAG = 1
    RETURN
ENDIF
BH = 3
KREC = 2
VI = FLOAT(IIMODEL)
CALL CHECK(VI,KLINE,KREC,BL,BH,IFLAG)
C SET VALUE OF QPOND AND RESET QX TO 1.0 FOR POND MODEL
IF(IIMODEL.EQ.2)THEN
    QI = QX
    QX = 1.0
ENDIF
C ***** RMI, TOPER, PNDFLX, THETAP, EVAP, WAEFF

    READ(1,*) RMI, TOPER, PNDFLX, THETAP, EVAP,WAEFF
    KREC = 1
    KLINE = KLINE + 1

C ***** DCF,RADMAX,ZRADMAX,SFACTOR,RFD
C READ AN ARRAY OF VALUES FOR RADIOLOGICAL DOSE CRITERIA
    KLINE = KLINE + 1
    IF(IIMODEL.LT.4)THEN
        IF(IIMODEL.EQ.1)THEN
            READ(1,*) (ADCF(I),I=1,NN)
        ENDIF
        IF(IIMODEL.EQ.2)THEN
            READ(1,*) (RCSF(I),I=1,NN)
        ENDIF
        IF(IIMODEL.EQ.3)THEN
            READ(1,*) (ARADMAX(I),I=1,NN)
        ENDIF
        ELSE
            READ(1,*) XDUMMY
        ENDIF
C XDUMMY WILL BE CONVERTED TO THE PROPER VALUE IN SUBROUTINE ASSIGN
C ***** XD AND YD AND ZD *****
    KLINE = KLINE + 1
    READ(1,*) XD,YD,ZD
    KREC = 3
    BL = 0.
    BH = THICK
C    zd cannot be greater than aquifer thickness
    CALL CHECK(ZD,KLINE,KREC,BL,BH,IFLAG)

C ***** EXPOSURE DATA *****
    KLINE = KLINE + 1
    READ(1,*) BW,AT,WI,EF,ED,DLIM,CRISK,HQ
C ***** NUMERICAL SOLVER DATA *****
    KLINE = KLINE + 1
    READ(1,*) ISOLVE,JSTART,JMAX,EPS
    KREC = 1
    BL = 1
    BH = 2
    VI = FLOAT(ISOLVE)
    CALL CHECK(VI,KLINE,KREC,BL,BH,IFLAG)
    IF(JSTART.GE.JMAX)THEN
        IFLAG = 1
        WRITE(*,*) 'ERROR: JSTART MUST BE LESS THAN JMAX'
        RETURN
    ENDIF
    KREC = 2
    BL = 6
    BH = 14
    VI = FLOAT(JSTART)

```

```

CALL CHECK(VI,KLINE,KREC,BL,BH,IFLAG)
BL=7
BH=15
KREC=3
VI=FLOAT(JMAX)
CALL CHECK(VI,KLINE,KREC,BL,BH,IFLAG)
KREC=4
BL=1E-6
BH=1.0
CALL CHECK(EPS,KLINE,KREC,BL,BH,IFLAG)
C ***** READ TIME PRINT-OUT TIMES IF KFLAG=0 AND SOURCE TABLE
IF(KFLAG.LT.1)THEN
  READ(1,*) NTIMES
  DO 50,I=1,NTIMES
    READ(1,*) T1(I),T2(I),TP(I)
50  CONTINUE
  IF(IMODEL.GT.2)THEN
    NP=0
    DO 60, I=1,1000
      READ(1,*,END=09) ATIME(I),QREL(I)
      NP=NP+1
60  CONTINUE
    ENDIF
  ENDIF

09 CLOSE(1,STATUS='KEEP')
1000 WRITE(2,1500)
  WRITE(2,*) ' >>> TITLE OF PROJECT:'
  WRITE(2,*) ' ',TITLE
  WRITE(2,*) ' -----
  !~~~~~'
  IF(ISOLVE.LT.2)THEN
    WRITE(2,2000)
  ELSE
    WRITE(2,2100) JSTART,JMAX,EPS
  ENDIF
  RETURN

1500 FORMAT(2X,' .....
  !/,2X,' * "
  !/,2X,' * This output was produced by the model: "
  !/,2X,' * "
  !/,2X,' * GWSCREEN "
  !/,2X,' * Version Control Copy, Version 2.4 "
  !/,2X,' * A semi-analytical model for the assessment "
  !/,2X,' * of the groundwater pathway from the leaching "
  !/,2X,' * of surficial and buried contamination and "
  !/,2X,' * release of contaminants from percolation ponds "
  !/,2X,' * 03-10-94 "
  !/,2X,' * Arthur S. Rood "
  !/,2X,' * Idaho National Engineering Laboratory "
  !/,2X,' * EG&G Idaho Inc. "
  !/,2X,' * Subsurface and Environmental Modeling Unit "
  !/,2X,' * PO Box 1625 "
  !/,2X,' * Idaho Falls, Idaho 83415 "
  !/,2X,' .....
2000 FORMAT(2X,'GAUSSIAN QUADRATURE SOLUTION')
2100 FORMAT(2X,'SIMPSON RULE SOLUTION')
  !/,2X,'JSTART = ',I2
  !/,2X,'JMAX = ',I2
  !/,2X,'EPS = ',1PE11.4)
  END
  SUBROUTINE LICENSE
  *
  * Identification
  *
  * Program Name: GWSCREEN
  * Module Name: license.f Version: 1.4
  * Date: 3/8/94 Time: 11:51:08

```

```

*
Character idkeyw*72
Data idkeyw /'@(#)license.f1.4 3/8/94 11:51:08\0'/
idkeyw = idkeyw
c WRITE(*,1000)
c WRITE(*,2000)
c WRITE(*,3000)
WRITE(2,1000)
WRITE(2,2000)
WRITE(2,3000)
RETURN

```

```

1000 FORMAT(2X,'=====
!=====
!/,2X,' ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND'
!/,2X,' LIMITATION OF LIABILITY '
!/,2X,'
!/,2X,'This material resulted from work developed under U.S. Departm
lent of'
!/,2X,'Energy, Office of Environmental Restoration and Waste Manage
lment,'
!/,2X,'DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.'
!/,2X,'This material is subject to a limited government license:'
!/,2X,'Copyright 1993, EG&G Idaho Inc., Idaho National Engineering
Laboratory,'
!/,2X,'all rights reserved. Neither the United States nor the Unit
led States'
!/,2X,'Department of Energy, nor any of their employees, makes any
lwarranty')

```

```

2000 FORMAT(2X,'expressed or implied, or assumes any legal liability or
!'
!/,2X,'responsibility for the accuracy, completeness, or usefulness
! of any'
!/,2X,'information, apparatus, product or process disclosed, or rep
resents that'
!/,2X,'its use would not infringe on privately owned rights. Subrou
ltines GOLDEN,')

```

```

3000 FORMAT(2X,'QSIMP, QGAUS, and TRAPZD are Copyright (C) 1992, Numeri
lcal Recipes'
!/,2X,'Software. Reproduced by permission from the book, Numerical
! Recipes,'
!/,2X,'Cambridge University Press.'
!/,2X,'=====
!=====
!/,2X,'
!/,2X,'
END

```

```

C .....
C SUBROUTINE CHECK
C .....
SUBROUTINE CHECK(VI,KLINE,KREC,BL,BH,IFLAG)
implicit real*8 (a-h,o-z)
C THIS SUBROUTINE CHECKS THE INPUT DATA
*
* Identification
*
* Program Name: GWSCREEN
* Module Name: checkn.f Version: 1.1
* Date: 4/6/93 Time: 16:46:46
*
Character idkeyw*72
Data idkeyw /'@(#)checkn.f 1.1 4/6/93 16:46:46\0'/
idkeyw = idkeyw

IF(VI.GE.BL.AND.VI.LE.BH)THEN

```

```

      RETURN
    ELSE
      WRITE(*,100) KLINE,KREC,VI,BH,BL
      IFLAG = 1
      PAUSE
    ENDIF
100 FORMAT(1X,'ERROR: IN LINE NUMBER ',I3,' RECORD ',I2,
  I/,1X,'VALUE OUT OF ACCEPTED BOUNDS'
  I/,1X,'INPUT VALUE: ',1PE11.4
  I/,1X,'ACCEPTED UPPER VALUE: ',1PE11.4
  I/,1X,'ACCEPTED LOWER VALUE: ',1PE11.4)
      RETURN
    END

```

```

C .....
C SUBROUTINE CTIME
C .....
SUBROUTINE CTIME(UNITS,TSL,TRANSIT,ADLR,T1,T2,TP,SFACTOR,RFD,
  IISOLVE,IMODEL,NN,NTIMES,INTIME,KFLAG,IMODE)

  IMPLICIT REAL*8(A-H,O-Z)

  *
  * Identification
  *
  * Program Name: GWSCREEN
  * Module Name: ctime.f Version: 1.4
  * Date: 3/8/94 Time: 16:47:28
  *
C CMAX=VARIABLE TO HOLD MAXIMUM CONCENTRATION
  PARAMETER (NSPEC=9)

  COMMON /EXPOSURE/BW,AT,WI,EF,ED,DLIM,CRISK,HQ
  COMMON /DECAY/ ADCF,AKD,ATHALF,ARD,ARADMAX,RCSF
  COMMON /FILES/ FILEIN,FILEOU,TITLE
  DIMENSION ADCF(NSPEC),AKD(NSPEC),ATHALF(NSPEC),ARADMAX(NSPEC),
  I,ARD(NSPEC),RCSF(NSPEC)
  DIMENSION ADLR(NSPEC),CONC(NSPEC),Q(NSPEC),QDX(NSPEC),DAIC(NSPEC)
  DIMENSION T1(NSPEC),T2(NSPEC),TP(NSPEC),AC(NSPEC),DAC(NSPEC,NSPEC)
  DIMENSION CMAX(NSPEC),TMAX(NSPEC),DOSE(NSPEC),PDOSE(NSPEC),
  IADOSE(NSPEC,NSPEC),TADOSE(NSPEC)
  CHARACTER*2 UNITS
  CHARACTER*78 TITLE
  CHARACTER*40 FILEIN,FILEOU
  CHARACTER SPC*12, MBR*8

  Character idkeyw*72
  Data idkeyw/'@(#)ctime.f 1.3 9/15/93 13:44:39\0'/
  idkeyw = idkeyw

  SPC='-----'
  MBR='member #'
  DO 5,I=1,NN
    CMAX(I)=0.0
5  CONTINUE

c only open dose file if imode <> 3 or 4
  IF(IMODE.NE.3.AND.IMODE.NE.4)THEN
    OPEN(3,FILE='DOSE.OUT',STATUS='UNKNOWN')
    WRITE(3,9000) IMODE,TITLE
  END IF

  WRITE(*,*) ' >>> CONCENTRATION VS TIME MODE '
  WRITE(2,*) ' >>> CONCENTRATION VS TIME MODE '
  IF(T2(NTIMES).LT.TRANSIT)THEN
    WRITE(*,300) T2(NTIMES),TRANSIT
    WRITE(2,300) T2(NTIMES),TRANSIT

```



```

RETURN
ENDIF
write(2,*)
IF(IMODE.LT.3)THEN
c   WRITE(*,500) (MBR,I,I=1,NN)
   WRITE(2,500) (MBR,I,I=1,NN)
c   write(*,700) units,units,units,units,(SPC,I=1,NN)
   write(2,700) units,units,units,units,(SPC,I=1,NN)
   ELSE
   WRITE(2,3000) (MBR,I,I=1,NN)
   WRITE(2,3500) UNITS
   WRITE(2,4000) (SPC,I=1,NN)
ENDIF

DO 10,I=1,NTIMES
TSTART=T1(I)
TEND=T2(I)
TPRINT=TP(I)
TADOSE(I)=0.0
DO 41 T=TSTART,TEND,TPRINT
TX=T-TRANSIT
IF(TX.LE.0.)THEN
DO 12,J=1,NN
CONC(J)=0.0
12  CONTINUE
ELSE
CONC(1)=FUNC(TX,TSL,IMODE,ISOLVE)
IF(NN.GT.1)THEN
C   SET PARENT INITIAL ACTIVITY TO 1.0 CI FOR DECAY CALCULATION
C   ALL OTHERS TO 0
Q(1)=1.0
DO 20, J=2,NN
Q(J)=0.0
20  CONTINUE
CALL RDK(T,ADLR,NN,Q,QDX)
DO 30,J=2,NN
CONC(J)=(CONC(1)/QDX(1))*QDX(J)*ARD(1)/ARD(J)
30  CONTINUE
ENDIF
C dose calculation = C(Ci/m3)*WI(L/d)*EF(d/y)*(1 m3/1000 L)*ADCF(rem/Ci) rad
C risk for rad = C(Ci/m3)*WI(L/d)*EF(d/y)*ED(y)*SF(1/Ci)*1m3/1000L
C risk for non rad carcin C(mg/m3)*WI(L/d)*EF(d/y)*ED(y)*SF(kg-d/mg))/(BW(kg)*AT(d))*1m3/1000L
C HQ calculation = C(mg/m3)*WI(L/d)*(1m3/1000L)*EF(d/y)*ED(y)/(BW(kg)*AT(d)*Rfd(mg/kg/d))

DO 35,K=1,NN
IF(CONC(K).GT.CMAX(K))THEN
CMAX(K)=CONC(K)
TMAX(K)=T
IF(IMODE.EQ.1)THEN
PDOSE(K)=CMAX(K)*WI*EF*ADCF(K)/1000.
ENDIF
IF(IMODE.EQ.2)THEN
PDOSE(K)=CMAX(K)*WI*EF*ED*RCSF(K)/1000.
ENDIF
IF(IMODE.EQ.5)THEN
PDOSE(K)=CMAX(K)*WI*EF*ED*SFACTOR/(AT*BW*1000)
ENDIF
IF(IMODE.EQ.6)THEN
PDOSE(K)=CMAX(K)*WI*EF*ED/(BW*AT*1000.*RFD)
ENDIF
ENDIF
35  CONTINUE
ENDIF
C compute dose
TDOSE=0.0
DO 36,K=1,NN
IF(IMODE.EQ.1)THEN
DOSE(K)=CONC(K)*WI*EF*ADCF(K)/1000.
TDOSE=TDOSE+DOSE(K)

```

```

ENDIF
IF(IMODE.EQ.2)THEN
  DOSE(K) = CONC(K) * WI * EF * ED * RCSF(K) / 1000.
  TDOSE = TDOSE + DOSE(K)
ENDIF
IF(IMODE.EQ.5)THEN
  DOSE(K) = CONC(K) * WI * EF * ED * SFACTOR / (AT * BW * 1000)
ENDIF
IF(IMODE.EQ.6)THEN
  DOSE(K) = CONC(K) * WI * EF * ED / (BW * AT * 1000. * RFD)
ENDIF
36 CONTINUE
IF(IMODE.LT.3)THEN
  CALL FLUXES(RELSRC,RELAQU,FAQU,TSL,T,TRANSIT,IMODE)
  IF(T.EQ.(TSTART + TPRINT).OR.T.EQ.(TEND-TPRINT))THEN
    WRITE(*,800) T,RELSRC,RELAQU,FAQU,(CONC(J),J=1,NN)
  ENDIF
  WRITE(2,800) T,RELSRC,RELAQU,FAQU,(CONC(J),J=1,NN)
  IF(IMODE.NE.3.AND.IMODE.NE.4)THEN
    IF(NN.GT.1)THEN
      WRITE(3,5000) T,(DOSE(J),J=1,NN),TDOSE
    ELSE
      WRITE(3,5000) T,(DOSE(J),J=1,NN)
    ENDIF
  ENDIF
  ELSE
    IF(T.EQ.(TSTART + TPRINT).OR.T.EQ.(TEND-TPRINT))THEN
      WRITE(*,5000) T,(CONC(J),J=1,NN)
    end if
    WRITE(2,5000) T,(CONC(J),J=1,NN)
    IF(IMODE.NE.3.AND.IMODE.NE.4)THEN
      IF(NN.GT.1)THEN
        WRITE(3,5000) T,(DOSE(J),J=1,NN),TDOSE
      ELSE
        WRITE(3,5000) T,(DOSE(J),J=1,NN)
      ENDIF
    ENDIF
  ENDIF
ENDIF
41 CONTINUE

C INTEGRATE CONCENTRATION FOR OUTPUT YEARS; DUMMY IS VARIABLE FOR
C HOLDING PEAK CONC AND TIME OF PEAK -- THESE OPTIONS ARE NOT UTILIZED
C IN THIS SUBROUTINE.
IF(TEND.GT.TRANSIT.AND.INTIME.GT.0)THEN
  DUMMY1 = 1.0
  DUMMY2 = 1.0
  T11 = TEND - TSTART
  T12 = T11 / 2 + TSTART - TRANSIT
  CALL GWINT(T11,T12,TRANSIT,TSL,AIC,DAIC,ADLR,DUMMY1,DUMMY2,
  I IMODE,ISOLVE,NN,KFLAG)
  AC(I) = AIC
C compute health impacts
  IF(IMODE.EQ.1)THEN
    ADOSE(I,1) = AC(I) * WI * EF * ADCF(1) / 1000.
    TADOSE(I) = TADOSE(I) + ADOSE(I,1)
  ENDIF
  IF(IMODE.EQ.2)THEN
    ADOSE(I,1) = AC(I) * WI * EF * ED * RCSF(1) / 1000.
    TADOSE(I) = TADOSE(I) + ADOSE(I,1)
  ENDIF
  IF(IMODE.EQ.5)THEN
    ADOSE(I,1) = AC(I) * WI * EF * ED * SFACTOR / (AT * BW * 1000)
  ENDIF
  IF(IMODE.EQ.6)THEN
    ADOSE(I,1) = AC(I) * WI * EF * ED / (BW * AT * 1000. * RFD)
  ENDIF
  IF(NN.GT.1)THEN
    DO 15,J=2,NN
      DAC(I,J) = DAIC(J)
  ENDIF

```

```

C compute health impacts for progeny
  IF(IMODE.EQ.1)THEN
    ADOSE(I,J)=DAC(I,J)*WI*EF*ADCF(J)/1000.
    TADOSE(I)=TADOSE(I)+ADOSE(I,J)
  ENDIF
  IF(IMODE.EQ.2)THEN
    ADOSE(I,J)=DAC(I,J)*WI*EF*ED*RCSF(J)/1000.
    TADOSE(I)=TADOSE(I)+ADOSE(I,J)
  ENDIF
15  CONTINUE
  ENDIF
ENDIF
10 CONTINUE

C compute health impacts for integrated concentration

  IF(INTIME.GT.0)THEN
    DO 60,I=1,NTIMES
      WRITE(2,1000) T1(I),T2(I),AC(I),units
      IF(IMODE.NE.3.AND.IMODE.NE.4)THEN
        WRITE(3,1100) T1(I),T2(I),ADOSE(I,1)
      ENDIF
      IF(NN.GT.1)THEN
        DO 50,J=2,NN
          WRITE(2,2000) J,DAC(I,J),UNITS
          IF(IMODE.NE.3.AND.IMODE.NE.4)THEN
            WRITE(3,2100) J,ADOSE(I,J)
          ENDIF
50      CONTINUE
        ENDIF

        IF(IMODE.NE.3.AND.IMODE.NE.4)THEN
          WRITE(3,2200) TADOSE(I)
        ENDIF
60    CONTINUE
      ENDIF
      WRITE(2,6000) UNITS, (CMAX(I),I=1,NN)
      WRITE(2,7000) (TMAX(I),I=1,NN)
      IF(IMODE.NE.3.AND.IMODE.NE.4)THEN
        WRITE(3,8000) (PDOSE(I),I=1,NN)
      ENDIF
300  FORMAT(2X,'CONCENTRATION IS ZERO FOR ALL TIME PERIODS REQUESTED'
  //,2X,'LAST TIME PERIOD REQUESTED (T2): ',1PE11.4,' YEARS'
  //,2X,'TRANSIT TIME IN UNSATURATED ZONE: ',1PE11.4,' YEARS')

500  FORMAT(3X,'TIME      CUMULATIVE CUMULATIVE AQUIFER    GW CO
  INC ... '
  //,3X,'          SOURCE FLUX AQUIFER FLUX  FLUX',6X,
  //,1A8,I1,3X,A8,I1,3X,A8,I1,3X,A8,I1,3X,A8,I1,3X,A8,I1,3X,A8,
  //,1I1,3X,A8,I1)

700  FORMAT(2X,' (years)',7x,'('',a2,'')',9X,'('',a2,'')',6x,'('',a2,'')/year)
  //,3X,'('',a2,'')/m**3)'
  //,2x,'-----',
  //,1A12,A12,A12,A12,A12,A12,A12,A12,A12)

800  FORMAT(2X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1
  //,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,
  //,1PE11.4,1X,1PE11.4)

1000 FORMAT(2X,'AVERAGE INTEGRATED CONCENTRATION FROM ',1PE11.4,1X,'TO'
  //,1X,1PE11.4,1X,'YEARS = ',1PE9.2,1X,a2,'/m**3')
1100 FORMAT(2X,'AVERAGE INTEGRATED DOSE FROM ',1PE11.4,1X,'TO',1X,
  //,1PE11.4,1X,'YEARS = ',1PE9.2)

2000 FORMAT(2X,'AVERAGE INTEGRATED CONCENTRATION FOR MEMBER #',I1,1X,
  //,1PE11.4,1X,a2,'/m**3')
2100 FORMAT(2X,'AVERAGE INTEGRATED DOSE FOR MEMBER #',I1,1X,
  //,1PE11.4)

```

```

2200 FORMAT(2X,'AVERAGE INTEGRATED DOSE FOR ALL MEMBERS',1X,
11PE11.4)

3000 FORMAT(2X,' TIME GW CONC.',
1/2X,' (years) ',A8,I1,3X,A8,I1,3X,A8,I1,3X,A8,I1,3X,
1A8,I1,3X,A8,I1,3X,A8,I1)
3500 FORMAT(15X,a2,'/m**3')
4000 FORMAT(2X,'-----',A12,A12,A12,A12,A12,A12,A12,A12)
5000 FORMAT(2X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1
1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4)

6000 FORMAT(2X,'MAXIMUM CONCENTRATION(S)',1X,A2,'/m**3'
1/2X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,
11PE9.2,1X,1PE9.2,1X,1PE9.2)

7000 FORMAT(2X,'TIME(S) OF MAXIMUM CONCENTRATIONS (years)'
1/2X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,
11PE9.2,1X,1PE9.2,1X,1PE9.2)

8000 FORMAT(2X,'MAXIMUM DOSE '
1/2X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,1PE9.2,1X,
11PE9.2,1X,1PE9.2,1X,1PE9.2)

9000 FORMAT(1X,'GWSCREEN DOSE CALCULATIONS FOR IMODE = ',I1
1/1X,'UNITS OF OUTPUT IMODE=1, rem;IMODE=2 AND 5, risk;IMODE=6, HQ'
1/1X,'TITLE: ',a78
1/1X,'TIME (years) DOSE OR RISK FOR MEMBER n AND TOTAL')

```

```

RETURN
END

```

```

C .....
C * FUNCTION FUNC(TI,TSL,IMODEL,ISOLVE) *
C .....
C This function calls the QGAUS2 routine to calculate the groundwater
C concentration at a point in time

```

```

REAL*8 FUNCTION FUNC(TI,TSL,IMODEL,ISOLVE)
IMPLICIT REAL*8(A-H,O-Z)

```

```

*
* Identification
*
* Program Name: GWSCREEN
* Module Name: func.f Version: 1.1
* Date: 4/6/93 Time: 17:06:52
*
Character idkeyw*72
Data idkeyw /'@(#)func.f 1.1 4/6/93 17:06:52\0'/
idkeyw = idkeyw

```

```

IF(ISOLVE.LT.2)THEN
CALL QGAUS2(TI,G,TSL,IMODEL)
ELSE
CALL SIMPSON(TI,G,TSL,IMODEL)
ENDIF
FUNC=G
RETURN
END

```

```

C .....
C SUBROUTINE FLUXES
C .....
SUBROUTINE FLUXES(RELSRC,RELAQU,FAQU,TSL,T,TRANSIT,IMODEL)
Implicit real*8 (a-h,o-z)

```

```

C This subroutine calculates the fluxes from the source volume
C and to the aquifer. Corrected 11-92 for missing decay term in
C flux and cumulative flux terms.

```

C RELSRC = CUMULATIVE FLUX FROM SOURCE
 C RELAQU = CUMULATIVE FLUX TO AQUIFER
 C TSRC = THE SOURCE RELEASE TIME FRAME
 C TAQU = THE AQUIFER RELEASE TIME FRAME
 C FAQU = FLUX OF CONTAMINANT TO AQUIFER

COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
 I QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW, RC2, IMODE,
 I ITYPE

COMMON /POND/ RMI, TOPER, PNDFLX, THETAP, EVAP, PLEACH, WAEFF
 PARAMETER (A=6.023E+23, CI=3.7E+10, SEC=3.1536E+7)

```

•
• Identification
•
• Program Name: GWSCREEN
• Module Name: fluxes.f Version: 1.5
• Date: 3/10/94 Time: 10:00:44
•
Character idkeyw*72
Data idkeyw /'@(#)fluxes.f 1.5 3/10/94 10:00:44\0'/
idkeyw = idkeyw
•
•
R1 = EVAP + DLR + PLEACH
R2 = DLR + SLEACH + RC2

C CALCULATE FLUXES FOR POND MODEL
IF (IMODEL.GT.1) THEN
  IF (T.LE.TOPER) THEN
    RELSRC = PLEACH*RMI*T/R1 + PLEACH*RMI*(EXP(-R1*T)-1)/(R1**2)
    I - PLEACH*QI*(EXP(-R1*T)-1)/R1
    TX = T-TRANSIT
    RELAQU = FRAC*(PLEACH*RMI*TX/R1 + PLEACH*RMI*(EXP(-R1*(TX))
    I -1)/(R1**2) - PLEACH*QI*(EXP(-R1*TX)-1)/R1)
    FAQU = FRAC*PLEACH*(RMI/R1*(1-EXP(-R1*TX)) +
    I QI*EXP(-R1*TX))
  ELSE
C T is greater than TOPER
    QMASS = RMI/R1*(1-EXP(-R1*TOPER)) + QI*EXP(-R1*TOPER)
    RELSRC = PLEACH*RMI*TOPER/R1 +
    I PLEACH*RMI*(EXP(-R1*TOPER)-1)/(R1**2) -
    I PLEACH*QI*(EXP(-R1*TOPER)-1)/R1 -
    I SLEACH*QMASS*(EXP(-R2*(T-TOPER))-1)/R2
    IF (T.GT.(TOPER + TRANSIT)) THEN
C T is greater than TOPER and T is greater than TRANSIT;
C Assume T is greater than TRANSIT since this case is taken care
C of later since RELAQU=0 and FAQU=0 if T less than TRANSIT
    RELAQU = FRAC*(PLEACH*RMI*TOPER/R1 +
    I PLEACH*RMI*(EXP(-R1*TOPER)-1)/(R1**2)-
    I PLEACH*QI*(EXP(-R1*TOPER)-1)/R1 +
    I SLEACH*QMASS*(1-EXP(-R2*(T-(TOPER + TRANSIT))))/R2)
    FAQU = FRAC*SLEACH*QMASS*EXP(-R2*(T-(TOPER + TRANSIT)))
    ELSE
C T is greater than TOPER and T greater than TRANSIT
C but TOPER + TRANSIT is less than T
    IF ((T-TRANSIT).LE.TOPER) THEN
C ***** pond still operational *****
    TX = T-TRANSIT
    RELAQU = FRAC*(PLEACH*RMI*TX/R1 + PLEACH*RMI*(EXP(-R1*TX)
    I -1)/(R1**2) - PLEACH*QI*(EXP(-R1*TX)-1)/R1)
    FAQU = FRAC*PLEACH*(RMI/R1*(1-EXP(-R1*TX)) +
    I QI*EXP(-R1*TX))
    ELSE
C ***** pond not operational ***** added this case 7/93
    TX = (T-TRANSIT)
    RELAQU = FRAC*(PLEACH*RMI*TOPER/R1 +
  
```

```

      PLEACH*QI*(EXP(-R1*TOPE)-1)/(R1**2)-
      PLEACH*QI*(EXP(-R1*TOPE)-1)/R1 +
      SLEACH*QMASS*(1-EXP(-R2*TX))/R2)
      FAQU=FRAC*SLEACH*QMASS*EXP(-R2*TX)
    ENDIF
  ENDIF
ENDIF
IF(T.LE.TRANSIT)THEN
  FAQU=0.0
  RELAU=0.0
ENDIF
RETURN
ENDIF

C  CALCULATE FLUXES FOR INTITAL MASS MODEL, NO SOLUBIL CONTROL
IF(TSL.EQ.0.0)THEN
  IF(T.LE.TRANSIT)THEN
    FAQU=0.0
    RELAU=0.0
    RELSRC=QI*(SLEACH/R2)*(1-EXP(-R2*T))
    RETURN
  ELSE
    RELSRC=QI*(SLEACH/R2)*(1-EXP(-R2*T))
    RELAU=FRAC*QI*(SLEACH/R2)*(1-EXP(-R2*(T-TRANSIT)))
    FAQU=FRAC*SLEACH*QI*EXP(-R2*(T-TRANSIT))
  ENDIF
ENDIF

C  CALCULATE FLUXES FOR SOLUBILITY LIMITED CONTROLLED RELEASE
IF(TSL.GT.0.0)THEN
  IF(TSL.GE.T)THEN
    RELSRC=WFLUX*SL*T
  ELSE
    RELSRC=WFLUX*SL*TSL + QSL*(SLEACH/R2)*(1-EXP(-R2*(T-TSL)))
  ENDIF
  IF(TSL.GT.(T-TRANSIT))THEN
    FAQU=FRAC*WFLUX*SL
    RELAU=FRAC*WFLUX*SL*(T-TRANSIT)
  ELSE
    FAQU=FRAC*SLEACH*QSL*EXP(-R2*(T-TRANSIT-TSL))
    RELAU=FRAC*(WFLUX*SL*TSL + QSL*(SLEACH/R2)*
      (1-EXP(-R2*(T-TSL-TRANSIT))))
  ENDIF
ENDIF

C  Convert mass to activity if a radionuclide for solubility limited
C  RELEASE CONVERT MG TO CI. USE THE CONVERSIONS 1 CI=3.7E10 DPS,
C  3.1536 S/Y 6.023E23 ATOMS/MOLE AND 1000 MG/G
IF(IMODE.LE.3)THEN
  RELDUM=(RELSRC/(1000*ZMW)*A*(DLR/SEC))/CI
  RELADUM=(RELAU/(1000*ZMW)*A*(DLR/SEC))/CI
  FAQU=FAQU/CI
  RELSRC=RELDUM
  FAQU=FAQU
  RELAU=RELADUM
ENDIF
ENDIF

IF(T.LE.TRANSIT)THEN
  FAQU=0.0
  RELAU=0.0
ENDIF

RETURN
END

C .....
C  SUBROUTINE SOURCEX
C .....
SUBROUTINE SOURCEX(UX,RDU,TSL,TRANSIT,ADLR,KFLAG,IMODEL,NN,UNITS)
  Implicit real*8 (a-h,o-z)
  PARAMETER (A=6.023E+23, CI=3.7E+10, SEC=3.1536E+7)

```

```

*
* Identification
*
* Program Name: GWSCREEN
* Module Name: sourcex.f Version: 1.6
* Date: 3/10/94 Time: 10:07:13
*
C CALCULATED VALUES IN SOURCE SUBROUTINE
C SLEACH = LEACH RATE CONSTANT (Y-1)
C UX = UNSATURATED PORE VELOCITY (M/Y)
C DLR = DECAY RATE CONSTANT (Y-1)
C RD = RETARDATION COEFFICIENT
C RDU = RETARDATION IN UNSATURATED ZONE
C TRANSIT = TRANSIT TIME IN UNSAT ZONE (Y)
C FRAC = FRACTION OF INVENTORY REMAINING AFTER UNSAT ZONE TRANSIT
C SL = SOLUBILITY LIMIT
C QSL = MASS IN SOURCE WHERE SOLUBILITY LIMIT WOULD BE EXCEEDED IN LEACHATE
C WFLUX = WATER FLUX THROUGH SOURCE COMPARTMENT (L/Y)
C RC= THE SUM OF THE DECAY RATE CONSTANT AND THE ADDITIONAL SOURCE LOSS RATE CONSTANT

COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
! QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW,RC2,IMODE,
! ITYPE
COMMON /SOURCE/ THETAS, THETAU, RHOS, THICKS, zKDS,
! DEPTH, PERC, THALF,RHOA, zKDU, RHOU, QM
PARAMETER (NSPEC=9)
COMMON /DECAY/ ADCF,AKD,ATHALF,ARD,ARADMAX,RCSF
DIMENSION ADCF(NSPEC),AKD(NSPEC),ATHALF(NSPEC),ARADMAX(NSPEC)
!,ARD(NSPEC),RCSF(NSPEC)
COMMON /POND/ RMI,TOPEP,PNDFLX,THETAP,EVAP,PLEACH,WAEFF
COMMON /TABLE/ ATIME,QREL,NP
PARAMETER (NPOINTS=1000)
DIMENSION ATIME(NPOINTS),QREL(NPOINTS)
DIMENSION ADLR(NSPEC)
Character idkeyw*72,UNITS*2
Data idkeyw/'@(#)sourcex.f' 1.6 3/10/94 10:07:13\0'/
idkeyw = idkeyw

C CALCULATE LEACH RATE CONSTANT (y-1)
SLEACH=PERC/(THETAS*THICKS*(1+zKDS*RHOS/THETAS))
C CALCULATE POND LEACH RATE CONSTANT PORE VEL IN UNSAT
IF(IMODEL.EQ.2)THEN
PLEACH=(PNDFLX/(AL*WA))/((THETAP*THICKS*(1+ZKDS*RHOS/THETAP))
UX=PNDFLX/(AL*WA)/THETAU
ELSE
UX=PERC/THETAU
ENDIF
C CALCULATE DECAY RATE (y-1) IF THALF = 1E38 THEN DLR=0
DO 20,I=1,NN
IF(ATHALF(I).EQ.1.0E+38)THEN
ADLR(I)=0.0
ELSE
ADLR(I)=LOG(2.)/ATHALF(I)
ENDIF
20 CONTINUE
DLR=ADLR(1)
C CALCULATE RD IN AQUIFER
DO 30, I=1,NN
ARD(I)=1+AKD(I)*RHOA/PHI
30 CONTINUE
RD=ARD(1)
WRITE(2,3000)
C CALCULATE FRACTION DECAYED DURING UNSAT ZONE TRANSIT
C RDU = retardation in unsaturated zone,
C TRANSIT = UNSATURATED TRANSIT TIME
RDU=1+zKDU*RHOU/THETAU
TRANSIT=DEPTH*RDU/UX
ARG=-DLR*TRANSIT
FRAC=EXP(-ARG)

```

```

C  CALCULATE WATER FLUX
WFLUX = AL*WA*PERC*1000
C  CALCULATE QSL FROM SL CONVERT LITERS TO M3 BY FACTOR OF 1000
IF(IMODEL.LT.2)THEN
  QSL = SL*AL*WA*THICKS*THETAS*(1 + ZKDS*RHOS/THETAS)*1000
ENDIF
C  CALCULATE MAXIMUM MASS IN SEDIMENT COMPARTMENT FOR POND MODEL
IF(IMODEL.EQ.2)THEN
  QM = RM/((PLEACH + DLR + EVAP)*(1-EXPF(-(PLEACH + DLR + EVAP)*TOPER))
  + Q1*EXPF(-(EVAP + DLR + PLEACH)*TOPER))
C  CONVERT ACTIVITY TO MASS
IF(IMODEL.LE.3)THEN
  QMA = QM
  QM = (((QMA*CI)*SEC*ZMW)/(LOG(2.)/THALF))/A)*1000
ENDIF
QSL = SL*AL*WA*THICKS*THETAP*(1 + ZKDS*RHOS/THETAP)*1000
C  CLS = MAXIMUM CONCENTRATION IN POND SEDIMENTS
CSL = QSL/(AL*WA*THICKS*THETAP*1000)
ENDIF
C  COMPARE QM TO QSL. IF QM IS GREATER QSL THEN CALCULATE TSL, THE TIME THE
C  SOLUBILITY LIMITED RELEASE DOMINATES ONLY IF CONC VS TIME IS DESIRED.
C  LET R = CONTAMINANT FLUX VIA SOLUBILITY = SOL LIMIT X WATER FLUX
IF(IMODEL.LT.2)THEN
  IF(QM.GT.QSL.AND.KFLAG.EQ.0)THEN
    R = WFLUX*SL
    RC = DLR + RC2
    CALL ROOT(R,RC,QM,QSL,TSL)
  ELSE
    TSL = 0.0
  ENDIF
C  CONVERT SOLUBILITY LIMITED MASS TO ACTIVITY
ENDIF
IF(IMODEL.LE.3)THEN
  QACT = (QSL*DLR*(1/3.1536E+07)*6.023E23)/(3.7E10*ZMW*1000)
  ELSE
    QACT = 0.0
  ENDIF
FRACD = 1.00-FRAC
IF(IMODEL.EQ.3)THEN
  SLEACH = 0.
  QSL = 0.0
  QACT = 0.0
ENDIF
WRITE(2,3025) SLEACH,UX
WRITE(2,3050) (ADLR(I),I=1,NN)
WRITE(2,3100) (ARD(I),I=1,NN)
IF(IMODEL.EQ.2)THEN
  WRITE(2,3150) PLEACH
C  SET WA EQUAL TO EFFECTIVE POND WIDTH
WA = WAEFF
ENDIF
WRITE(2,3200) RDU,QSL,QACT,TRANSIT,FRACD

IF(IMODEL.EQ.3)THEN
  WRITE(2,6000) UNITS
  DO 35,I=1,NP
    WRITE(2,7000) ATIME(I),QREL(I)
35  CONTINUE
ENDIF

C  IF INITIAL MASS IS GREATER THAN SOLUBILITY LIMITED MASS THEN PRINT
C  SOLUBILITY LIMITED MASS FLUX IS IN CONTROL FOR THE TIME TSL ONLY FOR
C  NON POND MODEL else print maximum concentration in pond sediments
IF(TSL.GT.0.AND.IMODEL.LT.2)THEN
  WRITE(2,3300)TSL
  WRITE(*,3300)TSL
ENDIF

IF(IMODEL.EQ.2)THEN

```



```

      IF(I.MODE.LE.3)THEN
        WRITE(2,3350) QMA,UNITS
      ELSE
        WRITE(2,3350) QM,UNITS
      ENDIF
    ENDIF

    IF(QM.GT.QSL.AND.I.MODEL.EQ.2)THEN
      WRITE(2,3400) CSL
    ENDIF

3000 FORMAT(2X,'>>> VALUES CALCULATED IN SOURCE SUBROUTINE '
  1/,2X,'.....')

3025 FORMAT(2X,'LEACH RATE CONSTANT (1/y)          ',1PE11.4
  1/,2X,'UNSATURATED PORE VELOCITY (m/y)          ',1PE11.4)

3050 FORMAT(2X,'DECAY CONSTANT(S) (1/y)          ',1PE11.4,
  1PE11.4,1PE11.4,1PE11.4,1PE11.4,1PE11.4,1PE11.4,1PE11.4)

3100 FORMAT(2X,'RETARDATION FACTOR(S) (SATURATED)   ',1PE11.4,
  1PE11.4,1PE11.4,1PE11.4,1PE11.4,1PE11.4,1PE11.4,1PE11.4)

3150 FORMAT(2X,'LEACH RATE CONSTANT FROM POND SEDIMENTS ',1PE11.4)

3200 FORMAT(2X,'RETARDATION FACTOR (UNSATURATED)     ',1PE11.4
  1/,2X,'SOLUBILITY LIMITED MASS (mg)              ',1PE11.4
  1/,2X,'SOLUBILITY LIMITED ACTIVITY (Ci)          ',1PE11.4
  1/,2X,'TRANSIT TIME IN UNSAT ZONE (years)        ',1PE11.4
  1/,2X,'FRACTION DECAYED DURING UNSAT TRANSPORT ',1PE11.4
  1/,2X,'-----')
3300 FORMAT(2X,'>>> SOLUBILITY LIMITED RELEASE FOR ',1PE11.4,' YEARS')

3350 FORMAT(2X,'POND SEDIMENT INVENTORY AT END OF OPERATIONS: ',1PE9.2,
  11X,A2)

3400 FORMAT(2X,'WARNING: THE MAXIMUM CONCENTRATION OF POND SEDIMENT '
  1/,2X,'LEACHATE OF ',1PE9.2,' mg/L EXCEEDS THE SOLUBILITY LIMIT OF'
  1/,2X,'THE CONTAMINANT')

6000 FORMAT(2X,'-----')
  1/,2X,'TABULATED SOURCE FUNCTION'
  1/,2X,'
  1/,2X,' TIME      SOURCE FLUX '
  1/,2X,' (years)   ',a2,'/year'
  1/,2X,'-----')
7000 FORMAT(2X,1PE11.4,2X,1PE11.4)
      RETURN
      END

C .....
C  SUBROUTINE ASSIGN
C .....
      SUBROUTINE ASSIGN(XDUMMY,ZRADMAX,SFACTOR,RFD,INTIME,
        IUNITS,MODE)
        implicit real*8 (a-h,o-z)
      *
      * Identification
      *
      * Program Name: GWSCREEN
      * Module Name: assign.f Version: 1.3
      * Date: 3/10/94 Time: 09:59:30
      *
      COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
        I QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW,RC2,IMODE,
        I ITYPE

      CHARACTER*2 UNITS

```

CHARACTER*45 MODE
 Character idkeyw*72
 Data idkeyw /'@(#)assign.f 1.3 3/10/94 09:59:30\0'/
 idkeyw = idkeyw

C ASSIGN A VALUE TO XDUMMY BASED ON THE VALUE OF IMODE

```

      IF(IMODE.EQ.1)THEN
        UNITS='Ci'
        MODE='RADIOLOGICAL DOSE CONVERSION FACTOR (rem/Ci)'
      C  USER IS WARNED THAT INTIME SHOULD BE SET TO 1.0 FOR RAD CALC
        IF(INTIME.GT.1)THEN
          WRITE(*,11)
          WRITE(2,11)
        ENDIF
      ENDIF

      IF(IMODE.EQ.2)THEN
        UNITS='Ci'
        MODE='RADIOLOGICAL CARCINOGENIC SLOPE FACTOR (1/Ci)'
      ENDIF

      IF(IMODE.EQ.3)THEN
        UNITS='Ci'
        MODE='LIMITING RADIONUCLIDE GW CONCENTRATION (Ci/L)'
      ENDIF

      IF(IMODE.EQ.4)THEN
        ZRADMAX=XDUMMY
        UNITS='mg'
        MODE='LIMITING CONTAMINANT GW CONCENTRATION (mg/L)'
      ENDIF

      IF(IMODE.EQ.5)THEN
        SFACTOR=XDUMMY
        UNITS='mg'
        MODE='CARCINOGENIC SLOPE FACTOR (mg/kg/d)**-1'
      ENDIF

      IF(IMODE.EQ.6)THEN
        RFD=XDUMMY
        UNITS='mg'
        MODE='NON-CARCINOGENIC REFERENCE DOSE Rfd (mg/kg/d)'
      ENDIF

      11 FORMAT('
      //,2X,'WARNING: VARIABLE INTIME SHOULD BE EQUAL TO 1 YEAR'
      //,12X,'FOR RADIOLOGICAL DOSE CALCULATION'
      //,' ')
      RETURN
      END
  
```

```

C
C .....
C
      REAL*8 FUNCTION ERF(X)
      IMPLICIT REAL*8 (A-H,O-Z)
  
```

-
- Identification
-
- Program Name: GWSCREEN
- Module Name: erf.f Version: 1.1
- Date: 6/8/93 Time: 17:40:53
-

Character idkeyw*72
 Data idkeyw /'@(#)erf.f 1.1 6/8/93 17:40:53\0'/

```

idkeyw = idkeyw
A=0.50
IF(X.LT.0.)THEN
    ERF=-GAMMP(A,X**2)
ELSE
    ERF=GAMMP(A,X**2)
ENDIF
RETURN
END

SUBROUTINE ERRORD(X,ERX)
C .....
C * SUBROUTINE ERRORD *
C .....
C This subroutine calculates the error function for an argument, X
C Adapted from Press et al, Numerical RECIPES: modified by A. Rood for
C use with double precision variables. This routine includes the subroutines
C GAMMLN, GSER, GAMMP AND GCF
C
    IMPLICIT REAL*8 (A-H,O-Z)

    IF(X.GE.25.) THEN
        ERX=1.0
    ELSE
        IF(X.LE.-25.) THEN
            ERX=-1.0
        ELSE
            ERX=ERF(X)
        ENDIF
    ENDIF
END
C .....
C * FUNCTION EXPF *
C .....
    REAL*8 FUNCTION EXPF(X)
    IMPLICIT REAL*8 (A-H,O-Z)

    IF(X.LT.-500)THEN
        X=-500
    ENDIF
    EXPF=EXP(X)
    RETURN
END
C
C .....
C
SUBROUTINE GCF(GAMMCF,A,X,GLN)
    IMPLICIT REAL*8 (A-H,O-Z)
    PARAMETER (ITMAX=100,EPS=3.E-7)
C WRITE(*,*) 'GAMMCF, A, X, GLN =',GAMMCF,A,X,GLN

    GLN=GAMMLN(A)
    GOLD=0.
    A0=1.
    A1=X
    B0=0.
    B1=1.
    FAC=1.
    DO 11 N=1,ITMAX
        AN=FLOAT(N)
        ANA=AN-A
        A0=(A1+A0*ANA)*FAC
        B0=(B1+B0*ANA)*FAC
        ANF=AN*FAC
        A1=X*A0+ANF*A1
        B1=X*B0+ANF*B1
        IF(A1.NE.0.)THEN

```

```

        FAC=1./A1
        G=B1*FAC
        IF(ABS((G-GOLD)/G).LT.EPS)GO TO 1
        GOLD=G
    ENDIF
11  CONTINUE
    PAUSE 'A too large, ITMAX too small'
1   GAMMCF=EXPF(-X+A*LOG(X)-GLN)*G
    RETURN
    END
C
C .....
C
    SUBROUTINE GSER(GAMSER,A,X,GLN)
    IMPLICIT REAL*8 (A-H,O-Z)
    PARAMETER (ITMAX=100,EPS=3.E-3)

    GLN=GAMMLN(A)
C   WRITE(*,*) 'A=',A
    IF(X.LE.O.)THEN
        IF(X.LT.O.)PAUSE
        GAMSER=O.
        RETURN
    ENDIF
    AP=A
    SUM=1./A
    DEL=SUM
    DO 11 N=1,ITMAX
        AP=AP+1.
        DEL=DEL*X/AP
        SUM=SUM+DEL
        IF(ABS(DEL).LT.ABS(SUM)*EPS)GO TO 1
11  CONTINUE
    PAUSE 'A too large, ITMAX too small'

1   GAMSER=SUM*EXPF(-X+A*LOG(X)-GLN)
    RETURN
    END
C
    REAL*8 FUNCTION GAMMLN(XX)
C .....
C   FUNCTION GAMMLN
C .....

    REAL*8 COF(6),STP,HALF,ONE,FPF,X,TMP,SER,XX
    DATA COF,STP/76.18009173D0,-86.50532033D0,24.01409822D0,
    * -1.231739516D0,.120858003D-2,-.536382D-5,2.50662827465D0/
    DATA HALF,ONE,FPF/0.5D0,1.0D0,5.5D0/

    X=XX-ONE
    TMP=X+FPF
    TMP=(X+HALF)*LOG(TMP)-TMP
    SER=ONE
    DO 11 J=1,6
        X=X+ONE
        SER=SER+COF(J)/X
11  CONTINUE
    GAMMLN=TMP+LOG(STP*SER)
    RETURN
    END
C
C .....
C
    REAL*8 FUNCTION GAMMP(A,X)
    IMPLICIT REAL*8 (A-H,O-Z)
    IF (X.LT.O..OR.A.LE.O.)PAUSE
    IF(X.LT.A+1.)THEN
        CALL GSER(GAMSER,A,X,GLN)
        GAMMP=GAMSER

```

```

ELSE
C  WRITE(*,*) 'A, X, GLN ',A,X,GLN
    CALL GCF(GAMMCF,A,X,GLN)
    GAMMP=1.-GAMMCF
ENDIF
RETURN
END
C .....
C  SUBROUTINE WRITEO
C .....
SUBROUTINE WRITEO(PKTIMEA,CS,CE,UNITS,IMODEL)
IMPLICIT REAL*8 (A-H,O-Z)
*
*  Identification
*
*  Program Name: GWSCREEN
*  Module Name: writeo.f Version: 1.4
*  Date: 3/10/94   Time: 10:11:07
*
COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
I QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW,RC2,IMODE,
I ITYPE

COMMON /SOURCE/ THETAS, THETAU, RHOS, THICKS, zKDS,
I DEPTH, PERC, THALF,RHOA, zKDU, RHO, QM
PARAMETER(A=6.023E23,SEC=3.1536E7,Ci=3.7E10)
CHARACTER UNITS*2
C  SP=SPECIFIC ACTIVITY Ci/KG
Character idkeyw*72
Data idkeyw /'@(#)writeo.f 1.4 3/10/94 10:11:07/'
idkeyw = idkeyw

C ..... OUTPUT RESULTS AND EXIT .....

WRITE(2,200) PKTIMEA

C CONVERT CONCENTRATION TO Ci/kg OR mg/KG AND CALCULATE TOTAL AMOUNT IN
C SOURCE VOLUME
IF(IMODEL.LT.2)THEN
    CSD=CS/(RHOS*1000)
    QCS=CS*AL*WA*THICKS
C  CONVERT LIMITING ACTIVITY TO AMOUNT TO MASS
IF(IMODE.LE.3)THEN
C  CALCULATE SPECIFIC ACTIVITY
    SP=(A*DLR/SEC)/(ZMW*Ci)
    QMCS=(((QCS*Ci)*SEC*ZMW)/DLR)/A)*1000
    ELSE
        QMCS=QCS
    ENDIF
    WRITE(2,300) UNITS,CS
    WRITE(2,350) UNITS,CSD
    WRITE(2,301) UNITS,QCS
    WRITE(*,300) UNITS,CS
    WRITE(*,350) UNITS,CSD
    WRITE(*,301) UNITS,QCS

    IF(IMODE.LE.3)THEN
        WRITE(2,302) QMCS
        WRITE(2,500) SP
        IF(SP.LT.CSD/1000)THEN
            WRITE(2,700) CSD/1000
        ENDIF
    ENDIF

C  COMPARE TOTAL MASS IN SOURCE VOLUME WITH THE SOLUBILITY
C  LIMITED MASS

IF(QMCS.GT.QSL)THEN
    WRITE(2,351) QMCS,QSL

```

```

ENDIF

ELSE
C      CONVERT TO AMOUNT TO LITERS
      CE=CE/1000
      WRITE(2,400) UNITS,CE
ENDIF

200 FORMAT(2X,'PEAK TIME (y):',1PE13.6)
300 FORMAT(2X,'LIMITING SOIL CONCENTRATION ('',a2,'/m**3): ',1PE10.3)
301 FORMAT(2X,'LIMITING INVENTORY IN SOIL ('',a2,'): ',1PE10.3)
302 FORMAT(2X,'LIMITING INVENTORY IN SOIL (mg): ',1PE10.3)
350 FORMAT(2X,'LIMITING SOIL CONCENTRATION ('',a2,'/kg): ',1PE10.3)
351 FORMAT(2X,'WARNING !!! THE LIMITING SOIL MASS OF ',1PE10.3,' mg'
  //,2X,'EXCEEDS THE SOLUBILITY LIMITED SOURCE MASS OF ',1PE10.3,' mg'
  //)

400 FORMAT(2X,'LIMITING POND EFFLUENT CONCENTRATION ('',a2,'/L): ',
  //1PE10.3)

500 FORMAT(2X,'SPECIFIC ACTIVITY (Ci/g): ',1PE10.3)
700 FORMAT(2X,'NOTE: THE LIMITING SOIL CONCENTRATION OF ',1PE10.3,
  // ' Ci/g'
  //,8X,'EXCEEDS THE SPECIFIC ACTIVITY OF THE NUCLIDE.')

RETURN
END

C .....
C SUBROUTINE GOLDEN
C .....
SUBROUTINE GOLDEN(AX,BX,CX,GMAX,TMAX,TSL,IMODEL,ISOLVE)
  IMPLICIT REAL*8 (A-H,O-Z)

C THIS SUBROUTINE IS FROM NUMERICAL RECIPES ,PRESS ET AL, 1987

  PARAMETER (R=.61803399,C=.38196602,TOL=0.001)

  *
  * Identification
  *
  * Program Name: GWSCREEN
  * Module Name: golden.f Version: 1.1
  * Date: 4/6/93 Time: 17:07:42
  *

  Character idkeyw*72
  Data idkeyw /'@(#)golden.f 1.1 4/6/93 17:07:42\0'/
  idkeyw = idkeyw

  X0=AX
  X3=CX
  IF(ABS(CX-BX).GT.ABS(BX-AX))THEN
    X1=BX
    X2=BX+C*(CX-BX)
  ELSE
    X2=BX
    X1=BX-C*(BX-AX)
  ENDIF
  F1=-FUNC(X1,TSL,IMODEL,ISOLVE)
  F2=-FUNC(X2,TSL,IMODEL,ISOLVE)
1 IF(ABS(X3-X0).GT.TOL*(ABS(X1)+ABS(X2)))THEN
  IF(F2.LT.F1)THEN
    X0=X1
    X1=X2
    X2=R*X1+C*X3
C    F0=F1
    F1=F2
    F2=-FUNC(X2,TSL,IMODEL,ISOLVE)
  ELSE
    X3=X2

```

```

      X2=X1
      X1=R*X2+C*X0
C     F3=F2
      F2=F1
      F1=-FUNC(X1,TSL,IMODEL,ISOLVE)
      ENDIF
      GOTO 1
      ENDIF
      IF(F1.LT.F2)THEN
        GMAX=-F1
        TMAX=X1
      ELSE
        GMAX=-F2
        TMAX=X2
      ENDIF
      RETURN
      END

C .....
C  SUBROUTINE GWINT
C .....
      SUBROUTINE GWINT(X1,X2,TRANSIT,TSL,AIC,DAIC,ADLR,GWPEAK,PKTIMEA,
      I IMODEL,ISOLVE,NN,KFLAG)
      IMPLICIT REAL*8 (A-H,O-Z)
      *
      * Identification
      *
      * Program Name: GWSCREEN
      * Module Name: gwint.f Version: 1.3
      * Date: 9/15/93 Time: 13:40:10
      *
C This subroutine calculates the limits of integration for
C regulatory criteria and the average integrated concentration.

C CALCULATED VALUES IN GWINT SUBROUTINE
C S = INTEGRATED CONCENTRATION
C AIC = AVERAGE INTEGRATED CONCENTRATION
C X1 IS EQUIVALENT TO THE INTEGRATION TIME CONVERTED TO A REAL NUMBER
C X2 IS THE PEAK TIME
C T1 = LOWER LIMIT OF INTEGRATION (Y)
C T2 = UPPER LIMIT OF INTEGRATION (Y)

C CHECK TO SEE IF INTEGRATION TIME IS BOUNDED EQUALLY ON BOTH SIDES OF THE
C OF THE PEAK T1 AND T2 ARE THE INTEGRATION LIMITS
      PARAMETER (NSPEC=9)
      COMMON /DECAY/ ADCF,AKD,ATHALF,ARD,ARADMAX,RCSF
      DIMENSION ADCF(NSPEC),AKD(NSPEC),ATHALF(NSPEC),ARADMAX(NSPEC)
      I,ARD(NSPEC),RCSF(NSPEC)
      DIMENSION ADLR(NSPEC),DAIC(NSPEC),Q(NSPEC),QDX(NSPEC)

      Character idkeyw*72
      Data idkeyw /'@(#)gwint.f 1.3 9/15/93 13:40:10\0'/
      idkeyw = idkeyw

      IF(X1.LE.1.)THEN
        AIC=GWPEAK
        DAIC(1)=GWPEAK
        IF(NN.GT.1)THEN
          Q(1)=1.0
          DO 10, I=2,NN
            Q(I)=0.0
10          CONTINUE
          CALL RDK(PKTIMEA,ADLR,NN,Q,QDX)
          DO 20,I=2,NN
            DAIC(I)=GWPEAK*(QDX(I)/QDX(1))*(ARD(1)/ARD(I))
20          CONTINUE
        ENDIF
        RETURN

```

```

ENDIF
IF((X2-X1/2).LT.0.0)THEN
  T1=0
  T2=X1
ELSE
  T1=X2-X1/2
  T2=X2+X1/2
ENDIF
c locate maximum average for pond model PERFORM 20 ITERATIONS
IF(IMODEL.EQ.2.AND.KFLAG.EQ.1)THEN
  J=1
  K=1
  OS=0.
  OP1=0.
  OP2=0.
  WRITE(*,1000) J
  DO WHILE (K.NE.20)
    P1=X2-X1
    IF(P1.LE.0.)THEN
      P1=0.0
      P2=X1
    ELSE
      P2=P1+X1
    ENDIF
    IF(OP1.NE.P1.OR.OP2.NE.P2)THEN
      CALL QGAUS1(P1,P2,S,TSL,TRANSIT,ADLR,IMODEL,ISOLVE,NN,J)
    ENDIF
    IF(S.LT.OS)THEN
      T1=OP1
      T2=OP2
      K=20
      S=OS
    ELSE
      OS=S
      OP1=P1
      OP2=P2
      K=K+1
    ENDIF
    X2=X2+0.1*X2
  END DO
ENDIF
C CALCULATE INTEGRATED CONCENTRATION USING GAUSSIAN QUAD FROM
C NUMERICAL RECIPES

DO 30, I=1,NN
  IF(IMODEL.EQ.2.AND.I.EQ.1.AND.KFLAG.EQ.1)THEN
    WRITE(*,2000) T1,T2
    WRITE(2,2000) T1,T2
  ELSE
    WRITE(*,1000) I
    CALL QGAUS1(T1,T2,S,TSL,TRANSIT,ADLR,IMODEL,ISOLVE,NN,I)
  ENDIF
  DAIC(I)=S/(T2-T1)
30 CONTINUE
AIC=DAIC(1)

1000 FORMAT(2X,'CALCULATING AVERAGE INTEGRATED CONCENTRATION FOR MEMBER
  I #',I1)
2000 FORMAT(2X,'MAXIMUM AVERAGE GW CONCENTRATION BETWEEN YEARS ',1PE9.2
  I,' AND ',1PE9.2)
  RETURN
  END
C .....
C  SUBROUTINE LIMITS
C .....
  SUBROUTINE LIMITS(T1,T2,TI,IFLAG,IMODEL)
  IMPLICIT REAL*8 (A-H,O-Z)
  PARAMETER (ARB=50)

```


- Identification
-
- Program Name: GWSCREEN
- Module Name: limits.f Version: 1.2
- Date: 3/10/94 Time: 10:02:11
-

C COMMON STATEMENTS

```
COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
! QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW,RC2,IMODE,
! ITYPE
```

```
Character idkeyw*72
Data idkeyw /'@(#)limits.f 1.2 3/10/94 10:02:11\0'/
idkeyw = idkeyw
```

C DETERMINE LIMITS FOR INTEGRATION

```
C T1 = LOWER LIMIT T2 = UPPER LIMIT THESE VALUES ARE IN UNITS OF SECONDS
C INTEGRATION LIMITS ARE SELECTED BY CODELL'S METHOD. THE LIMITS ARE
C BASED ON THE VALUE OF ARB WHEN EXP(-ARB) APPROACHES ZERO. DEPENDING
C ON THE MACHINE USED, ARB MAY BE -50 TO -200
C XC1 AND XC2 = THE X DISTANCE USED IN CALCULATION OF THE INTEGRATION LIMITS.
C XC1 = XD + AL/2 AND
C XC2 = XD - AL/2 FOR HORIZONTAL AREA SOURCES. THE TEMP VARIABLES STORE THE
C INTERMEDIATE VALUES
```

```
IFLAG = -1
DXX = ABS(AX*VX)
XC1 = XD + AL/2
XC2 = XD - AL/2
```

```
TEMP1 = (2*VX*XC1/RD + 4*DXX*ARB/RD)/((VX/RD)**2
! + 4*DXX*DLR/RD)
```

```
TEMP2 = TEMP1**2 - (2*XC2)**2/((VX/RD)**2
! + 4*DXX*DLR/RD)
```

C IF TEMP2 IS LESS THAN ZERO THEN DO NOT PROCEED WITH INTEGRATION

```
IF(TEMP2.LE.0.0)THEN
  IFLAG = 1
  RETURN
ENDIF
```

```
TEMP3 = (2*VX*XC2/RD + 4
! *DXX*ARB/RD)/((VX/RD)**2
! + 4*DXX*DLR/RD)
```

```
T2 = T1 - (TEMP3 - SQRT(TEMP2))/2
```

```
T1 = T1 - (TEMP1 + SQRT(TEMP2))/2
```

C CONDITIONAL STATEMENTS

C IF THE UPPER LIMIT IS EQ TO 0 THEN RETURN

```
IF(T2.LE.0.) THEN
  IFLAG = 1
  RETURN
ENDIF
```

C CHECK LOWER LIMIT OF INTEGRATION TO MAKE SURE IS NOT LESS THAN 0

```
IF(T1.LE.0.) THEN
  T1 = 0.0
ENDIF
```

C CHECK TO SEE IF INTEGRATION LIMIT IS GREATER THAN DESIRED TIME

```
IF(T2.GE.TI) THEN
  T2 = TI
ENDIF
```

C CUT OFF SOURCE TERM AFTER EXPONENT ARGUMENT IS -500 (APP. 700 HALF LIVES)

```
IF(DLR.GT.0.AND.IMODEL.LT.2)THEN
  CUTOFF = 700*(LOG(2.)/DLR)
```

```

      IF(T2.GT.CUTOFF)THEN
        T2 = CUTOFF
      ENDIF
    ENDIF
  RETURN
END

C .....
C * SUBROUTINE LINT *
C .....
SUBROUTINE LINT(X,Y)
*
* Identification
*
* Program Name: GWSCREEN
* Module Name: lint.f Version: 1.1
* Date: 4/6/93 Time: 17:09:30
*
* subroutine for linear interpolation
*
IMPLICIT REAL*8(A-H,O-Z)
COMMON /TABLE/ ATIME,QREL,NP
PARAMETER (NPOINTS=1000)
DIMENSION ATIME(NPOINTS),QREL(NPOINTS)
Character Idkeyw*72
Data Idkeyw /'@(#)lint.f 1.1 4/6/93 17:09:30\0'/
Idkeyw = Idkeyw
C IF RELEASE TIME IS GREATER THAN SOURCE INPUT TIME THEN FLUX =0
IF(X.GT.ATIME(NP))THEN
  Y=0.0
  RETURN
ENDIF
N=NP
KLO=1
KHI=N
1 IF (KHI-KLO.GT.1) THEN
  K=(KHI+KLO)/2
  IF(ATIME(K).GT.X)THEN
    KHI=K
  ELSE
    KLO=K
  ENDIF
GOTO 1
ENDIF
H=ATIME(KHI)-ATIME(KLO)
IF (H.EQ.0.) PAUSE 'Bad XA Input.'
Y = QREL(KLO) + (X-ATIME(KLO))/H * (QREL(KHI)-
! QREL(KLO))
RETURN
END

REAL*8 FUNCTION AREA(TI,Q)
IMPLICIT REAL*8 (A-H,O-Z)
C .....
C * FUNCTION AREA *
C .....
C This subroutine calculates the ground water concentration for an area source
C ALL UNITS ARE IN METERS AND YEARS
*
* Identification
*
* Program Name: GWSCREEN
* Module Name: area.f Version: 1.3
* Date: 3/10/94 Time: 16:11:28
*
C COMMON STATEMENTS
COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
! QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW,RC2,IMODE,
! ITYPE

```

```

DIMENSION X(8),W(8)

Character idkeyw*72
Data idkeyw /'@(#)area.f 1.3 3/10/94 16:11:28\0'/
idkeyw = idkeyw

DATA X/ 0.0950125098,0.281603558,0.4580167777,0.617876244
*,0.755404484,0.8656312024,0.9445750231,0.9894009350/

DATA W/ 0.1894506105,0.1826034150,0.1691565194,0.149595988
*,0.1246289713,0.0951585117,0.0622535239,0.0271524594/

IF(TI.LE.0.0)THEN
  AREA=0.0
  RETURN
ENDIF

DX=ABS(AX*VX)
DY=ABS(AY*VX)
ZX=ZD

C X ARGUMENTS
ARG1=((XD+AL/2)-VX*TI/RD)/SQRT(4*DX*TI/RD)
ARG2=((XD-AL/2)-VX*TI/RD)/SQRT(4*DX*TI/RD)
CALL ERRORD(ARG1,EX1)
CALL ERRORD(ARG2,EX2)
X2=(EX1-EX2)*EXP(-DLR*TI)/(2*AL)

C Y ARGUMENTS
ARG1=(WA/2+YD)/SQRT(4*DY*TI/RD)
CALL ERRORD(ARG1,EY1)
ARG2=(WA/2-YD)/SQRT(4*DY*TI/RD)
CALL ERRORD(ARG2,EY2)
Y2=(EY1+EY2)/(2*WA)

C CALCULATE Z PARAMETER AND GROUNDWATER CONC. FOR NON VERT AVERAGED SOL,
C AVERAGED BETWEEN 0 AND ZD

IF(ITYPE.EQ.2)THEN
c*****
c integrate groundwater concentration USING 16 POINT GAUS QUAD

  XM=0.5*(ZX+ZI)
  XR=0.5*(ZX-ZI)
  SS=0
  DO 20 J=1,8
    DX=XR*X(J)
    Z1=ZARG(TI,(XM+DX))
    G1=(Q*X2*Y2*Z1)/(PHI*RD)
    Z1=ZARG(TI,(XM-DX))
    G2=(Q*X2*Y2*Z1)/(PHI*RD)
    SS=SS+W(J)*(G1+G2)
20  CONTINUE
  AREA=(XR*SS)/ZX
  RETURN
ENDIF
c*****
C CALCULATE Z PARAMETER
IF(ITYPE.EQ.1)THEN
  Z1=ZARG(TI,ZX)
ELSE
  Z1=1/THICK
ENDIF
C CALCULATE GROUND WATER CONCENTRATION
GWCON=(Q*X2*Y2*Z1)/(PHI*RD)
AREA=GWCON
RETURN
END

```

```

C .....
C SUBROUTINE PEAK
C .....
SUBROUTINE PEAK(GWPEAK,PKTIME,TSL,IMODEL,ISOLVE)
IMPLICIT REAL*8 (A-H,O-Z)

*
* Identification
*
* Program Name: GWSCREEN
* Module Name: peak.f Version: 1.10
* Date: 3/10/84 Time: 10:03:16
*

C This subroutine calculates the peak concentration
C Called by MAIN
C CALCULATED VALUES IN PEAK SUBROUTINE
C DEL = TIME INCREMENT FOR PEAK BRACKET LOCATION
C TI = TIME SLOPE IS CALCULATED AT
C GWPEAK = PEAK CONCENTRATION
C PKTIME = TIME OF PEAK CONCENTRATION (Y)
C THE MINIMUM-MAXIMUM BOUNDARIES ARE THE VARIABLES ZMIN AND ZMAX
C THE MIDDLE POINT IS VARIABLE ZMID
C TX=DUMMY VARIABLE TO HOLD OPERATION TIME OF POND FOR POND MODEL
C Routine was re-written 8-31-92 because problems developed when short
C half-lived contaminants were evaluated.
C An additional mistake in coding was found in the first IF-THEN statement
C defining the TX variable.

COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
! QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW,RC2,IMODE,
! ITYPE
COMMON /POND/ RMI,TOPEP,PNDFLX,THETAP,EVAP,PLEACH,WAEFF
PARAMETER (R1=1.1,R2=2.1)
Character idkeyw*72
Data idkeyw /'@(#)peak.f 1.10 3/10/84 10:03:16\0'/
idkeyw = idkeyw
WRITE(*,*) ' CALCULATING PEAK CONCENTRATION'
TX=0.0
C CALCULATE PEAK FOR POND MODEL DURING STEADY STATE IF THERE IS NO INITIAL MASS
C removed approximation for pond model steady state peak concentration calc
C 9/13/93
IF(IMODEL.GT.1)THEN
TX=TOPEP
ELSE
TX=0.0
ENDIF

C BRACKET MAXIMUM AND MINIMUM VALUE
IF(DLR.GT.1.0E-20)THEN
ZHR=(LOG(2.)/DLR)*VX/((0.1+XD)*RD)
IF(ZHR.GT.1.)THEN
ZHR=1.0
ENDIF
ELSE
ZHR=1.0
ENDIF

C SET ZMIN EQUAL TO 1E-10 IF POND MODEL HAS INITIAL MASS
IF(IMODEL.GT.1.AND.QI.GT.0.)THEN
ZMIN=1E-10
ELSE
ZMIN=((TX+(XD-AL)*RD/VX)/5.)*ZHR
ENDIF
IF(ZMIN.LE.1.0E-10)THEN
ZMIN=1.0E-10
ENDIF
ZMAX=(TX+(XD+AL)*RD/VX)*4.
C CHECK THAT ZMAX IS NON ZERO
ZSTEP=(ZMAX-ZMIN)/100.

```

```

DO 20,I=1,100
  ZC=FUNC(ZMAX,TSL,IMODEL,ISOLVE)
  IF(ZC.GT.0.)THEN
    ZMID=ZMIN+(ZMAX-ZMIN)/2.
    CALL GOLDEN(ZMAX,ZMID,ZMIN,GWPEAK,PKTIME,TSL,IMODEL,ISOLVE)
    RETURN
  ELSE
    ZMAX=ZMAX-ZSTEP
  ENDIF
20 CONTINUE
WRITE(2,2000)
WRITE(*,2000)
RETURN

1000 FORMAT(' POND OPERATION TIME EXCEEDS STEADY STATE CUTOFF TIME OF'
  1,1X,1PE9.2,'YEARS ')

2000 FORMAT(2X,'PEAK CONCENTRATION CANNOT BE FOUND WITH PEAK FINDER ROU
  ITIME:'
  1/,2X,'USE CONCENTRATION VS TIME MODE TO DETERMINE PEAK')

END

C .....
C SUBROUTINE ROOT
C .....
SUBROUTINE ROOT(R,RCS,Q0,QSL,T)
C This subroutine calculates the time roots of the solubility release function

  IMPLICIT REAL*8(A-H,O-Z)
  PARAMETER (MAXIT=100)

  *
  * Identification
  *
  * Program Name: GWSCREEN
  * Module Name: root.f Version: 1.3
  * Date: 4/15/93 Time: 18:13:40
  *

  Character idkeyw*72
  Data idkeyw /'@(#)root.f 1.3 4/15/93 18:13:40\0'/
  idkeyw = idkeyw

C perform calculation for decaying source only if the sum of the half
C times is greater than 1E10 years
IF(RCS.GT.6.93E-11)THEN
  T=-LOG((QSL+R/RCS)/(Q0+R/RCS))/RCS
  ZMB=Q0*EXP(-RCS*T)-R/RCS*(1-EXP(-RCS*T))-QSL
ELSE
  T=(Q0-QSL)/R
  ZMB=Q0-R*T-QSL
ENDIF
WRITE(*,1000) ZMB
1000 FORMAT(2X,'SOLUBILITY MASS BALLANCE (mg)',1PE11.4)

RETURN
END

C .....
C SUBROUTINE QGAUS1
C .....
SUBROUTINE QGAUS1(A,B,SS,TSL,TRANSIT,ADLR,IMODEL,ISOLVE,NN,K)
  IMPLICIT REAL*8 (A-H,O-Z)

  *
  * Identification
  *
  * Program Name: GWSCREEN
  * Module Name: qgaus1.f Version: 1.1
  * Date: 4/6/93 Time: 17:11:56
  *

```

```

PARAMETER (NSPEC=9)
COMMON /DECAY/ ADCF,AKD,ATHALF,ARD,ARADMAX,RCSF
DIMENSION ADCF(NSPEC),AKD(NSPEC),ATHALF(NSPEC),ARADMAX(NSPEC)
I,ARD(NSPEC),RCSF(NSPEC)
DIMENSION X(8),W(8),ADLR(NSPEC),Q(NSPEC),QDX(NSPEC)

```

C ZEROS AND WEIGHTS FOR 16 POINT GAUSSIAN QUADRATURE: FROM NUMERICAL
C METHODS, ROBERT W. HORNBECK, QUANTUM PUBLISHERS INC, NEW YORK PG 293

```

DATA X/ 0.0850125098,0.281603558,0.4580167777,0.617876244
*,0.755404484,0.8656312024,0.9445750231,0.9894009350/

```

```

DATA W/ 0.1894506105,0.1826034150,0.1691565194,0.149595988
*,0.1246289713,0.0951585117,0.0622535239,0.0271524594/
Character ldkyw*72
Data ldkyw /'@(#)qgaus1.f          1.1 4/6/93 17:11:56\0'/
ldkyw = ldkyw

```

```

XM=0.5*(B+A)
XR=0.5*(B-A)
SS=0
IF(NN.GT.1)THEN
  DO 10,I=1,NN
    Q(I)=0.0
10  CONTINUE
    Q(1)=1.0
  ENDIF

  DO 20 J=1,8
    DX=XR*X(J)
C   CALCULATE DECAY INGROWTH FACTORS
    IF(NN.GT.1)THEN
      T=XM+DX+TRANSIT
      CALL RDK(T,ADLR,NN,Q,QDX)
      F1=(QDX(K)/QDX(1))*ARD(1)/ARD(K)
      T=XM-DX+TRANSIT
      CALL RDK(T,ADLR,NN,Q,QDX)
      F2=(QDX(K)/QDX(1))*ARD(1)/ARD(K)
      ELSE
        F1=1.0
        F2=1.0
      ENDIF
      SS=SS+W(J)*(FUNC((XM+DX),TSL,IMODEL,ISOLVE)*F1+FUNC((XM-DX),TSL,
IMODEL,ISOLVE)*F2)
20  CONTINUE
      SS=XR*SS
      RETURN
    END

```

```

C .....
C SUBROUTINE QGAUS2
C .....

```

```

SUBROUTINE QGAUS2(TI,SS,TSL,IMODEL)
IMPLICIT REAL*8 (A-H,O-Z)

```

```

*
* Identification
*
* Program Name: GWSCREEN
* Module Name: qgaus2.f Version: 1.2
* Date: 3/10/94 Time: 10:04:32
*

```

```

DIMENSION X(17),W(17)

```

C TIME UNITS ARE YEARS, CONCENTRATION UNITS ARE AMOUNT/M3
C This routine calculates the groundwater concentration at time TI. This
C routine has been adapted from Numerical Recipes, Press et al.

C COMMON STATEMENTS

```

COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
I QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW,RC2,IMODE,
I ITYPE
C ZEROS AND WEIGHTS FOR 34 POINT GAUSSIAN QUADRATURE:
C CALCULATED WITH GAUSLEG SUBROUTINE

```

```

DATA X/ 0.0455098220,0.1361523573,0.2256666916,0.3133110813
*,0.3983592778,0.4801065452,0.5578755007,0.6310217271
*,0.6989391132,0.7610648766,0.8168842279,0.8659346383
*,0.9078096777,0.9421623974,0.9687082625,0.9872278164
*,0.9975717538/

```

```

DATA W/ 0.0909567403,0.0902030444,0.0887018978,0.0864657397
*,0.0835130997,0.0798684443,0.0755619747,0.0706293758
*,0.0651115216,0.0590541358,0.0525074146,0.0455256115
*,0.0381665938,0.0304913806,0.0225637220,0.0144501627
*,0.0062291406/

```

```

Character idkeyw*72
Data idkeyw /'@(#)qgaus2.f          1.2 3/10/94 10:04:32\0'/
idkeyw = idkeyw

```

```

C INITIALIZE VARIABLES IF TI=0.0 RETURN TO START

```

```

IF(TI.EQ.0) THEN
  SS=0.0
  RETURN
ENDIF

```

```

C DETERMINE INTEGRATION LIMITS

```

```

CALL LIMITS(A,B,TI,IFLAG,IMODEL)
IF(IFLAG.GT.0)THEN
  SS=0.0
  RETURN
ENDIF

```

```

XM=0.5*(B+A)
XR=0.5*(B-A)
SS=0

```

```

DO 11 J=1,17

```

```

C TX1 AND TX2 ARE THE TIMES TO BE USED IN THE AREA SUBROUTINE

```

```

DX=XR*X(J)
TX1=TI-(XM+DX)
TX2=TI-(XM-DX)

```

```

C CALCULATE SOURCE TERM

```

```

T=XM+DX
CALL SRCTERM(T,TSL,Q1,IMODEL)

T=XM-DX
CALL SRCTERM(T,TSL,Q2,IMODEL)
SS=SS+W(J)*(AREA(TX1,Q1)+AREA(TX2,Q2))

```

```

11 CONTINUE

```

```

SS=XR*SS

```

```

RETURN
END
SUBROUTINE SIMPSON(TI,S,TSL,IMODEL)

```

```

C .....

```

```

C * SUBROUTINE SIMPSON

```

```

C .....

```

```

IMPLICIT REAL*8(A-H,O-Z)

```

```

*

```

- Identification
-
- Program Name: GWSCREEN
- Module Name: simpson.f Version: 1.2
- Date: 4/7/93 Time: 15:33:23
-

C COMMON STATEMENTS

COMMON /SIMP/ EPS,JMAX,JSTART

Character Idkeyw*72

Data Idkeyw /'@(#)simpson.f 1.2 4/7/93 15:33:23\0'/

Idkeyw = Idkeyw

IF(TI.EQ.0) THEN

S=0.0

RETURN

ENDIF

C DETERMINE INTEGRATION LIMITS

CALL LIMITS(T1,T2,TI,IFLAG,IMODEL)

IF(IFLAG.GT.0)THEN

S=0.0

RETURN

ENDIF

C INTEGRATION IS NOW PERFORMED BY SIMPSONS RULE. ROUTINE WAS ADAPTED FROM

C NUMERICAL RECIPES (PRESS ET AL., 1992) PAGE 130 - 133

C INITIALIZE VARIABLES

ST=0.0

OST=-1.0E38

OS=-1.0E-30

DO 11,J=1,JMAX

CALL TRAPZD(T1,T2,ST,TI,TSL,J,IMODEL)

S=(4.0*ST-OST)/3

C check for convergence

IF(ABS(S-OS).LE.EPS*ABS(OS).AND.J.GT.JSTART)THEN

RETURN

ELSE

TOS=OS

OS=S

OST=ST

ENDIF

11 CONTINUE

N1=2*(JMAX-1)

V1=(ABS(S-TOS))/ABS(TOS)

WRITE(*,1000) n1,V1

1000 FORMAT(2X,'Convergence not Achieved After',I6,' Steps; EPS value
' ,1pe11.4)

999 RETURN

END

SUBROUTINE TRAPZD(A,B,S,T2,TSL,N,IMODEL)

IMPLICIT REAL*8(A-H,O-Z)

C

C • SUBROUTINE TRAPZD •

C

COMMON /SIMP/ EPS,JMAX,JSTART

IF(N.EQ.1) THEN

CALL SRCTERM(A,TSL,Q,IMODEL)

T4=T2-A

F1=AREA(T4,Q)

CALL SRCTERM(B,TSL,Q,IMODEL)

T4=T2-B

F2=AREA(T4,Q)


```

S=0.5*(B-A)*(F1+F2)
ELSE
  IT=2**(N-2)
  TNM=FLOAT(IT)
  DEL=(B-A)/TNM
  X=A+0.5*DEL
  SUM=0
  DO 11, J=1,IT
    T4=T2-X
    CALL SRCTERM(X,TSL,Q,IMODEL)
    SUM=SUM+AREA(T4,Q)
    X=X+DEL
11  CONTINUE
  S=0.5*(S+(B-A)*SUM/TNM)
ENDIF
RETURN
END
C .....
C * SUBROUTINE RDK .....
C .....
SUBROUTINE RDK(T,DLR,NN,Q,QDX)
*
* Identification
*
* Program Name: GWSCREEN
* Module Name: rdkgws.f Version: 1.1
* Date: 4/6/93 Time: 17:13:05
*

C FEBRUARY, 1992
C This program is based on an algorithm written by A. Birchall and presented
C in Health Physics Vol 50, No 3 (March 1986, pp 389-397. The program calculates
C the amount of material in n number of first order compartments.

IMPLICIT REAL*8(A-H,O-Z)
PARAMETER (ND=10,NSPEC=9)

C ND = THE TOTAL NUMBER OF COMPARTMENTS AVAILABLE
C NC = NUMBER OF COMPARTMENTS IN SIMULATION
C IDP=THE PROGENY INDEX
C ND = THE TOTAL NUMBER OF PROGENY AVAILABLE
C NC = NUMBER OF PROGENY IN SIMULATION
C AOUTPUT = OUTPUT MATRIX
C DLR = INPUT RATE CONSTANTS (Y-1)
C R = RATE AND INITIAL ACTIVITY MATRIX (CI AND S-1)
C Q = INITIAL ACTIVITIES (CI)
C QDX = DECAYED ACTIVITIES (CI)
C DT = TIME CONVERTED TO SECONDS
DIMENSION R(0:ND,0:ND),KPATH(0:ND,0:ND),MAX(0:ND),SUM(0:ND)
DIMENSION DLR(NSPEC),Q(NSPEC),QDX(NSPEC)

Character idkeyw*72
Data idkeyw /'@{#}rdkgws.f 1.1 4/6/93 17:13:05\0'/
idkeyw = idkeyw

NC=NN+1

C RESET R,PATH,MAX AND SUM MATRIX
DO 5, I=1,NC
  DO 6,J=1,NC
    R(I,J)=0
    KPATH(I,J)=0
6  CONTINUE
  MAX(I)=0
  SUM(I)=0
  QDX(I)=0.0
5  CONTINUE

C INPUT MATRIX VALUES

```

```

      DO 10,I=1,NC
        R(I,I)=Q(I)
10    CONTINUE

C READ DECAY CONSTANTS AND CONVERTS TO SEC**-1
      DO 20,I=1,NC
        R(I,I+1)=DLR(I)/3.1536E7
20    CONTINUE
C      CONVERSION FROM CI TO DIS PER SECOND
      CONVERTF = 3.7E+10

C CONVERT ACTIVITY TO NUMBER OF ATOMS AND TIME TO SECONDS

      DO 21,I=1,NC
        IF(I+1.GT.NC)THEN
          GOTO 21
        ENDIF
        R(I,I)=R(I,I)*CONVERTF/R(I,I+1)
21    CONTINUE
      DT=T*3.1536E7
C SET UP KPATH MATRIX

      DO 30,J=2,NC
        DO 40,I=1,J-1
          IF(R(I,J).EQ.0.0)THEN
            GOTO 40
          ENDIF
          MAX(J)=MAX(J)+1
          KPATH(MAX(J),J)=I
40        CONTINUE
30      CONTINUE

      ZLAM=0.0
C CALCULATE SUM VALUE
      DO 50,I=1,NC
        SUM(I)=ZLAM
        DO 60,J=I+1,NC
          SUM(I)=SUM(I)+R(I,J)
60        CONTINUE
50      CONTINUE

C THE AMOUNT IN THE COMPARTMENT AND THE INTEGRATED NUMBER OF DISINTEGRATIONS
C IS RETURNED IN THE VARIABLES TSUM AND TDIS

      DO 100,I=1,NC

        CALL S1000(I,DT,R,MAX,KPATH,SUM,ZLAM,NC,TSUM,TDIS)
C      CONVERT NUMBER OF ATOMS TO ACTIVITY DO NO CONVERT LAST COMPARTMENT

        QDX(I)=TSUM*R(I,I+1)/CONVERTF

        IF(QDX(I).LT.0.)THEN
          QDX(I)=0.
        ENDIF

100    CONTINUE
      RETURN
      END

C .....
C *      SUBROUTINE S1000      *
C .....
      SUBROUTINE S1000(KCOM,T,R,MAX,KPATH,ZSUM,ZLAM,NC,TSUM,TDIS)
      IMPLICIT REAL*8(A-H,O-Z)

      PARAMETER (ND=10)

```

```

    DIMENSION R(0:ND,0:ND),KPATH(0:ND,0:ND),MARK(0:ND),MAX(0:ND)
    DIMENSION IPA(0:ND),IP(0:ND)
    DIMENSION ZNO(0:ND),ZK(0:ND),ZKT(0:ND),ZSUM(0:ND),ZI(0:ND)
    TDIS=0
    TSUM=0
    NP=0

    DO 70, I3=1,NC
        MARK(I3)=1
        ZI(I3)=R(I3,I3)
70    CONTINUE

1020 IPL=1
    IPA(1)=KCOM

    IF(MAX(KCOM).EQ.0.)THEN
        GOTO 1040
    ENDIF

1030 KCOM=KPATH(MARK(KCOM),KCOM)
    IPL=IPL+1
    IPA(IPL)=KCOM
    IF(MAX(KCOM).GT.0)THEN
        GOTO 1030
    ENDIF

1040 DO 80,I3=1, IPL
    IP(I3)=IPA(IPL-I3+1)
80    CONTINUE

    N=IPL
    KCOM=IP(N)

    NP=NP+1
    DO 90, I3=1,N

        ZNO(I3)=ZI(IP(I3))
        ZKT(I3)=ZSUM(IP(I3))
90    CONTINUE

    DO 100,I3=1,N-1
        ZK(I3)=R(IP(I3),IP(I3+1))
100    CONTINUE

    CALL S2000(XSUM,DIS,ZNO,ZK,ZKT,T,N,ZLAM)

    TSUM=TSUM+XSUM

    TDIS=TDIS+DIS

    DO 110,I3=1,N
        ZI(IP(I3))=0
110    CONTINUE

    DO 120,I3=2,IPL
        IF(MARK(IP(I3)).EQ.MAX(IP(I3)))THEN
            GOTO 120
        ENDIF
        M=IP(I3)
        MARK(M)=MARK(M)+1
        DO 130,I4=1,M-1
            MARK(I4)=1
            ZI(I4)=R(I4,I4)
130    CONTINUE
        GOTO 1020
120    CONTINUE

    KCOM=IP(IPL)

```

```

RETURN
END

```

```

C .....
C *      SUBROUTINE S2000      *
C .....
SUBROUTINE S2000(XSUM,DIS,ZNO,ZK,ZKT,T,N,ZLAM)
IMPLICIT REAL*8(A-H,O-Z)
PARAMETER (ND=10)
DIMENSION ZNO(0:ND),ZK(0:ND),ZKT(0:ND)
XSUM=0
DIS=0

DO 140,I1=1,N
  S1=1
  DO 150,I2=I1,N-1
    S1=S1*ZK(I2)
150  CONTINUE
  S2=0
  S4=0
  DO 160,I2=I1,N
    S3=1
    DO 170,I3=I1,N
      IF(I3.EQ.I2)THEN
        GOTO 170
C      LINE 170 IS EQUAL TO LINE 2040 IN BASIC PROGRAM
      ENDIF
      S3=S3*(ZKT(I3)-ZKT(I2))
      IF(S3.EQ.0)THEN
        RETURN
      ENDIF
170    CONTINUE

      S2=S2+ZNO(I1)*EXP(-ZKT(I2)*T)/S3
      IF(ZLAM.EQ.0.)THEN
        GOTO 160
C      LINE 160 IS EQUAL TO LINE 2070 IN BASIC PROGRAM
      ENDIF

      IF(ZKT(I2)*T.GT.0.01)THEN
        S4=S4+ZNO(I1)*(1-EXP(-ZKT(I2)*T))/S3/ZKT(I2)
      ENDIF

      IF(ZKT(I2)*T.LE.0.01)THEN
        S4=S4+ZNO(I1)*(T-0.5*ZKT(I2)*T)/S3
      ENDIF
160  CONTINUE
  XSUM=XSUM+S1*S2
  DIS=DIS+ZLAM*S1*S4
140  CONTINUE
  RETURN
END

```

```

C .....
C SUBROUTINE SRCPOND
C .....
SUBROUTINE SRCPOND(T,Q)
IMPLICIT REAL*8 (A-H,O-Z)
PARAMETER (A=6.023E+23, CI=3.7E+10, SEC=3.1536E7)

```

```

*
* Identification
*
* Program Name: GWSCREEN
* Module Name: srcpond.f Version: 1.3
* Date: 3/10/94 Time: 10:08:30
*
C This subroutine calculates the mass or activity released from a pond
COMMON /POND/ RMI,TOPE,PNDFLX,THETAP,EVAP,PLEACH,WAEFF

```

```

COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
! QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW,RC2,IMODE,
! ITYPE
Character idkeyw*72
Data idkeyw /'@(#)srcpond.f          1.3 3/10/94 10:08:30'0'/
idkeyw = idkeyw
IF(T.LE.TOPER)THEN
  QMASS=RMI*(1-EXPF(-(EVAP+DLR+PLEACH)*T))/(EVAP+PLEACH
! +DLR)+QI*EXPF(-(EVAP+PLEACH+DLR)*T)
  Q=PLEACH*QMASS*FRAC
ELSE
C   calculate flux from sediments already in pond
  QMASS=RMI*(1-EXPF(-(EVAP+DLR+PLEACH)*TOPER))/(EVAP+
! PLEACH+DLR)+QI*EXPF(-(EVAP+PLEACH+DLR)*TOPER)
  Q=FRAC*SLEACH*QMASS*EXPF(-(SLEACH+DLR)*(T-TOPER))
ENDIF
RETURN
END
C .....
C SUBROUTINE SRCTERM
C .....
SUBROUTINE SRCTERM(T,TSL,Q,IMODEL)
IMPLICIT REAL*8 (A-H,O-Z)
PARAMETER (A=6.023E+23,C1=3.7E+10,SEC=3.1536E7)
*
* Identification
*
* Program Name: GWSCREEN
* Module Name: srcterm.f Version: 1.3
* Date: 3/10/94 Time: 10:09:38
*
C This subroutine calculates the mass or activity released

COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
! QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW,RC2,IMODE,
! ITYPE

Character idkeyw*72
Data idkeyw /'@(#)srcterm.f          1.3 3/10/94 10:09:38'0'/
idkeyw = idkeyw

C CHECK SOURCE CUTOFF TIME FOR NON TABULATED SOURCE
ARG=(SLEACH+DLR+RC2)*T
IF(ARG.GT.500.AND.IMODEL.NE.3)THEN
  Q=0.0
  RETURN
ENDIF

C Call pond model if IMODEL = 2
IF(IMODEL.EQ.2)THEN
  CALL SRCPOND(T,Q)
  RETURN
ENDIF

C Call linear interpolation routine if IMODEL=3
IF(IMODEL.EQ.3)THEN
  CALL LINT(T,Q)
  Q=Q*FRAC
  RETURN
ENDIF

C IF TSL=0 THEN DO LEACH EQUATION FOR EITHER ACTIVITY OR MASS
IF(TSL.EQ.0.0)THEN
  ARG=(-(SLEACH+DLR+RC2)*(T))
  Q=FRAC*SLEACH*QI*EXPF(ARG)
  RETURN
ENDIF

C IF T IS LESS THAN TSL THEN A SOLUBILITY LIMITED RELEASE IS CALCULATED FOR
C THE SOURCE TERM. IF A RADIONUCLIDE, THEN MASS IS CONVERTED TO ACTIVITY

```

```

IF(T.GE.TSL)THEN
  ARG = (- (SLEACH + DLR + RC2) * (T-TSL))
  Q = QSL*FRAC*SLEACH*EXP(-ARG)
ELSE
  Q = FRAC*WFLUX*SL
ENDIF
C convert mass to activity if a radionuclide
C CONVERT MG TO CI. USE THE CONVERSIONS 1 CI=3.7E10 DPS, 3.1536 S/Y
C 6.023E23 ATOMS/MOLE AND 1000 MG/G
IF(IMODE.LE.3)THEN
  QA = (Q/(1000*ZMW)*A*(DLR/SEC))/CI
  Q = QA
ENDIF
RETURN
END

C .....
C SUBROUTINE RAD
C .....
SUBROUTINE RAD(CS,CE,AIC,AICI,VOL,PKT,ADLR,NN,IMODEL)
IMPLICIT REAL*8 (A-H,O-Z)

*
* Identification
*
* Program Name: GWSCREEN
* Module Name: rad.f Version: 1.3
* Date: 9/13/93 Time: 13:45:22
*

COMMON /EXPOSURE/BW,AT,WI,EF,ED,DLIM,CRISK,HQ
PARAMETER (NSPEC=9)
COMMON /DECAY/ ADCF,AKD,ATHALF,ARD,ARADMAX,RCSF
DIMENSION ADCF(NSPEC),AKD(NSPEC),ATHALF(NSPEC),ARADMAX(NSPEC)
I,ARD(NSPEC),RCSF(NSPEC)
COMMON /POND/ RMI,TOPE,PNDFLX,THETAP,EVAP,PLEACH,WAEFF
DIMENSION ADLR(NSPEC),Q(NSPEC), QDX(NSPEC),C(NSPEC),D(NSPEC)
C VARIABLES
C DLIM = DOSE LIMIT (4 REM/Y)
C CL = LIMITING GROUNDWATER CONCENTRATION CI/M**3
C WI = WATER INTAKE RATE (L/D)
C CDCF = COMPOSITE DOSE COVERSION FACTOR
C CX = THE CONCENTRATION IN THE POND EFFLUENT
C C(I) = CONCENTRATION OF THE ITH PROGENY MEMBER (CI/L)

Character Idkeyw*72
Data Idkeyw /'@(#)rad.f 1.3 9/13/93 13:45:22\0'/
Idkeyw = Idkeyw

WRITE(2,500)
CDCF=0.0
C CALCULATE DECAY-INGROWTH FACTORS, CONCENTRATIONS AND COMPOSITE DCF
C CONCENTRATION IN CI/L
IF(NN.GT.1)THEN
  Q(1)=1.0
  DO 10, I=2,NN
    Q(I)=0.0
  10 CONTINUE
  CALL RDK(PKT,ADLR,NN,Q,QDX)
  WRITE(2,1000) (QDX(I),I=1,NN)
  DO 20,I=1,NN
    C(I) = (AICI*(QDX(I)/QDX(1)))*(ARD(1)/ARD(I))/1000.
  20 CONTINUE
C CALCULATE COMPOSITE DOSE CONVERSION FACTOR
DO 30, I=1,NN
  CDCF = CDCF + ADCF(I)*(QDX(I)/QDX(1))*(ARD(1)/ARD(I))
30 CONTINUE
ELSE
  C(1) = AICI/1000
  CDCF = ADCF(1)
ENDIF

```

```

      CL=DLIM/(CDCF*WI*EF/1000)
      WRITE(2,2000) CDCF,CL/1000
C    CALCULATE DOSE
      DT=0.0
      IF(NN.GT.1)THEN
        WRITE(2,4000)
      ENDIF
      DO 40,I=1,NN
        D(I)=C(I)*WI*EF*ADCF(I)
        DT=DT+D(I)
        WRITE(2,3000) I,C(I),D(I)
40    CONTINUE
      WRITE(2,4500) DT

C    CALCULATE LIMITING SOIL OF POND EFFLENT CONCENTRATIONS
      IF(IMODEL.LT.2)THEN
C      1/VOL=THE SOIL CONCENTRATION FOR A UNIT INVENTORY
        CS=CL/AIC*(1/VOL)
        ELSE
          CU=RMI/PNDFLX
          CE=(CL*CU/AIC)
        ENDIF

500  FORMAT(2X,'COMMITTED EFFECTIVE DOSE EQUIVALENT CALCULATION')

1000 FORMAT(2X,'DECAY-INGROWTH FACTORS ',1PE11.4,1X,1PE11.4,1X,1PE11.4,
11X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4)
2000 FORMAT(2X,'COMPOSITE DOSE CONVERSION FACTOR (rem/Ci): ',1PE9.2
1/2X,'LIMITING GROUNDWATER CONCENTRATION (Ci/L): ',1PE9.2)
3000 FORMAT(2X,'MAXIMUM GW CONCENTRATION FOR MBR #',I1,' : ',1PE9.2,
11X,'Ci/L',2X,'CEDE = ',1PE9.2,' rem')
4000 FORMAT(2X,'NOTE: PROGENY CONCENTRATIONS ARE REPORTED AT THE TIME O
IF THE MAXIMUM PARENT CONCENTRATION')
4500 FORMAT(2X,'MAXIMUM CEDE ',1PE9.2,' rem')

      RETURN
      END
C .....
C  SUBROUTINE CRAD
C .....
      SUBROUTINE CRAD(CS,CE,AIC,DAIC,VOL,GWMAXI,PKT,ADLR,NN,IMODEL)
      IMPLICIT REAL*8 (A-H,O-Z)

      *
      *
      * Identification
      *
      * Program Name: GWSCREEN
      * Module Name: crad.f Version: 1.6
      * Date: 9/13/93 Time: 13:55:34
      *

      COMMON /EXPOSURE/BW,AT,WI,EF,ED,DLIM,CRISK,HQ
      PARAMETER (NSPEC=9)
      COMMON /DECAY/ ADCF,AKD,ATHALF,ARD,ARADMAX,RCSF
      DIMENSION ADCF(NSPEC),AKD(NSPEC),ATHALF(NSPEC),ARADMAX(NSPEC)
      I,ARD(NSPEC),RCSF(NSPEC)
      COMMON /POND/ RMI,TOPEP,PNDFLX,THETAP,EVAP,PLEACH,WAEFF
      DIMENSION ADLR(NSPEC),Q(NSPEC), QDX(NSPEC),CM(NSPEC),D(NSPEC),
      I DAIC(NSPEC)
C  VARIABLES
C  RCSF = RADIOLOGICAL CARCINOGENIC SLOPE FACTOR (1/Ci)
C  CL = LIMITING GROUNDWATER CONCENTRATION Ci/M**3
C  WI = WATER INTAKE RATE (L/D)
C  CSF=COMPOSITE SLOPE COVERSION FACTOR
C  CX=THE CONCENTRATION IN THE POND EFFLUENT
C  DAIC(I) = CONCENTRATION OF THE ITH PROGENY MEMBER (Ci/M**3)
      Character idkeyw*72
      Data idkeyw /'@(#)crad.f 1.6 9/13/93 13:55:34\0'/
      idkeyw = idkeyw

```

```

WRITE(2,500)
C  CALCULATE DECAY-INGROWTH FACTORS AND MAX CONC FOR PROGENY
C  CONVERT CONCENTRATIONS TO CI/L
IF(NN.GT.1)THEN
  Q(1)=1.0
  DO 10, I=2,NN
    Q(I)=0.0
10  CONTINUE
  CALL RDK(PKT,ADLR,NN,Q,QDX)
  WRITE(2,1000) (QDX(I),I=1,NN)
  DO 20,I=1,NN
    CM(I)=GWMAXI*(QDX(I)/QDX(1))*(ARD(1)/ARD(I))/1000.
    DAIC(I)=DAIC(I)/1000
20  CONTINUE
    ELSE
      DAIC(1)=DAIC(1)/1000.
      CM(1)=GWMAXI/1000.
  ENDIF
C  CALCULATE RISK
RISK=0.0
IF(NN.GT.1)THEN
  WRITE(2,4000)
ENDIF
DO 40,I=1,NN
  D(I)=DAIC(I)*WI*EF*ED*RCSF(I)
  RISK=RISK+D(I)
  WRITE(2,2500) I,CM(I)
  WRITE(2,3000) I,DAIC(I),D(I)
40  CONTINUE
WRITE(2,4500) RISK
C CALCULATE LIMITING GROUNDWATER CONCENTRATION
CL=(DAIC(1)*CRISK)/RISK
WRITE(2,2000) CL
C  CALCULATE LIMITING SOIL OF POND EFFLENT CONCENTRATIONS
IF(IMODEL.LT.2)THEN
C  1/VOL=THE SOIL CONCENTRATION FOR A UNIT INVENTORY
c convert alc to CI/L
  CS=CL/(AIC/1000)*(1/VOL)
  ELSE
    CU=RMI/PNDFLX
c CL must be converted to CI/m3 so that CE is passed in units of CI/m3
  CE=((CL*1000.)*CU/AIC)
ENDIF

500 FORMAT(2X,'CARCINOGENIC RISK CALCULATION FOR RADIONUCLIDES')
1000 FORMAT(2X,'DECAY-INGROWTH FACTORS:',1PE11.4,1X,1PE11.4,1X,1PE11.4,
11X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4)
2000 FORMAT(2X,'LIMITING PARENT GROUNDWATER CONC. (CI/L): ',1PE9.2)

2500 FORMAT(2X,'MAXIMUM GW CONCENTRATION FOR MBR #',I1,': ',1PE9.2,
11X,'CI/L')
3000 FORMAT(2X,'AVERAGE GW CONCENTRATION FOR MBR #',I1,': ',1PE9.2,
11X,'CI/L RISK = ',1PE9.2)
4000 FORMAT(2X,'NOTE: PROGENY CONCENTRATIONS ARE REPORTED AT THE TIME 0
IF THE MAXIMUM PARENT CONCENTRATION')
4500 FORMAT(2X,'MAXIMUM CARCINOGENIC RISK:',1PE9.2)

RETURN
END
C .....
C  SUBROUTINE MAXRAD
C .....
SUBROUTINE MAXRAD(CS,CE,AIC,DAIC,VOL,GWMAXI,PKT,ADLR,NN,IMODEL)
  Implicit real*8 (a-h,o-z)

*
*  Identification
*
*  Program Name: GWSCREEN

```


- Module Name: maxrad.f Version: 1.3
- Date: 9/13/93 Time: 13:52:54
-

```
COMMON /POND/ RMI,TOPE,PNDFLX,THETAP,EVAP,PLEACH,WAEFF
PARAMETER (NSPEC=9)
COMMON /DECAY/ ADCF,AKD,ATHALF,ARD,ARADMAX,RCSF
DIMENSION ADCF(NSPEC),AKD(NSPEC),ATHALF(NSPEC),ARADMAX(NSPEC)
I,ARD(NSPEC),RCSF(NSPEC)
DIMENSION ADLR(NSPEC),C(NSPEC),Q(NSPEC),QDX(NSPEC),DAIC(NSPEC)
```

```
Character idkeyw*72
Data idkeyw /'@(#)maxrad.f          1.3 9/13/93 13:52:54'0'/
idkeyw = idkeyw
```

C VARIABLES

```
C CL = LIMITING GROUNDWATER CONCENTRATION CI/M**3 FOR PARENT INCLUDING
C   CONTRIBUTIONS FROM PROGENY
C AIC=AVERAGE INTEGRATED CONC FOR UNIT INVENTORY OF PARENT CI/M**3
C AICI=AVERAGE INTEGRATED CONC FOR ACTUAL INVENTORY OF PARENT CI/M**3
C DAIC=THE AVERAGE INTEGRATED CONC FOR PROGENY CI/M**3 (CONVERTED TO CI/L)
C C(I)=THE MAXIMUM CONCENTRATION FOR PARENT AND PROGENY
C THE FACTOR OF 1000 IN THE BELOW EQUATION CONVERTS FROM L/D TO
C CUBIC METERS PER DAY
C SUMX = TEMP VARIABLE FOR HOLDING INTERMEDIATE VALUES FOR CALCULATION OF THE
C   LIMITING PARENT GROUNDWATER CONCENTRATION ADJUSTED FOR PROGENY
C   CONTRIBUTIONS
WRITE(2,500)
C   CALCULATE DECAY-INGROWTH FACTORS PRODUCTS AND PEAK CONCENTRATIONS
IF(NN.GT.1)THEN
  Q(1)=1.0
  DO 10, I=2,NN
    Q(I)=0.0
10  CONTINUE
  SUMX=0.0
C   UNITS DAIC(I)=CI/L  ARADMAX=CI/L
  CALL RDK(PKT,ADLR,NN,Q,QDX)
  WRITE(2,1000) (QDX(I),I=1,NN)
  DO 20,I=1,NN
    C(I)=(GWMAXI*(QDX(I)/QDX(1))*(ARD(1)/ARD(I)))/1000.
    DAIC(I)=DAIC(I)/1000.
    SUMX=SUMX+DAIC(I)/ARADMAX(I)
20  CONTINUE
  CL=DAIC(1)/SUMX
  ELSE
    C(1)=GWMAXI/1000.
    DAIC(1)=DAIC(1)/1000
    CL=ARADMAX(1)
  ENDIF
WRITE(2,1500) CL
C   CONVERT CL TO CI/M3
C   1/VOL=THE SOIL CONCENTRATION FOR A UNIT INVENTORY
CL=CL*1000

C   CALCULATE LIMITING SOIL CONC AND POND EFFLENT CONCENTRATIONS
IF(IMODEL.LT.2)THEN
C   1/VOL=THE SOIL CONCENTRATION FOR A UNIT INVENTORY
  CS=CL/AIC*(1/VOL)
  ELSE
    CU=RMI/PNDFLX
    CE=(CL*CU/AIC)
  ENDIF
C PRINT PEAK AND AVERAGE CONCENTRATIONS
IF(NN.GT.1)THEN
  WRITE(2,4000)
ENDIF
DO 30, I=1,NN
  WRITE(2,2000) I,C(I)
  WRITE(2,3000) I,DAIC(I)
30  CONTINUE
```

```

c   0   10   20   30   40   50   60
c2345678901234567890123456789012345678901234567890123456789012345
500 FORMAT(2X,'MAXIMUM RADIONUCLIDE CONCENTRATION LIMIT CALCULATION')
1000 FORMAT(2X,'DECAY-INGROWTH FACTORS ',1PE11.4,1X,1PE11.4,1X,1PE11.4,
11X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4,1X,1PE11.4)
1500 FORMAT(2X,'LIMITING PARENT GW CONCENTRATION ADJUSTED FOR PROGENY =
1',1PE9.2,1X,'CI/L')
2000 FORMAT(2X,'MAXIMUM GW CONCENTRATION FOR MBR #',I1,':',1PE9.2,
11X,'CI/L')
3000 FORMAT(2X,'AVERAGE GW CONCENTRATION FOR MBR #',I1,':',1PE9.2,
11X,'CI/L')
4000 FORMAT(2X,'NOTE: PROGENY CONCENTRATIONS ARE REPORTED AT THE TIME O
IF THE MAXIMUM PARENT CONCENTRATION')
RETURN
END
C .....
C SUBROUTINE MAXNRAD
C .....
SUBROUTINE MAXNRAD(CS,CE,AIC,AICI,GWMAXI,VOL,ZRADMAX,IMODEL)
IMPLICIT REAL*8 (A-H,O-Z)
*
* Identification
*
* Program Name: GWSCREEN
* Module Name: maxnrad.f Version: 1.2
* Date: 6/21/93 Time: 16:48:43
*

COMMON /POND/ RMI,TOPER,PNDFLX,THETAP,EVAP,PLEACH,WAEFF

Character idkeyw*72
Data idkeyw /'@(#)maxnrad.f 1.2 6/21/93 16:48:43\0'/
idkeyw = idkeyw
WRITE(2,500)
C CONVERT ZRADMAX TO mg/M3
C 1/VOL=THE SOIL CONCENTRATION FOR A UNIT INVENTORY
CL=ZRADMAX*1000
C CALCULATE LIMITING SOIL CONC AND POND EFFLENT CONCENTRATIONS
IF(IMODEL.LT.2)THEN
C 1/VOL=THE SOIL CONCENTRATION FOR A UNIT INVENTORY
CS=CL/AIC*(1/VOL)
ELSE
CU=RMI/PNDFLX
CE=(CL*CU/AIC)
ENDIF
WRITE(2,1000) GWMAXI/1000,AICI/1000
500 FORMAT(2X,'MAXIMUM NON RADIOLOGICAL CONTAMINANT CALCULATION')
1000 FORMAT(2X,'MAXIMUM CONCENTRATION ',1PE9.2,' mg/L'
1/,2X,'AVERAGE CONCENTRATION ',1PE9.2,' mg/L')

RETURN

END
C .....
C SUBROUTINE CARCIN
C .....
SUBROUTINE CARCIN(CS,CE,AIC,VOL,SFACTOR,AICI,GWMAXI,IMODEL)
IMPLICIT REAL*8 (A-H,O-Z)
*
* Identification
*
* Program Name: GWSCREEN
* Module Name: carcin.f Version: 1.2
* Date: 6/21/93 Time: 16:49:42
*

COMMON /EXPOSURE/BW,AT,WI,EF,ED,DLIM,CRISK,HQ
COMMON /POND/ RMI,TOPER,PNDFLX,THETAP,EVAP,PLEACH,WAEFF
C VARIABLES
C BW = BODY WEIGHT (kg)

```

```

C I = WATER INTAKE RATE (L/d)
C ED = EXPOSURE DURATION (YEARS)
C AT = AVERAGING TIME (days)
C EF=EXPOSURE FREQUENCY (DAYS/YEAR)
C DLIM = DOSE LIMIT (4 REM/Y)
C CRISK = CARCINOGENIC RISK FACTOR (1.0E-6)
C CL = LIMITING GROUNDWATER CONCENTRATION CI/M**3
C WI = WATER INTAKE RATE (L/D)
C THE FACTOR OF 1000 IN THE BELOW EQUATION CONVERTS FROM L/D TO
C CUBIC METERS PER DAY
*
Character idkeyw*72
Data idkeyw /'@(#)carcin.f 1.2 6/21/93 16:49:42\0'/
idkeyw = idkeyw

WRITE(2,500)
CL=(CRISK*BW*AT)/(SFACTOR*WI*EF/1000*ED)
RSK=((AICI/1000)*SFACTOR*WI*EF*ED)/(BW*AT)
C 1/VOL=THE SOIL CONCENTRATION FOR A UNIT INVENTORY
CS=CL/AIC*(1/VOL)
C CALCULATE LIMITING SOIL CONC AND POND EFFLENT CONCENTRATIONS
IF(IMODEL.LT.2)THEN
C 1/VOL=THE SOIL CONCENTRATION FOR A UNIT INVENTORY
CS=CL/AIC*(1/VOL)
ELSE
CU=RMI/PNDFLX
CE=(CL*CU/AIC)
ENDIF
WRITE(2,1000) CL/1000,GWMAXI/1000,AICI/1000,RSK
500 FORMAT(2X,'CARCINOGENIC RISK CALCULATION')
1000 FORMAT(2X,'LIMITING GROUNDWATER CONCENTRATION (mg/L): ',1PE9.2
1/2X,'MAXIMUM GROUNDWATER CONCENTRATION (mg/L): ',1PE9.2
1/2X,'AVERAGE GROUNDWATER CONCENTRATION (mg/L): ',1PE9.2
1/2X,'CARCINOGENIC RISK FOR USER INPUT MASS: ',1PE9.2)

RETURN
END
C .....
C SUBROUTINE NCARCIN
C .....
SUBROUTINE NCARCIN(CS,CE,AIC,VOL,RFD,AICI,GWMAXI,IMODEL)
IMPLICIT REAL*8 (A-H,O-Z)
COMMON /POND/ RMI,TOPEP,PNDFLX,THETAP,EVAP,PLEACH,WAEFF
COMMON /EXPOSURE/BW,AT,WI,EF,ED,DLIM,CRISK,HQ
C VARIABLES
C BW = BODY WEIGHT (kg)
C I = WATER INTAKE RATE (L/d)
C ED = EXPOSURE DURATION (YEARS)
C AT = AVERAGING TIME (days)
C EF=EXPOSURE FREQUENCY (DAYS/YEAR)
C DLIM = DOSE LIMIT (4 REM/Y)
C CRISK = CARCINOGENIC RISK FACTOR (1.0E-6)
C CL = LIMITING GROUNDWATER CONCENTRATION CI/M**3
C WI = WATER INTAKE RATE (L/D)
C THE FACTOR OF 1000 IN THE BELOW EQUATION CONVERTS FROM L/D TO
C CUBIC METERS PER DAY
*
* Identification
*
* Program Name: GWSCREEN
* Module Name: ncrcin.f Version: 1.3
* Date: 6/21/93 Time: 16:50:48
*
Character idkeyw*72
Data idkeyw /'@(#)ncrcin.f 1.3 6/21/93 16:50:48\0'/
idkeyw = idkeyw

CL=(HQ*BW*AT*RFD)/(WI*EF/1000*ED)
HQX=((AICI/1000)*WI*EF*ED)/(BW*AT*RFD)

```

```

C 1/VOL=THE SOIL CONCENTRATION FOR A UNIT INVENTORY

      CS=CL/AIC*(1/VOL)
C  CALCULATE LIMITING SOIL CONC AND POND EFFLENT CONCENTRATIONS
      IF(IMODEL.LT.2)THEN
C    1/VOL=THE SOIL CONCENTRATION FOR A UNIT INVENTORY
      CS=CL/AIC*(1/VOL)
      ELSE
      CU=RMI/PNDFLX
      CE=(CL*CU/AIC)
      ENDIF
      WRITE(2,1000) CL/1000,GWMAXI/1000,AICI/1000,HQX

500 FORMAT(2X,'NON-CARCINOGENIC RISK CALCULATION')
1000 FORMAT(2X,'LIMITING GROUNDWATER CONCENTRATION (mg/L): ',1PE9.2
1/2X,'MAXIMUM GROUNDWATER CONCENTRATION (mg/L): ',1PE9.2
1/2X,'AVERAGE GROUNDWATER CONCENTRATION (mg/L): ',1PE9.2
1/2X,'HAZARD QUOTIENT FOR INPUT MASS: ',1PE9.2)
      RETURN
      END
C .....
C * FUNCTION ZARG *
C .....
      FUNCTION ZARG(TI,ZX)
      *
      * Identification
      *
      * Program Name: GWSCREEN
      * Module Name: zarg.f Version: 1.5
      * Date: 4/13/94 Time: 12:50:41
      *
C This subroutine calculates the non vertically averaged Z value

      IMPLICIT REAL*8 (A-H,O-Z)
      PARAMETER (EP=1.0E-10,P1=3.141592)
      COMMON /GW/ AX, AY, AZ, VX, THICK, AL, WA, GWLIM, RD, PHI, DLR,
      I QX, SLEACH, FRAC, WFLUX, SL, QSL, QI, XD, YD, ZD, ZMW,RC2,IMODE,
      I ITYPE
      Character idkeyw*72
      Data idkeyw /'@(#)zarg.f 1.5 4/13/94 12:50:41\0'/
      Idkeyw = idkeyw
      DZ=ABS(AZ*VX)
      TEMP1=(P1**2)*DZ*TI/(RD*THICK**2)
      TEMP2=P1*ZX/THICK
C Z ARGUMENTS
      M=1
      OEXPAN=1.0D-80
      EXPAN=0.0
      IFLG=0
C MAXIMUM NUMBER OF TERMS ALLOWED IS 20 SUCH THAT WHEN M=20, EXP(ARG)=0
      DO WHILE (IFLG.EQ.0)
      XM=FLOAT(M)
      ARG=(-(XM**2)*TEMP1)
      EXPAN=EXPAN+EXPF(ARG)*COS(XM*TEMP2)
      IF(DABS(OEXPAN-EXPAN).LE.EP*DABS(EXPAN).OR.M.GT.20)THEN
      IFLG=1
      ELSE
      M=M+1
      OEXPAN=EXPAN
      ENDIF
      END DO
      ZARG=(1+2*EXPAN)/THICK
      RETURN
      END

```