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Additional Cover/Cap Scenario Streamtube Fate and Transport Modeling for the Old Radioactive Waste Burial Ground, Savannah River Site, Aiken, South Carolina (U)

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Executive Summary

The modeling described in this report is an extension of previous fate and transport modeling for the Old Radioactive Waste Burial Ground (ORWBG) Corrective Measures Study/Feasibility Study (CMS/FS). The purpose of this and the previous modeling is to provide quantitative input to the screening of remedial alternatives for the CMS/FS for this site. This new modeling was undertaken to address new remedial alternatives, and to specifically compare results of four alternatives: Soil Cover, RCRA Cap, Synthetic Cap (with an effective barrier of 10^{-9} cm/sec), and Synthetic Cap (with an effective barrier of 10^{-11} cm/sec).

Two water table concentrations were calculated: maximum and minimum bounding values. The maximum bounding value essentially assumes no mixing of leaching fluid with groundwater flow, whereas the minimum bounding value essentially assumes complete mixing of the leaching fluid with the an assumed non-reduced groundwater flow. Actual groundwater concentrations would be somewhere in-between these bounding values. Cumulative fluxes for each remedial alternative were also computed and presented.

When comparing maximum bounding concentrations, the results show that there are a few differences between remedial alternatives. In general, the lower permeability remedial alternatives result in higher maximum bounding concentrations for most of the simulation time. This is a direct result of the potential migration of COIs prior to emplacement of the “final” remedial alternative, and because the extremely low permeability alternatives effectively freeze the concentrations at the water table for the remainder of the simulation. When comparing minimum bounding concentrations, the results show that there are significant differences between remedial alternatives as no COIs are above standards for either synthetic cap alternative.

Cumulative fluxes for each COI also show few differences between the remedial alternatives. There appears to be no significant flux difference between the two synthetic alternatives. The only difference seen between the cap and synthetic alternatives is for cadmium, and to a lesser extent, carbon-14. The only significant flux differences between the cover and cap alternatives are for carbon-14, strontium-90, cadmium, and mercury.

Overall, these results are consistent with the results seen with the previous modeling.

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LIST OF ACRONYMS AND ABBREVIATIONS

Ci	Curies
CMS/FS	Corrective Measures Study/Feasibility Study
COI	constituent of interest
ft	feet
GSA	General Separations Area
kg	kilogram
L	liter
m	meter
ml	milliliter
OOM	order-of-magnitude
ORWBG	Old Radioactive Waste Burial Ground
pCi	picoCuries
RCRA	Resource, Conservation and Recovery Act
SCDHEC	South Carolina Department of Health and Environmental Control
SRS	Savannah River Site
ug	micrograms
US DOD	United States Department of Defense
US DOE	United States Department of Energy
US EPA	United States Environmental Protection Agency
WSRC	Westinghouse Savannah River Company
yr	year

1.0 INTRODUCTION

The modeling described in this report is an extension of previous fate and transport modeling for the Old Radioactive Waste Burial Ground (ORWBG) Corrective Measures Study/Feasibility Study (CMS/FS) (HSI GeoTrans, 1999; WSRC, 1999a; WSRC, 1999b). The purpose of this new modeling is to provide a prediction of the effects of additional Cover/Cap remedial alternatives. As this effort is a direct extension of previous work, the reader is referred to WSRC-RP-99-4215 for a complete discussion of ORWBG background information, the hydrogeologic conceptual model, and the mathematical framework of the streamtube modeling approach. The general conceptual model of this effort is revisited in Figures 1-1 through 1-3.

Results from four remedial alternatives (Table 1-1) were compared. The Cover and Cap alternatives were previously simulated, with the two Synthetic Cap (effective barriers of 10^{-9} and 10^{-11} cm/sec) alternatives simulated as part of this effort. Each alternative assumes that no degradation of cover/cap performance occurs for the entire simulation period (1000 years), that leaching started in 1974 (early-timing), and that source leaching and vadose zone flow is affected by the cover/cap alternative (full-impact).

Consistent with the previous modeling, 16 constituents of interest (COIs) from 60 assumed source areas/configurations are modeled. The COIs include 12 radioactive constituents and four hazardous constituents, each with different initial source distributions, leaching rates, and geochemical properties. The total initial mass/activity for each COI is given in Table 1-2. Note that the initial VOC mass is equal to the previous modeling initial mass, which is 10x the assumed ORWBG VOC source term quantity.

2.0 REMEDIAL ALTERNATIVES

With this streamtube fate and transport modeling, the only difference between remedial alternatives is with infiltration rates. Infiltration rates were calculated for the Cover, Cap, and Synthetic Cap (10^{-9}) remedial alternatives in the previous modeling (HSI GeoTrans, 1999) using the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al., 1994). The

Synthetic Cap (10^{-11}) remedial alternative infiltration rates were calculated as part of this work, as documented in Appendix A.

The assumed configuration for each remedial alternative is given in Figure 2-1. The resulting infiltration curves are given in Figure 2-2, with the pertinent values listed in Table 2-1. All non-infiltration model parameters are the same as those used in the previous work.

3.0 ASSUMPTIONS AND LIMITATIONS

The limitations and assumptions of this modeling effort are similar to the previous ORWBG streamtube modeling efforts. Several simplifying assumptions have been made in order to conduct this analysis. In general, the assumptions are conservative and should tend to overestimate concentrations at the top of the water table.

One of the biggest assumptions relates to the acceptance of the source term data. Although an intensive study to quantify burial locations, inventories, and waste forms has been conducted (WSRC, 1997a), there is uncertainty associated with these values. In many instances, due to lack of information, it was assumed that the entire inventory of a constituent was evenly distributed across the ORWBG. Although this may appear to be a non-conservative assumption, it provides a consistent relative comparison for evaluation of remedial alternatives.

Although many constituents have waste forms that may provide some delay or reduction in leaching, the only waste form that has been taken credit for is encapsulation in concrete. Even in the case of concrete, the water flow through the waste is assumed to be unaffected (same as in soil), however the sorption properties are changed, resulting in a lower K_d for some COIs. This assumption overestimates concentrations and underestimates travel times. This assumption tends to predict quicker-than-actual release of waste from the source to the vadose zone, and thus may underpredict the effectiveness of caps that are installed in the future, after much of a COI's inventory has leached out of the waste in the model.

A one-dimensional flow tube that does not spread deep into the aquifer is assumed. This is a conservative assumption because the shortest possible flow length is modeled, without credit for a more tortuous path or attenuation in clay layers that underlie the water table aquifer. In addition, credit for lateral dispersion, which would tend to lower concentrations, has not been taken.

The assumed geochemical properties are based on best engineering judgement from studies conducted at SRS. Although some of these values have been roughly verified by the presence or absence of constituents in groundwater, their exact quantification is uncertain. Furthermore, it is assumed that these parameters do not change as a result of the presence of other constituents (competition for sorption sites, facilitated transport, etc). Note that neither COI ingrowth nor daughter products are considered.

Finally, due to limitations and assumptions of the computer models (some of which are more fully discussed in other sections of this report), the results of this modeling should only be used to compare remedial alternatives and should not be used to predict specific vadose zone or saturated zone concentrations. Further, the comparison of alternatives/scenarios should only be to an order-of-magnitude level, with any differences between scenarios of less than a factor of 10 not considered significant. Additionally, although the computer code outputs concentration (and mass/activity) values at very low levels (i.e., 1.0E-45, etc.), any concentration (or mass/activity) value less than approximately 1.0E-5 should be considered as equivalent to zero.

4.0 RESULTS

As with the previous modeling, a “streamtube” approach was used to account for variable distribution of COIs in the ORWBG and for flowpaths that vary depending on location in the ORWBG. Rather than performing a single one-dimensional analysis with the entire ORWBG as the source, the modeling involved performing numerous one-dimensional analyses with elements of the ORWBG as independent sources. Summation/averaging of the individual streamtube results provides a total picture of the fate and transport from the entire ORWBG.

This work focuses on the concentration for each COI in the saturated zone directly beneath the ORWBG (i.e., at the water table). As described in the previous modeling reports (HSI GeoTrans, 1999; WSRC, 1999b) each saturated zone streamtube flow area is adjusted for the flow received from the vadose zone. Thus, if the vadose zone flow rate is reduced, the saturated zone flow area is reduced, and a constant saturated zone flow velocity is maintained. The saturated zone flow velocity was based on the aquifer hydraulic properties and streamtube geometry, independent of remedial alternative effects on leaching and vadose zone flow.

The water table concentration calculated using the weighted average of the concentrations at the water table for each COI (based on vadose zone flow for each streamtube) effectively assumes "no mixing" of the contaminant transport with the "natural" groundwater flow, resulting in concentrations that can be considered maximum bounding values (see Figure 4-1a). Alternatively, using the total mass (activity) flux for each COI and an assumed non-reduced groundwater flow, the computed concentration effectively assumes "total mixing" with the groundwater, resulting in concentrations that can be considered minimum bounding values (see Figure 4-1b). Actual groundwater concentrations would be somewhere in-between these bounding values.

Only maximum bounding concentrations were presented in the previous modeling reports, as they would reflect the highest concentrations for the remedial alternatives previously considered. This was consistent with the ORWBG Core Team's original intent of this modeling: to predict relative differences between cap/cover systems in reducing contaminant fluxes at the point of exposure (i.e., Four Mile Branch). With the current very-low permeability remedial alternatives being simulated (the two Synthetic alternatives), the maximum bounding concentrations may be more unlikely than for the other remedial alternatives, since these simulations effectively discount any mixing effects. However, the location of the ORWBG source (on the border of a groundwater divide – hence slow groundwater rates) and the degree of heterogeneity present in the subsurface create uncertainty in any predictions of mixing. Therefore, both bounding concentrations are presented in this report, along with the total flux predictions, to support the remedial alternative comparison.

The maximum bounding concentration for each COI was computed as follows:

$$C_{\max} = \frac{\sum_i [C_i \times a_i]}{A}$$

where C_i is the computed water table concentration [ug/L or pCi/ml], a_i is the area [m^2] of each element i, and A is the total ORWBG area [m^2]. The minimum bounding concentration for each COI was computed as follows:

$$C_{\min} = \frac{\sum_i F_i}{0.48 \times A} \times c$$

where F_i is the computed water table flux [kg/yr or Ci/yr] for each element i, 0.48 x A is the base flow rate (m^3/yr), and c is a conversion factor to get the resulting concentration in acceptable units. The base flow rate is assumed to be equivalent to yearly natural infiltration (0.48 m/yr) on the ORWBG footprint (A).

Time versus concentration plots for each COI are given in Figures 4-2 and 4-3 for the minimum bounding concentration and the maximum bounding concentration, respectively. The calculated concentrations for each COI at specified times during the simulation period were compared to the values given in Table 4-1. Those COIs with maximum bounding concentrations exceeding the Table 4-1 values are reported in Table 4-2. Those COIs with minimum bounding concentrations exceeding the Table 4-1 values are reported in Table 4-3. The mass flux to the water table for all COIs for selected times are given in Table 4-4.

5.0 CONCLUSIONS

This study involved applying the streamtube approach to assess fate and transport of 16 designated COIs for the ORWBG for four remedial alternatives. In particular, the maximum and minimum bounding concentrations at the water table and the mass (activity) flux to the water table were presented. This study was a continuation of the previous modeling effort for the ORWBG. A 1000-year simulation strategy was used that considered infiltration, leaching of constituents from their waste form, vadose zone solute transport, and saturated zone solute transport. Many simplifying assumptions were made which introduce uncertainty into the analysis. However, the approach is consistent with the reliability of the available data and the objectives of the study.

The results show that there are a few differences between remedial alternatives using the maximum bounding concentrations. All alternatives result in maximum bounding water table concentrations above standards for all selected times for carbon-14, and iodine-129. Other COIs (technetium-99, strontium-90, tritium, cobalt-60, cadmium, mercury, and VOC) were above standards at one or more selected times. In general, the lower permeability remedial alternatives result in higher maximum bounding concentrations for most of the simulation time. This is a direct result of the potential migration of COIs prior to emplacement of the "final" remedial alternative, and because the extremely low permeability alternatives effectively lock-in the concentrations at the water table for the remainder of the simulation (i.e., the flow slowly moves, with little concentration changes).

The results show that there are significant differences between remedial alternatives using the minimum bounding concentrations. A number of COIs are above standards for the Cover and Cap alternatives throughout the simulation timeframe. No COIs are above standards for either synthetic cap alternative at the times examined. It should be noted, however, that a number of COIs are above standards with the two synthetic cap alternatives prior to existing cover and final system placement as noted in Table 4-3.

Because concentration predictions in this modeling are only for bounding conditions, cumulative COI fluxes should also be examined for a complete assessment of impacts from remedial alternatives. As shown in Table 4-4, cumulative fluxes for each COI show few differences between the remedial alternatives. There appears to be no significant flux difference between the two synthetic alternatives. The only significant flux difference seen between the cap and synthetic alternatives is for cadmium, and to a lesser extent, carbon-14. The only significant flux differences between the cover and cap alternatives are for carbon-14, strontium-90, cadmium, and mercury.

One final observation on the flux results is that the two COIs with significant mass (activity) flux are tritium and VOC – both of which exceed standards (based on actual field monitoring data), are highly mobile, and are unaffected by remedial alternatives.

Overall assessment of the bounding concentration results and the cumulative flux results leads to the conclusion that there are few differences between remedial alternatives under the conditions simulated. These results are consistent with the results seen with the previous modeling.

6.0 REFERENCES

HSI GeoTrans, 1999. Source Term Fate and Transport Model for the Old Radioactive Waste Burial Ground, Task No. GW39-013, February 25, 1999.

Schroeder, P.R. Aziz, N.M., Lloyd. C.M. and Zappi, P.A. 1994. The Hydrologic Evaluation of Landfill Performance (HELP) Model: User's Guide for Version 3, EPA/600/R-94/168a, September 1994, U.S. Environmental Protection Agency Office of Research and Development, Washington, D.C.

Westinghouse Savannah River Company, 1999a. Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground (ORWBG), 643-E (U), WSRC-RP-98-4012, Revision 0.

Westinghouse Savannah River Company, 1999b. Streamtube Fate and Transport Modeling of the Source Term for the Old Radioactive Waste Burial Ground Savannah River Site, Aiken, Sourth Carolina (U), WSRC-RP-99-4215, Revision 0.

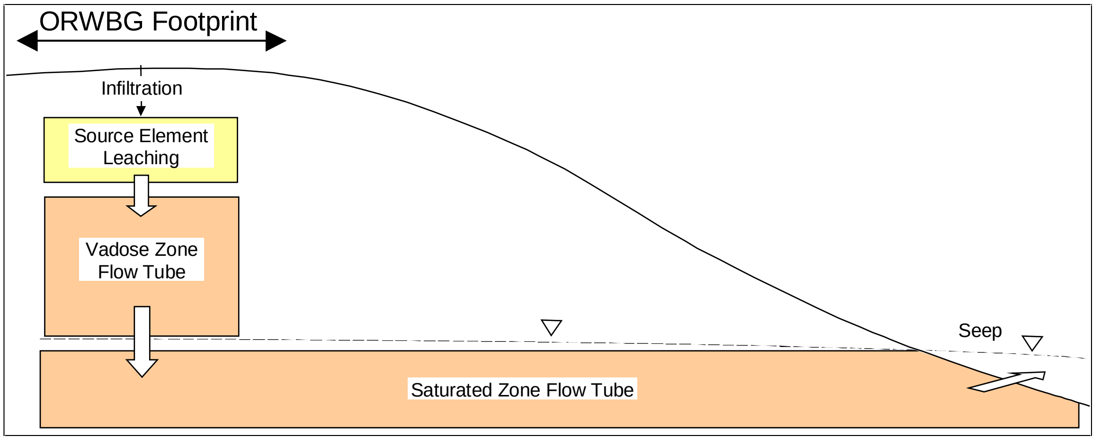
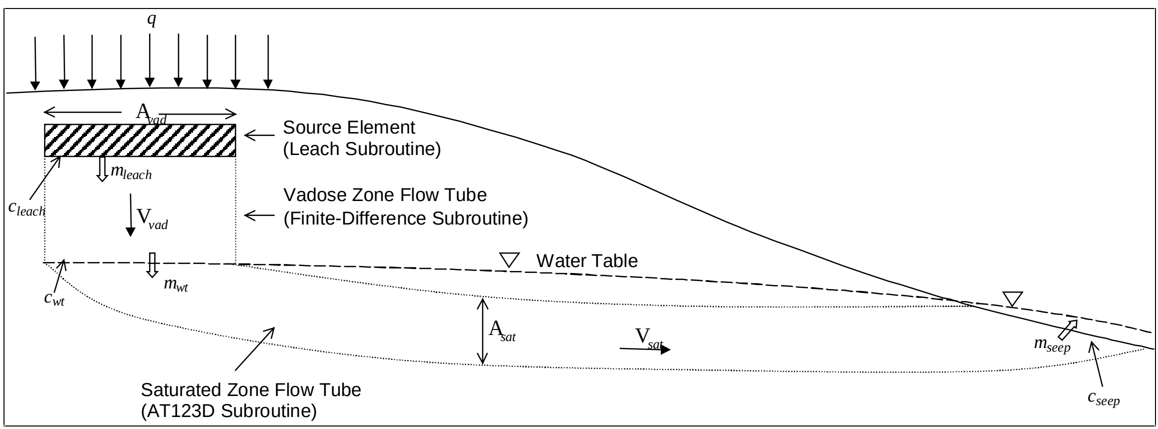


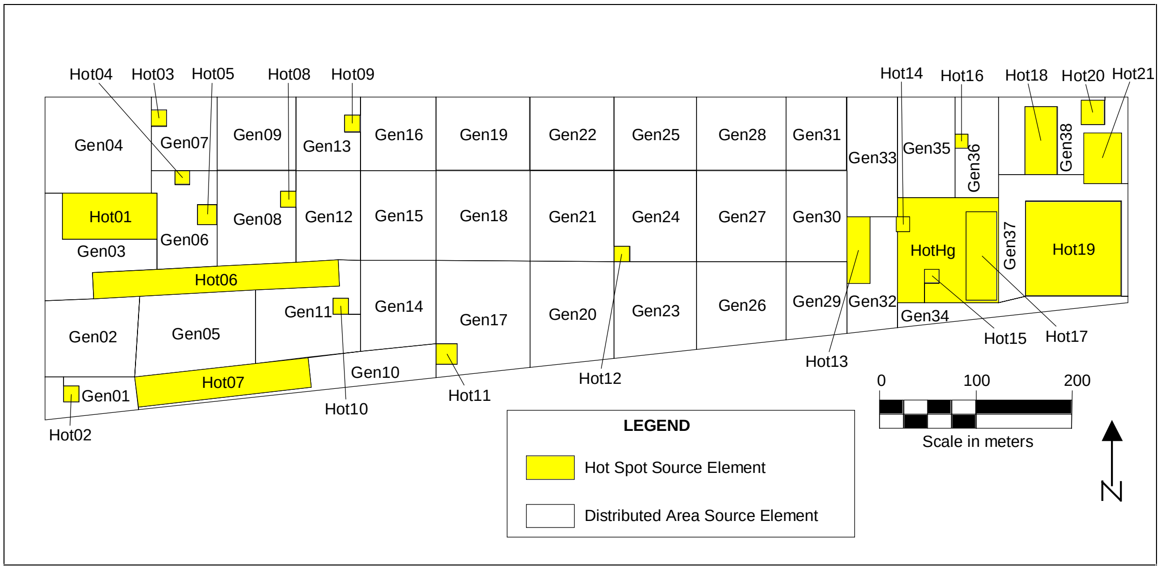
Figure 1-1. Conceptual Model of the Hydrologic Processes



Symbols

q	=	infiltration rate [L/T]
A_{vad}	=	source element area, vadose zone flow tube area [L^2]
$\dot{m}_{leach}$	=	leachate mass (activity) flux [M/T]
c_{leach}	=	leachate concentration [M/L^3]
V_{vad}	=	vadose zone groundwater velocity [L/T]
$\dot{m}_{wt}$	=	mass (activity) flux across water table [M/T]
c_{wt}	=	concentration at the water table [M/L^3]
A_{sat}	=	saturated zone flow tube area [L^2]
V_{sat}	=	saturated zone groundwater velocity [L/T]
$\dot{m}_{seep}$	=	mass (activity) flux to seeps [M/T]
c_{seep}	=	concentration at the seeps [M/L^3]

Figure 1-2. Detailed Conceptual Model for each Streamtube



Note: Elements do not overlap. Some general elements wrap around hot-spot elements.

Figure 1-3. Schematic of Source Element Locations

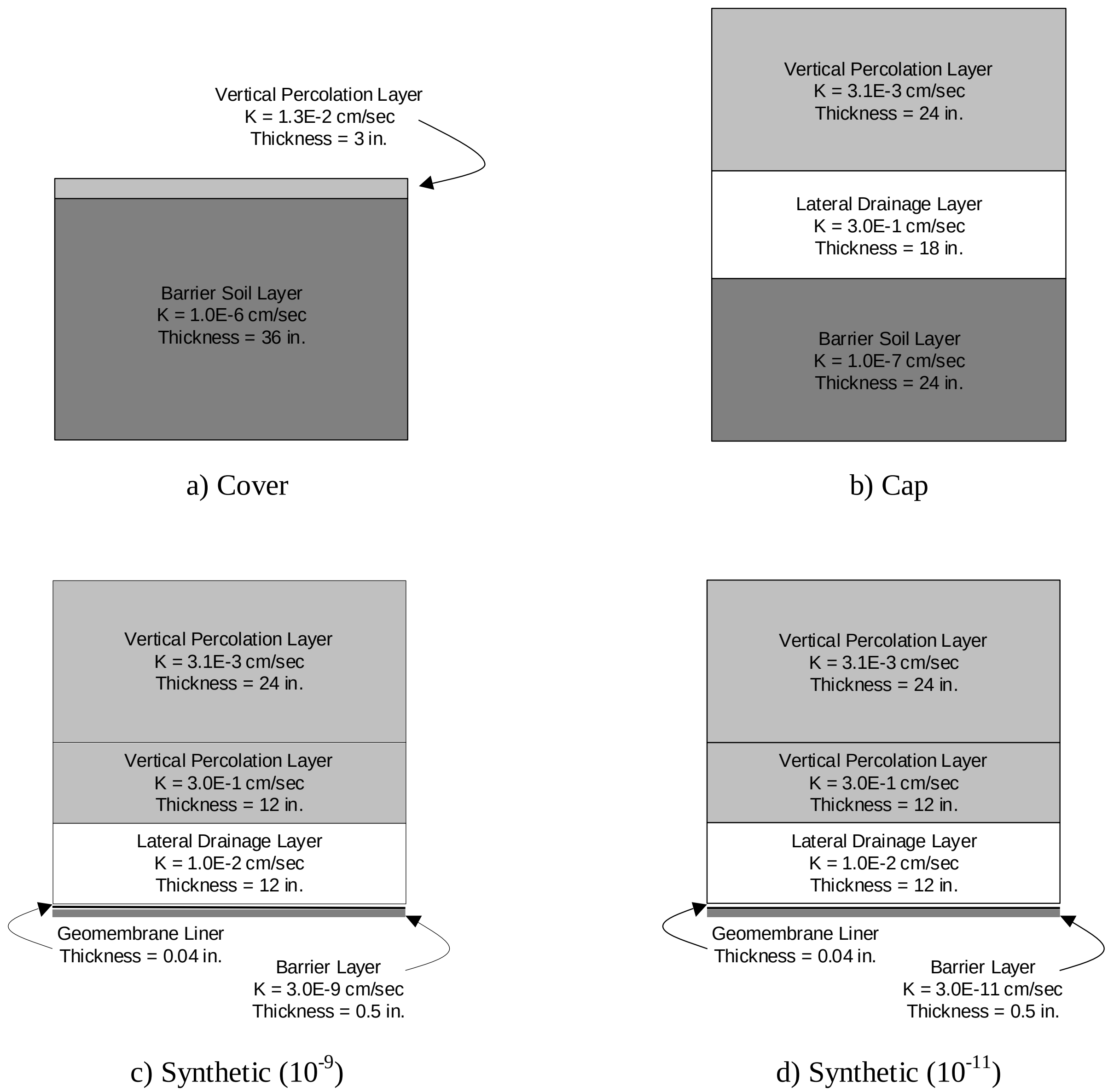
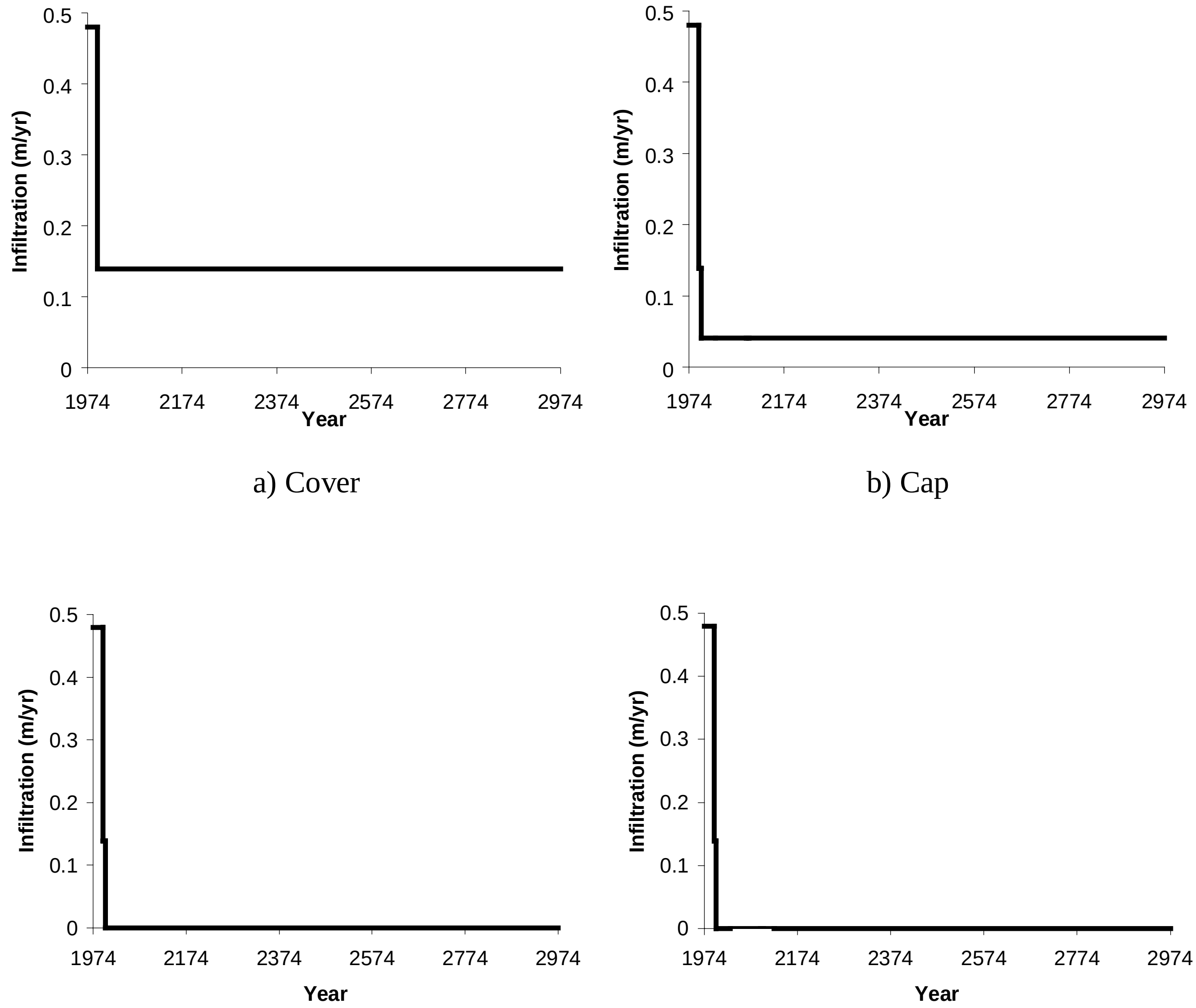


Figure 2-1. Conceptual Models for Cover/Cap Alternatives



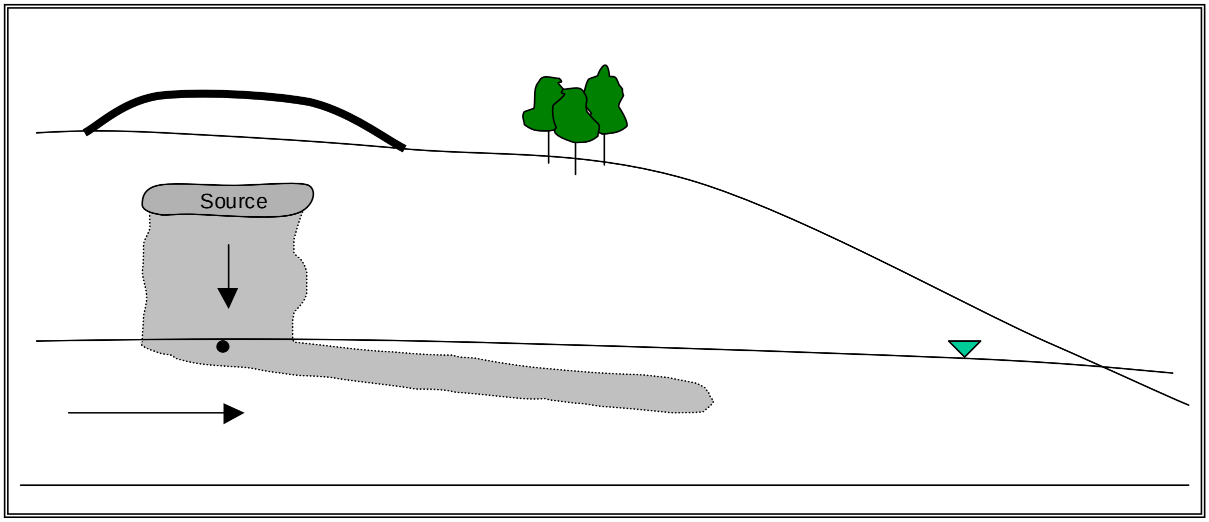
a) Cover

b) Cap

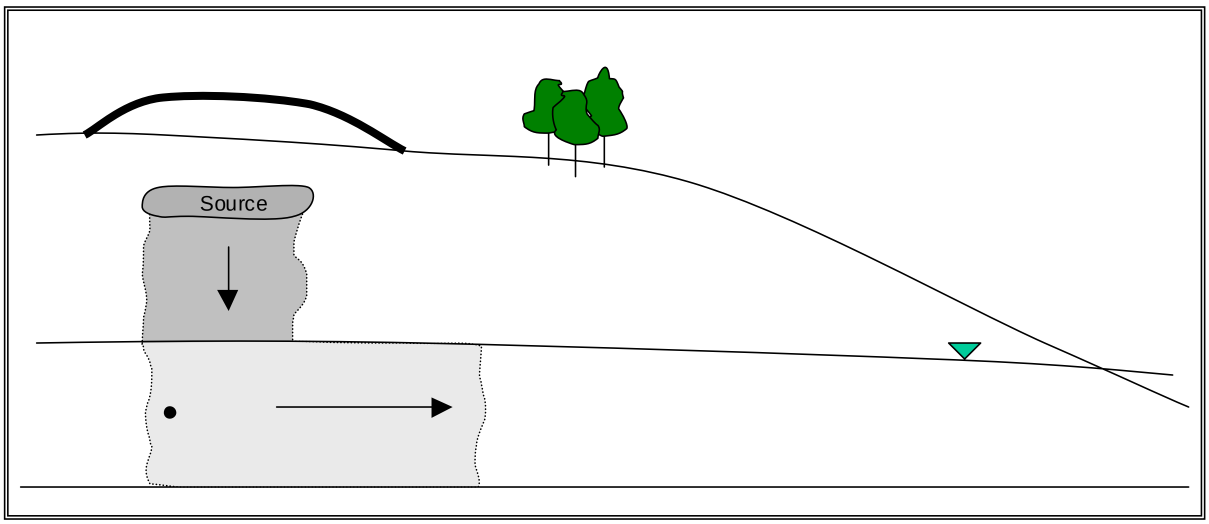
c) Synthetic (10^{-9})

d) Synthetic (10^{-11})

Figure 2-2. Infiltration for the Cover/Cap Alternatives of the Variable Vadose Zone Infiltration Modeling Scenarios (Full-Impact/Early-Timing)

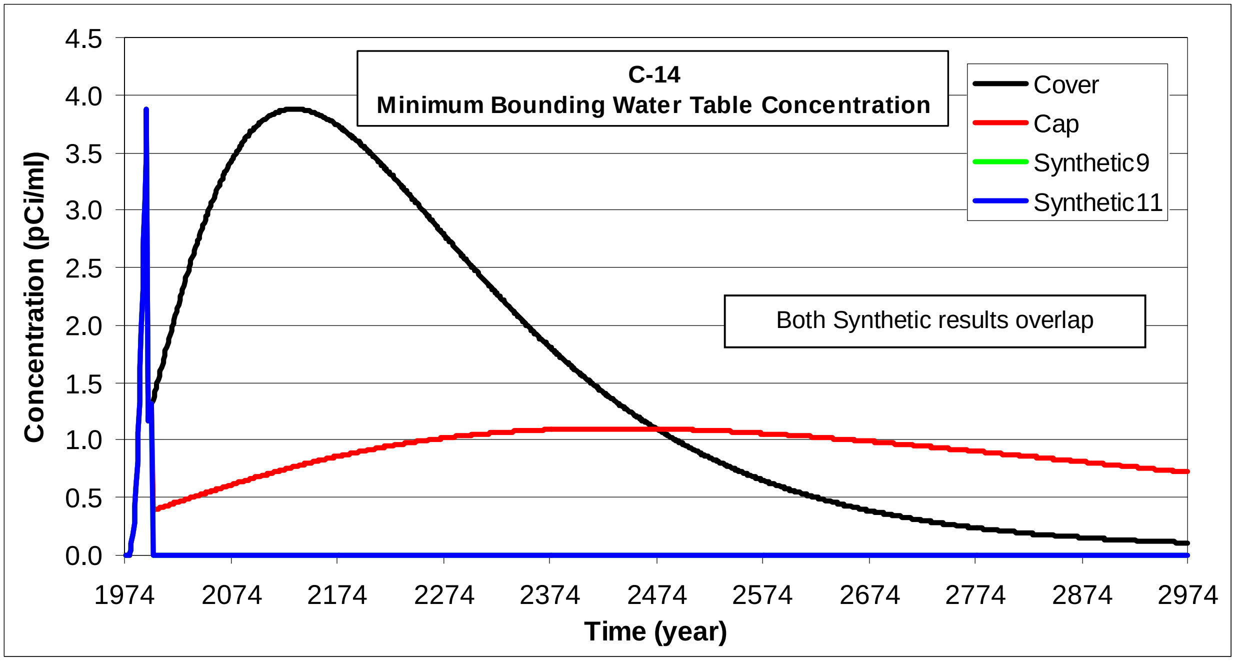


a) Maximum Bounding Concentration

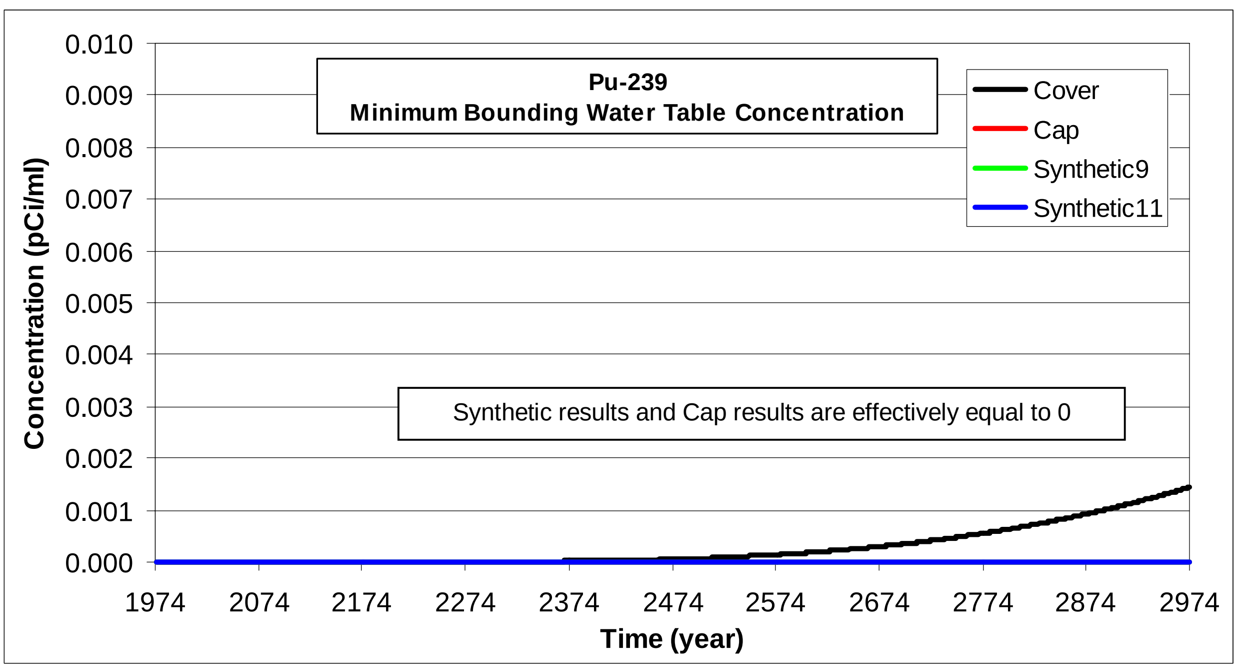


b) Minimum Bounding Concentration

Figure 4-1. Conceptual Models for Bounding Concentration Calculations

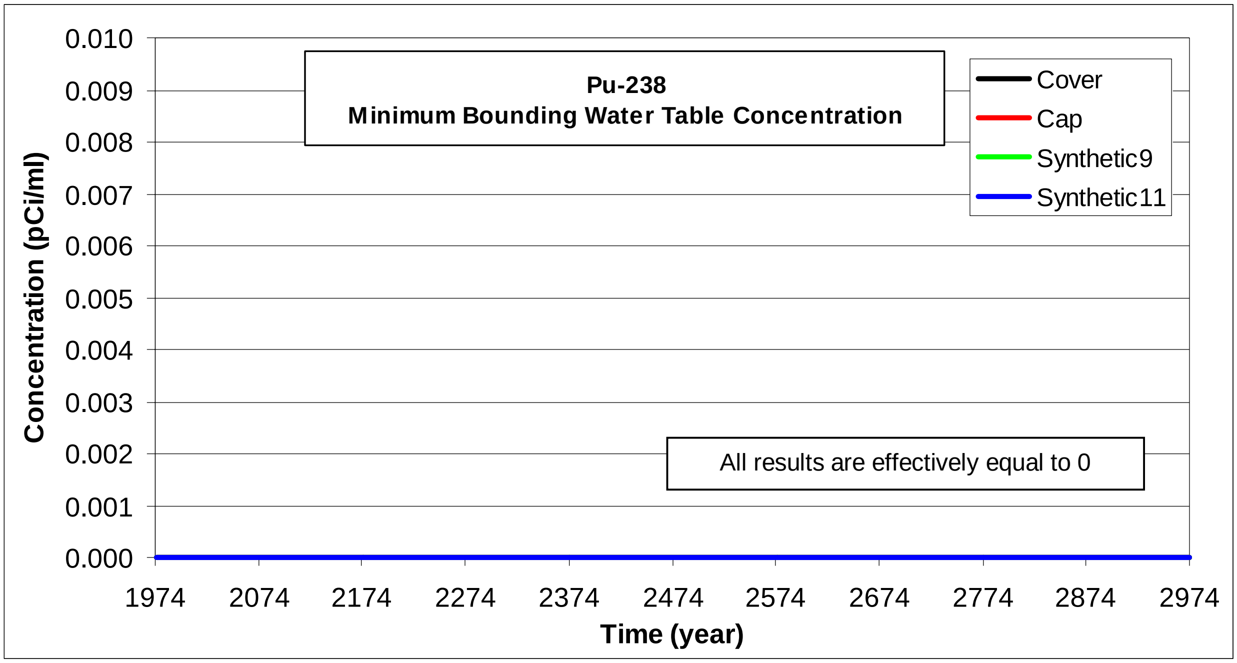


a) carbon-14

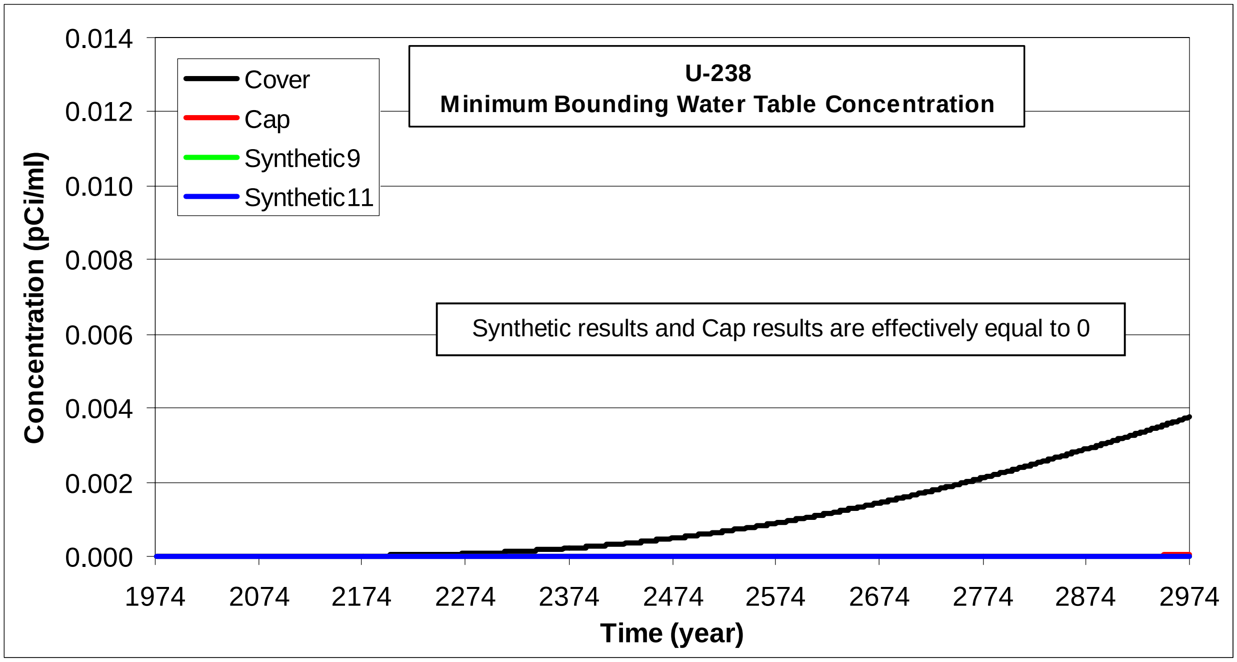


b) plutonium-239

Figure 4-2. Minimum Bounding Water Table Concentrations for each COI

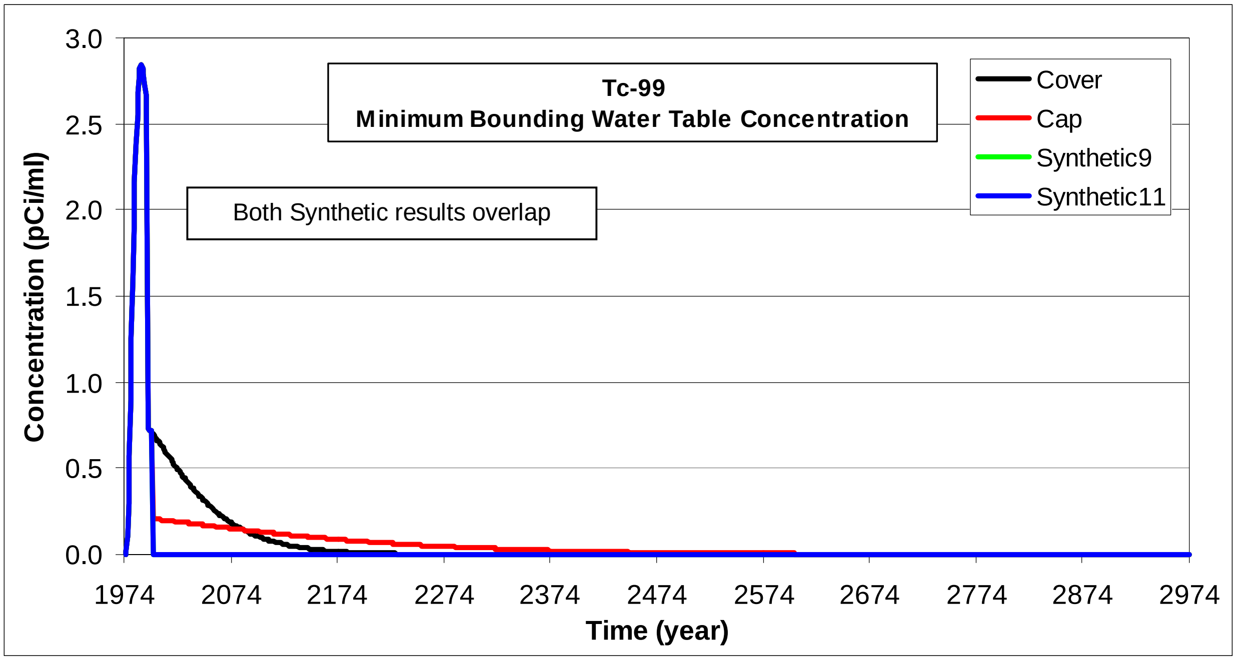


c) plutonium-238

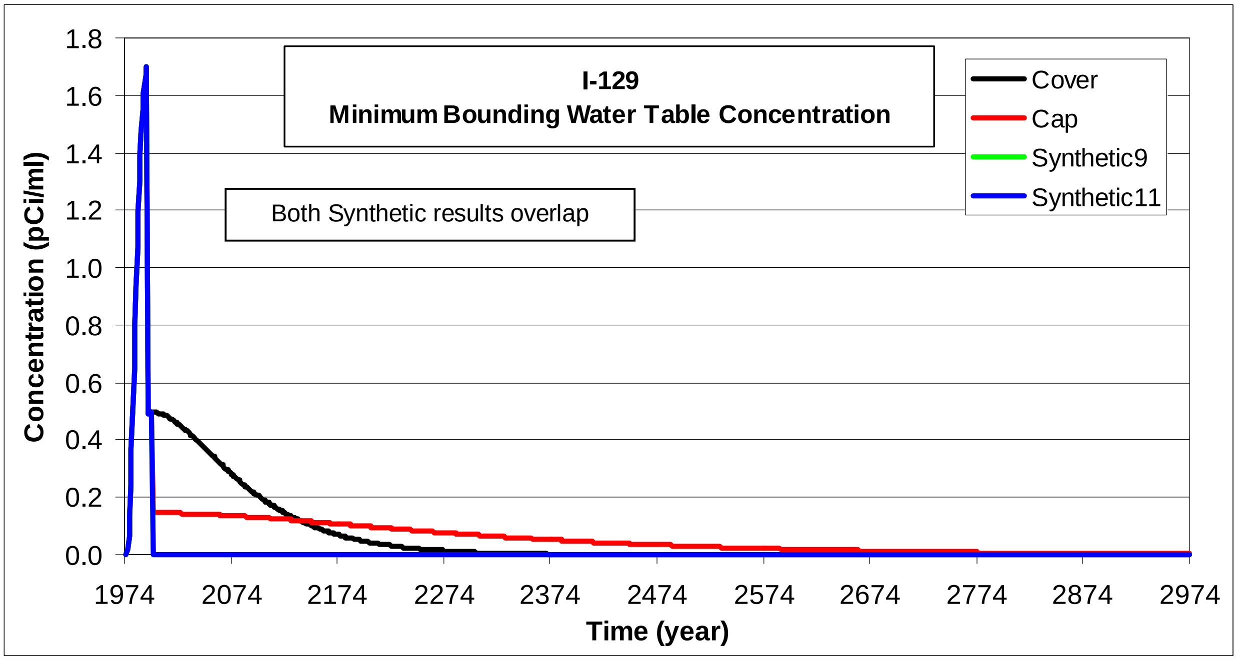


d) uranium-238

Figure 4-2 (con't). Minimum Bounding Water Table Concentrations for each COI

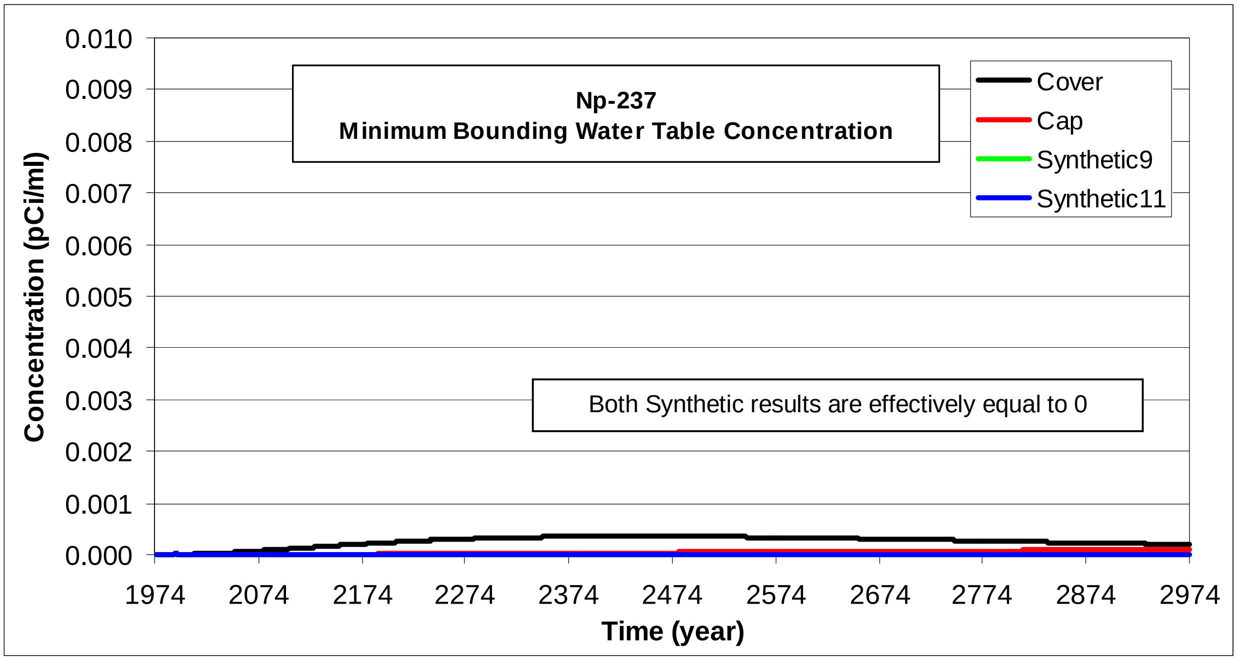


e) technetium-99

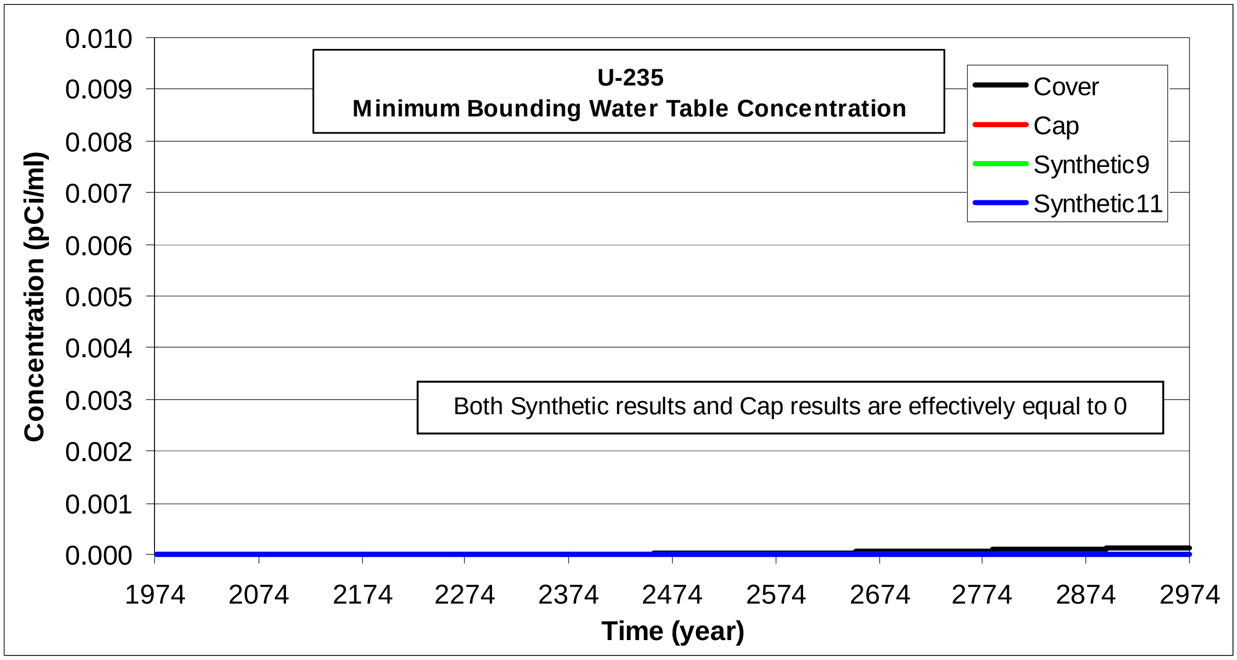


f) iodine-129

**Figure 4-2 (con't).	Minimum Bounding Water Table Concentrations for each COI**

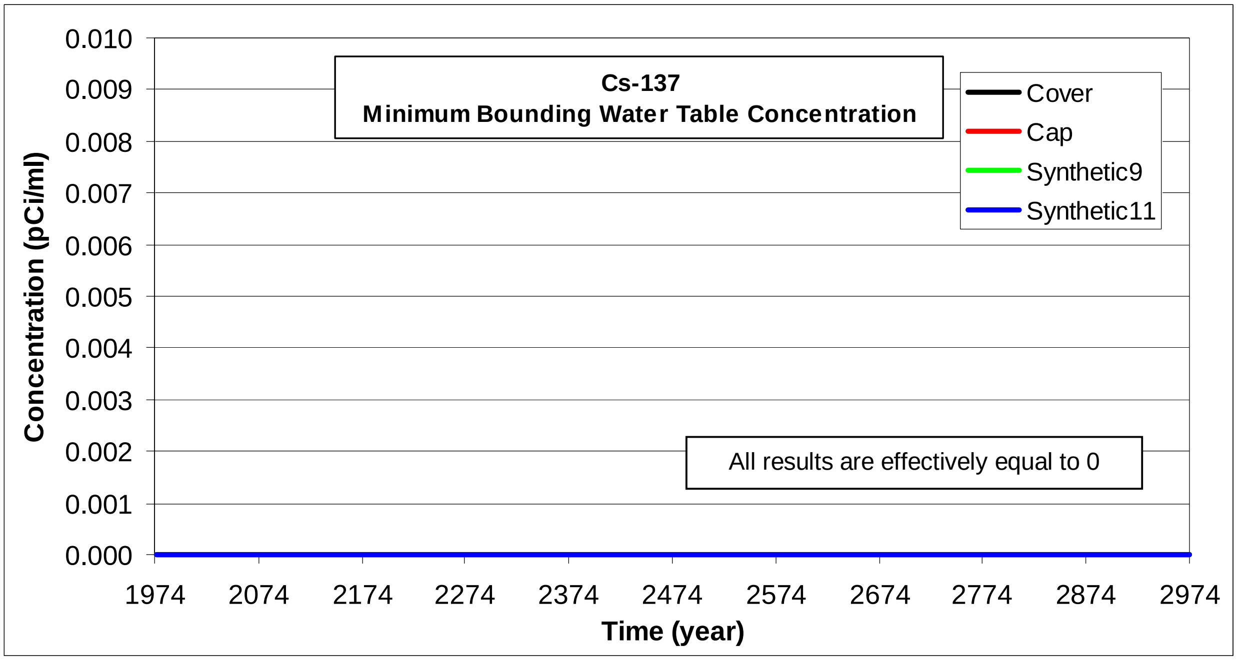


g) neptunium-237

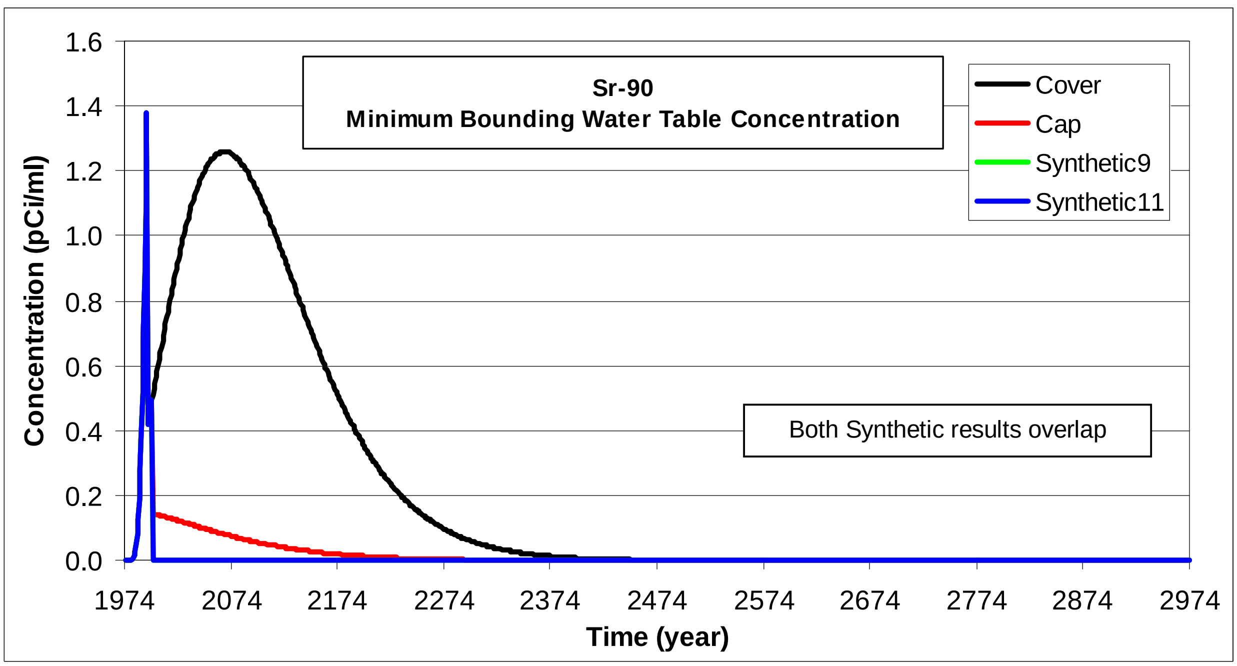


h) uranium-235

Figure 4-2 (con't). Minimum Bounding Water Table Concentrations for each COI

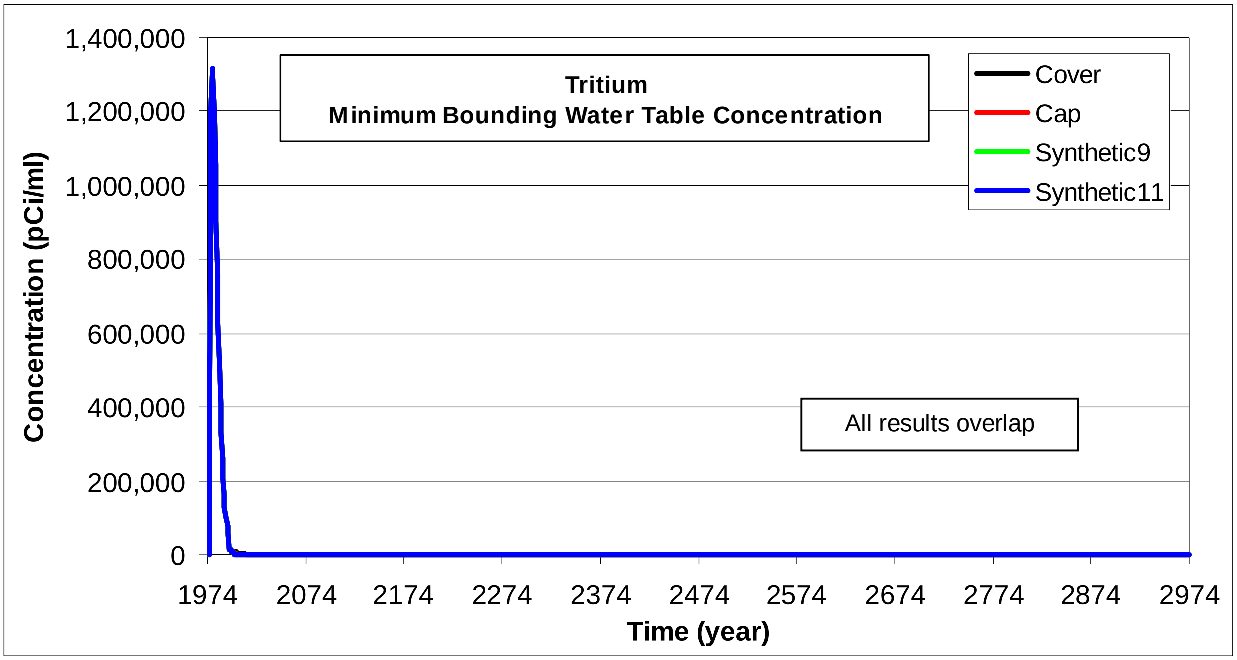


i) cesium-137

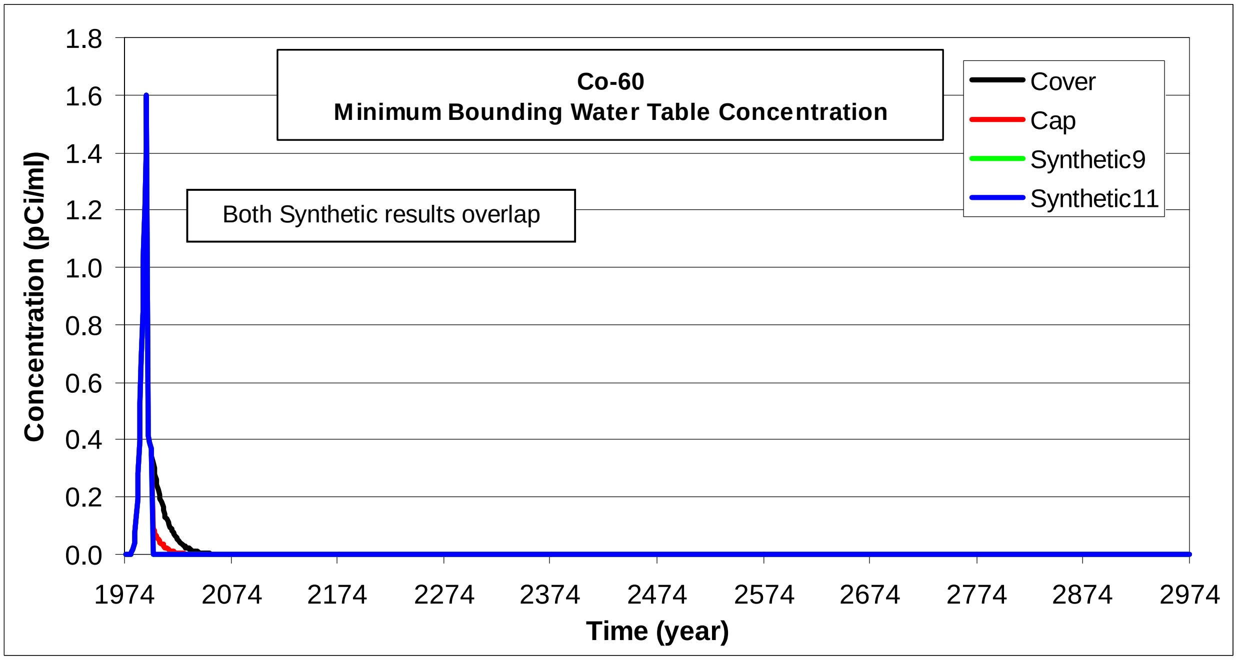


j) strontium-90

Figure 4-2 (con't). Minimum Bounding Water Table Concentrations for each COI

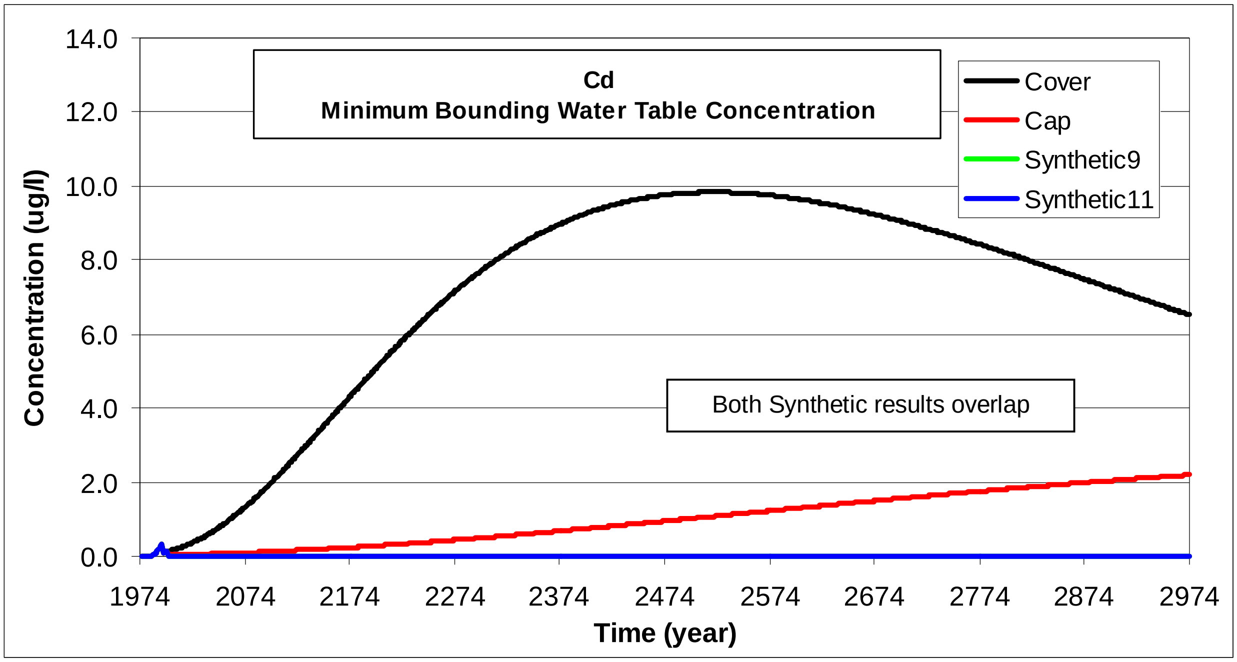


k) tritium

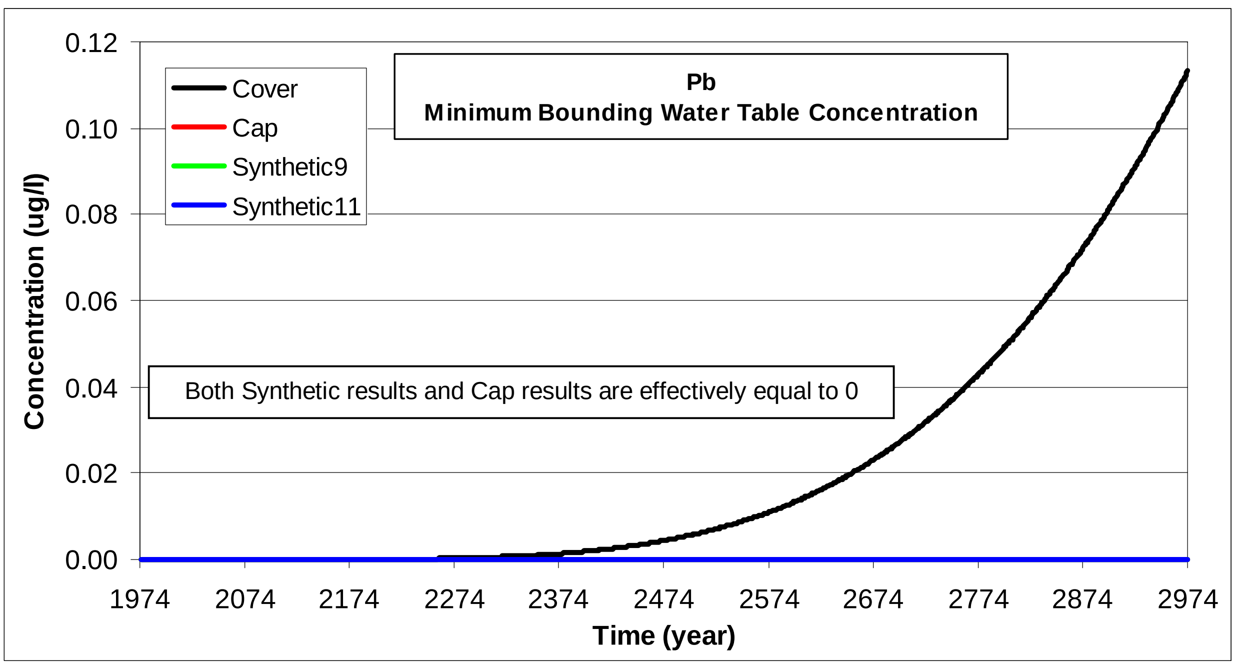


l) cobalt-60

Figure 4-2 (con't). Minimum Bounding Water Table Concentrations for each COI

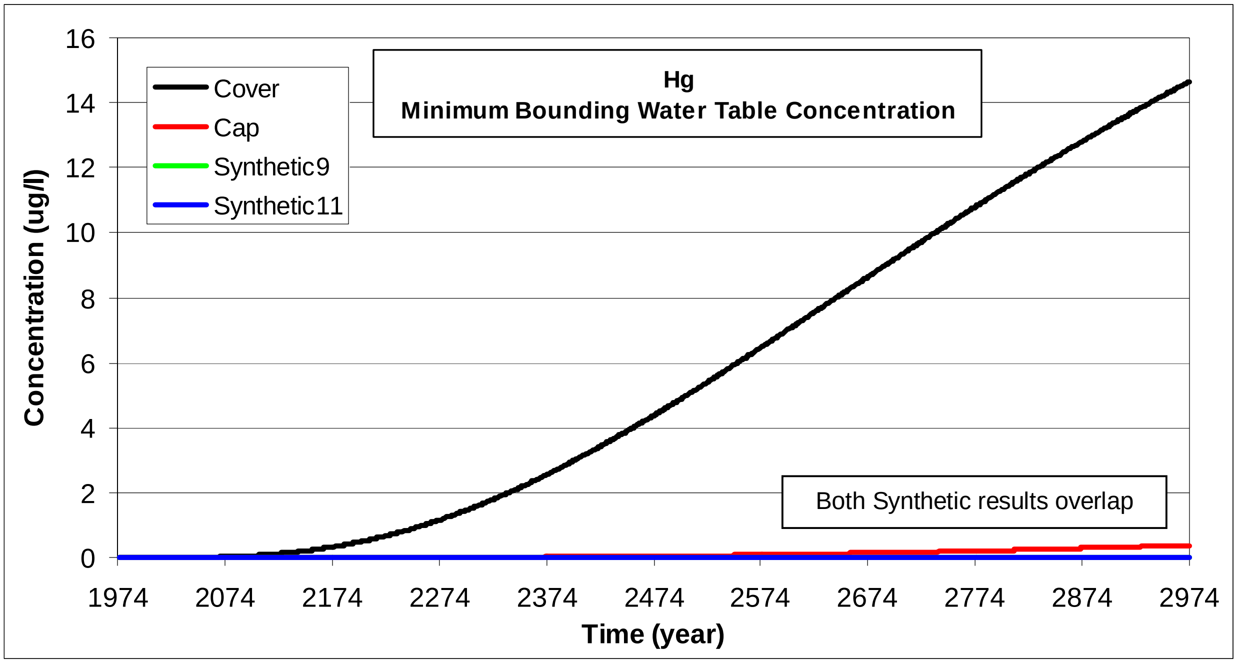


m) cadmium

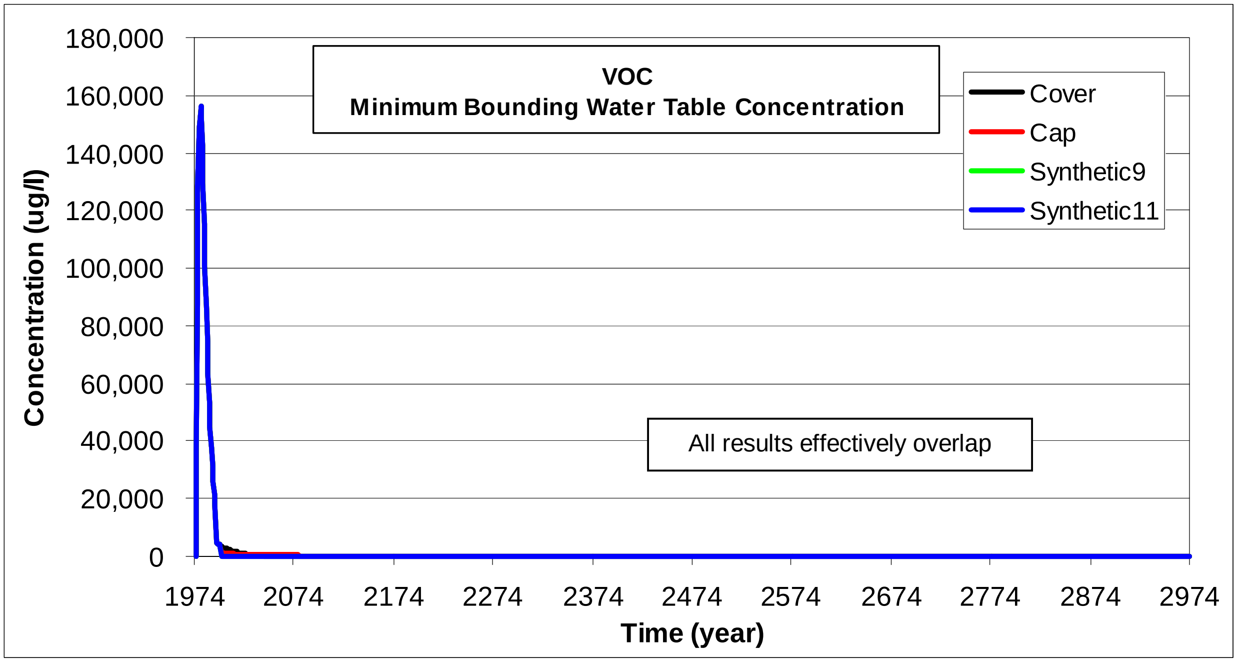


n) lead

Figure 4-2 (con't). Minimum Bounding Water Table Concentrations for each COI

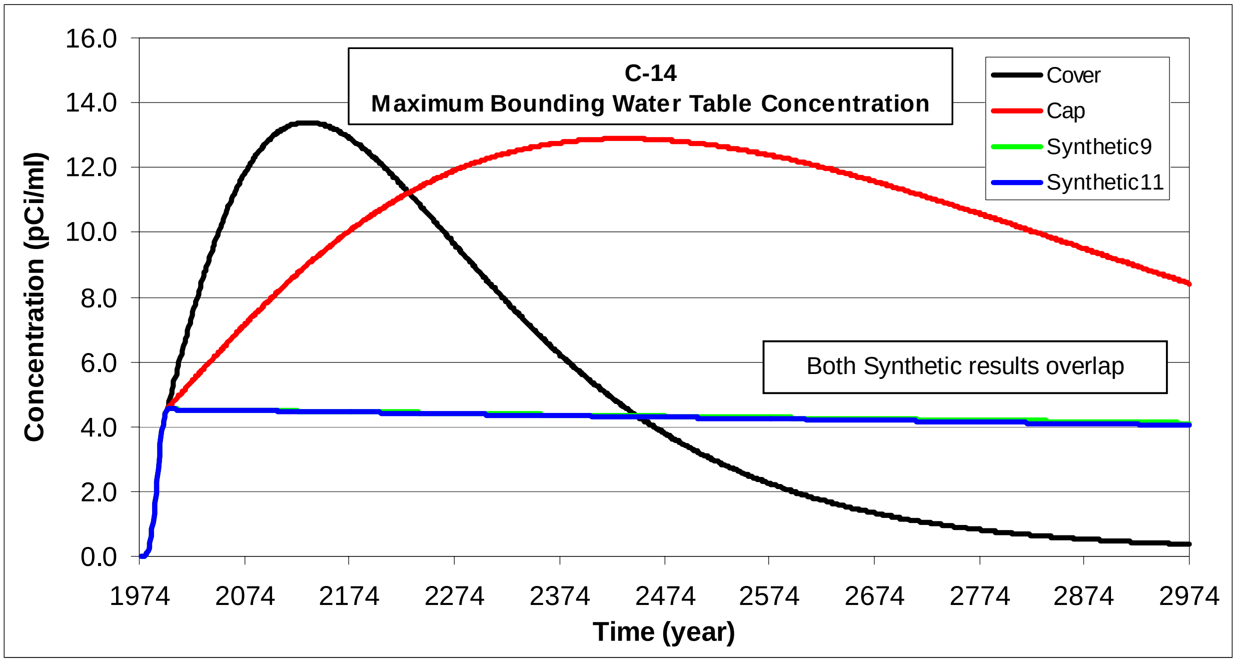


o) mercury

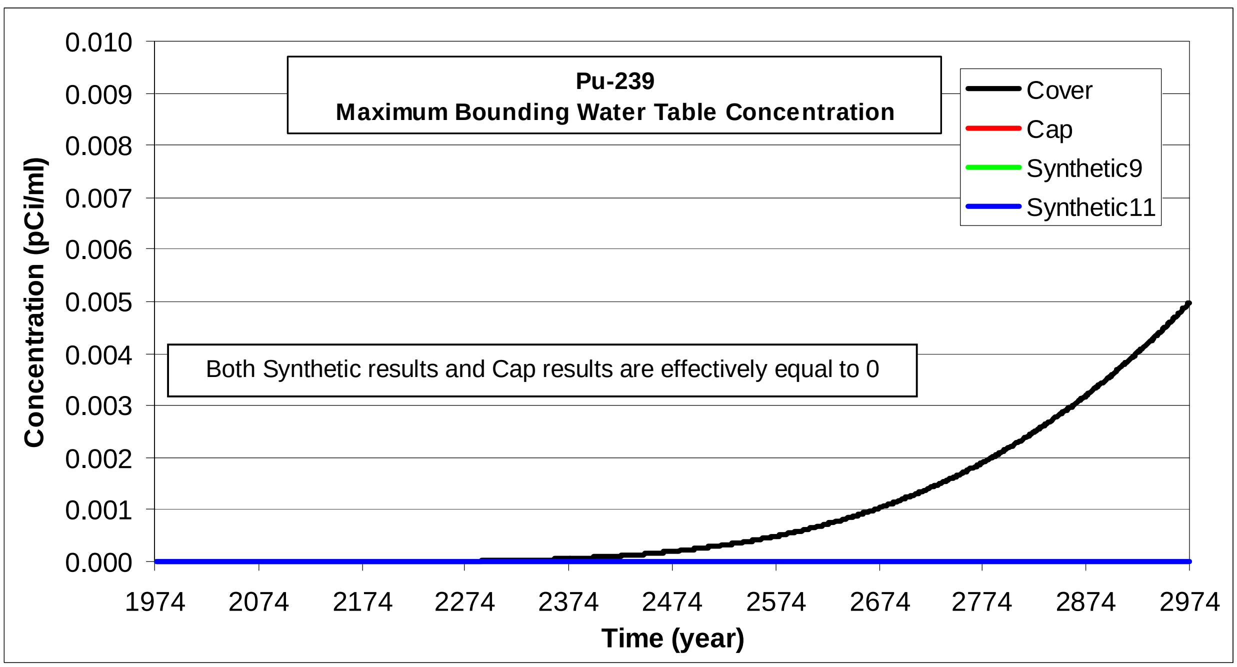


p) VOC

**Figure 4-2 (con't).	Minimum Bounding Water Table Concentrations for each COI**

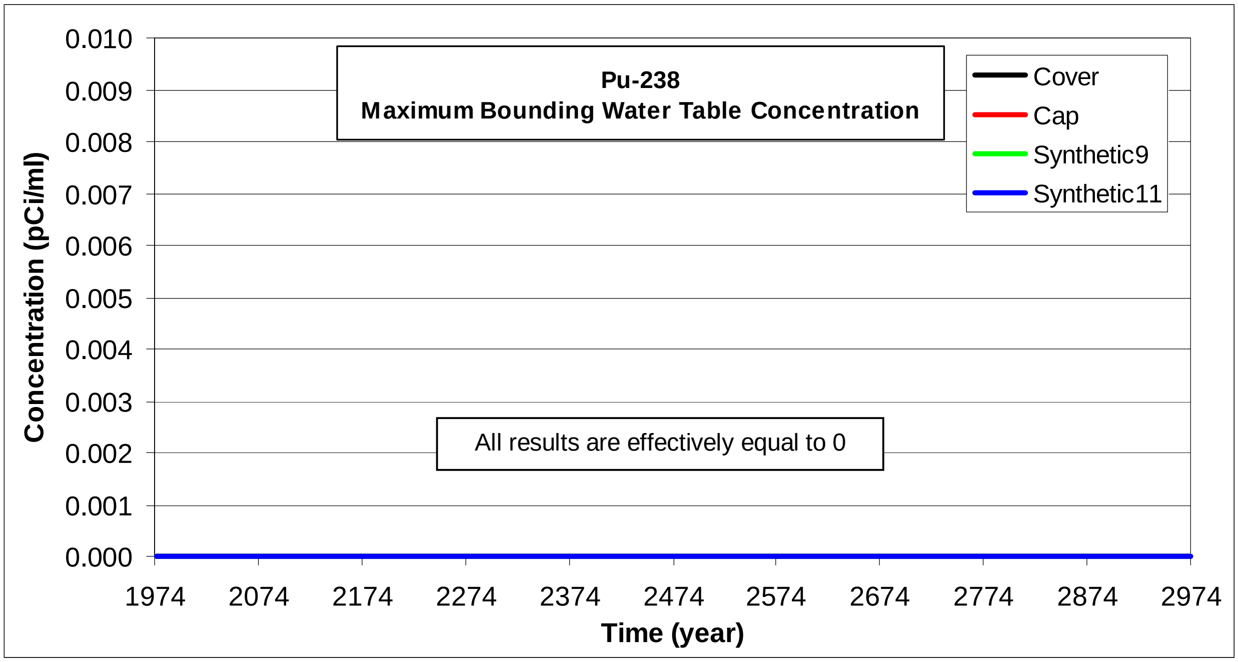


a) carbon-14

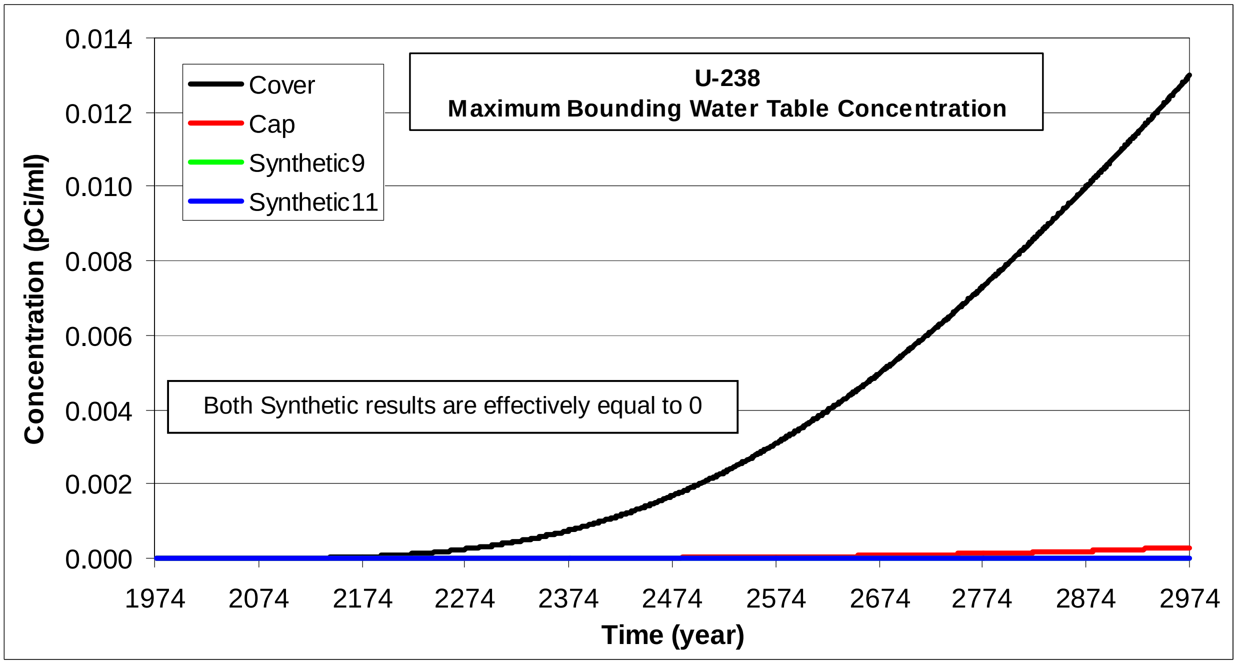


b) plutonium-239

Figure 4-3. Maximum Bounding Water Table Concentrations for each COI

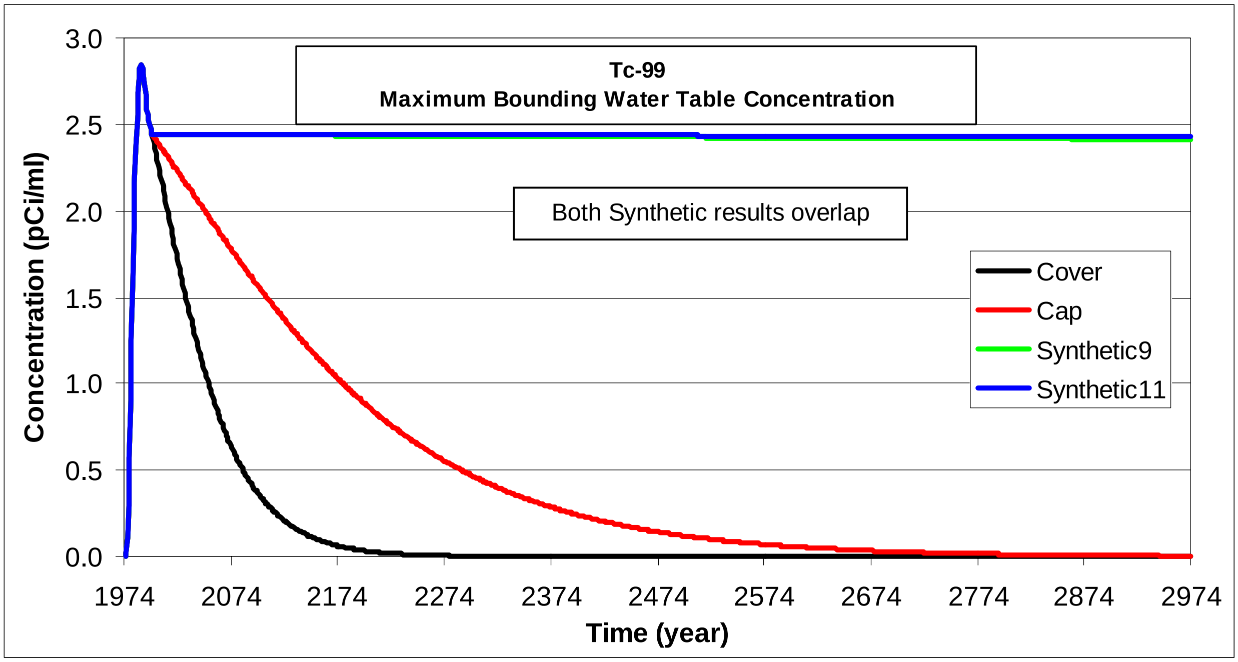


c) plutonium-238

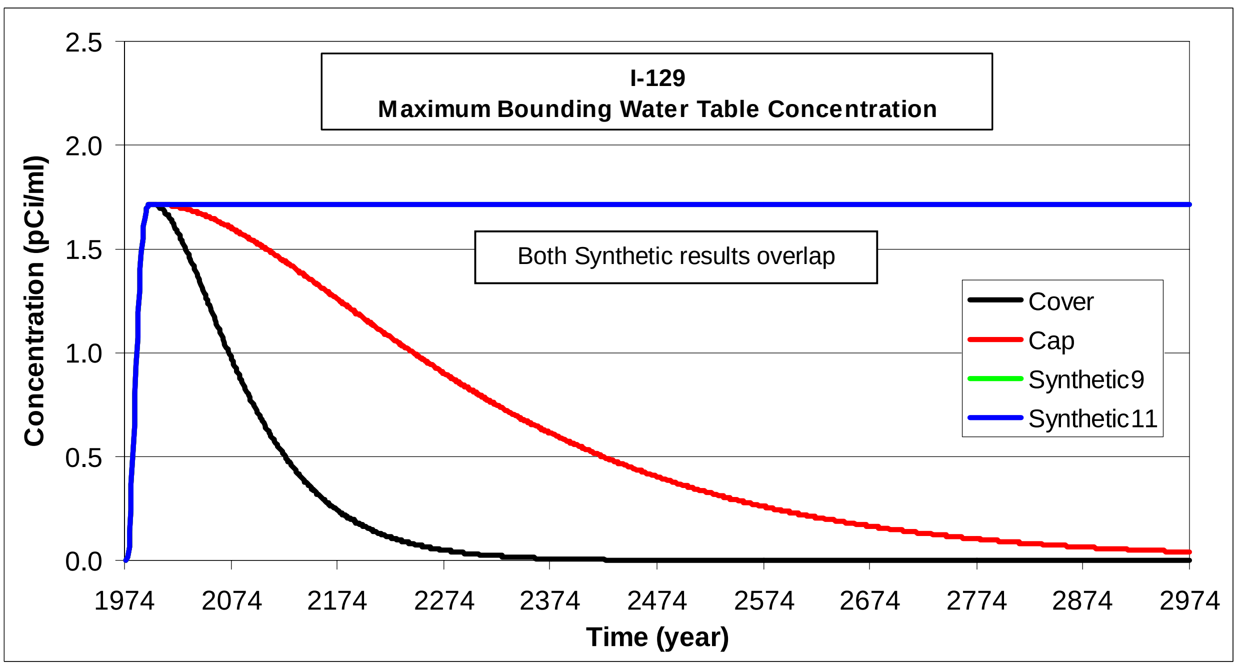


d) uranium-238

Figure 4-3 (con't). Maximum Bounding Water Table Concentrations for each COI

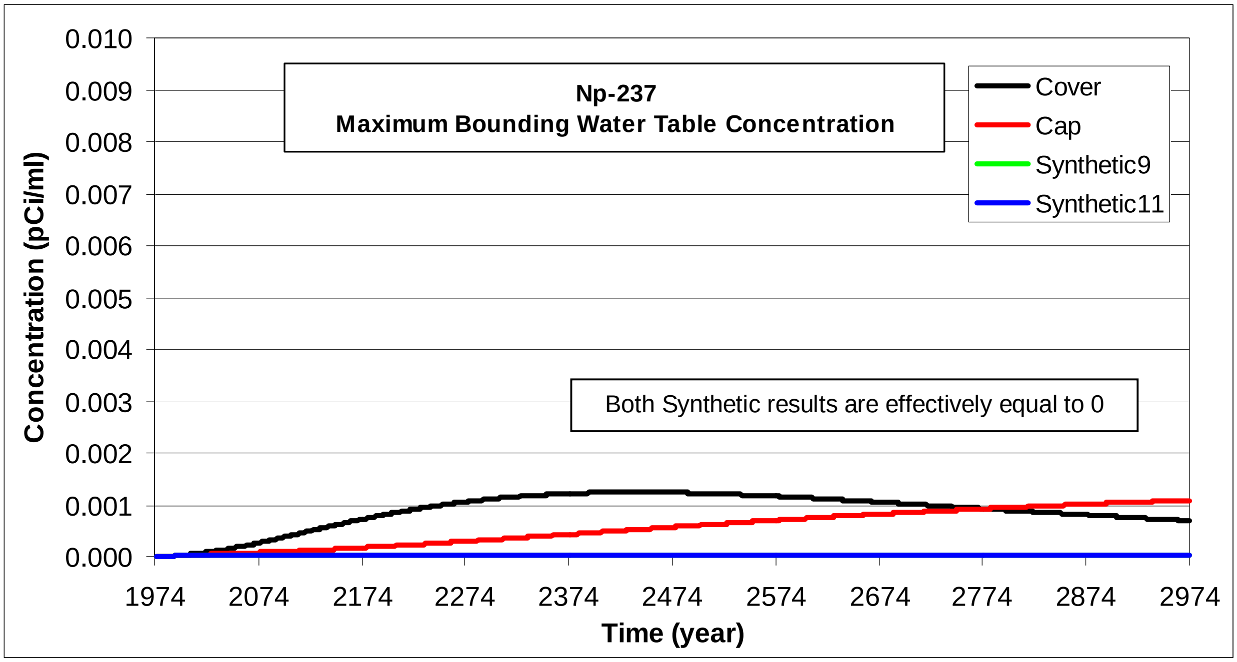


e) technetium-99

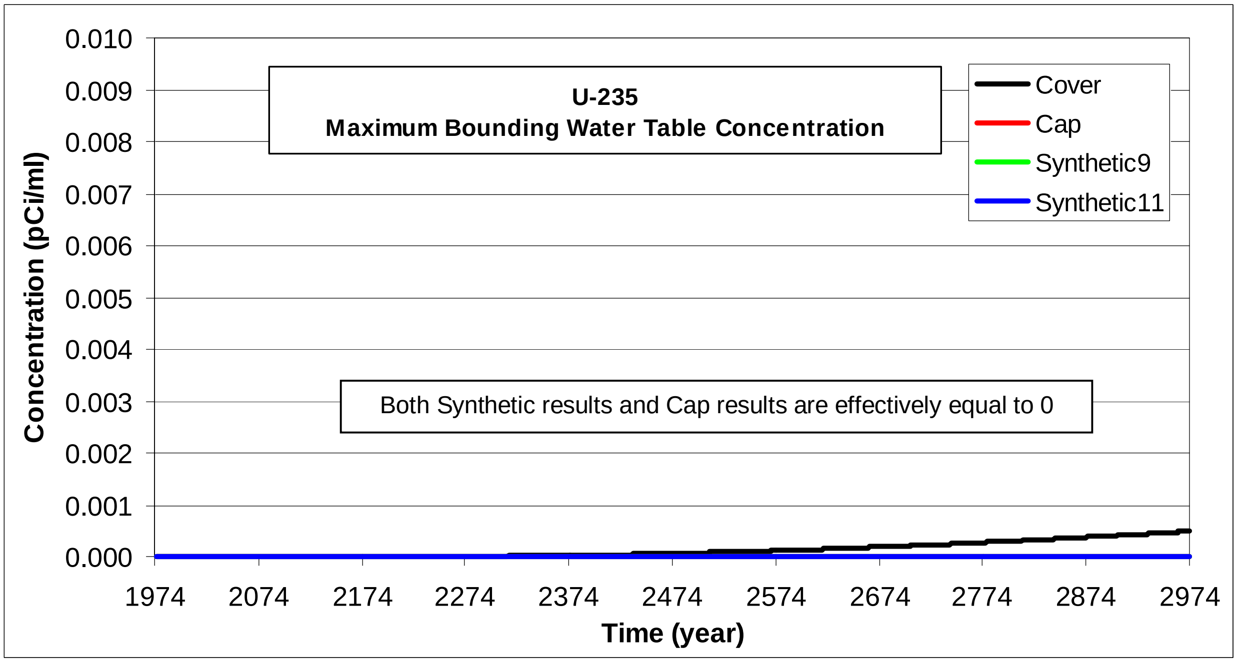


f) iodine-129

Figure 4-3 (con't). Maximum Bounding Water Table Concentrations for each COI

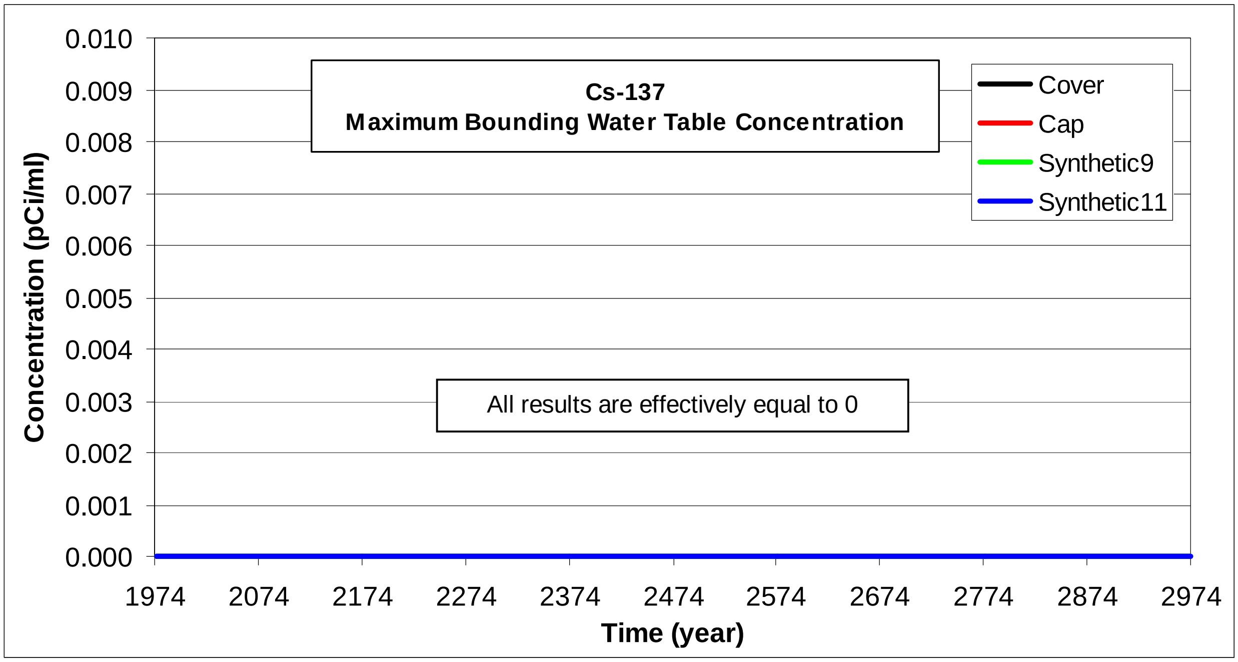


g) neptunium-237

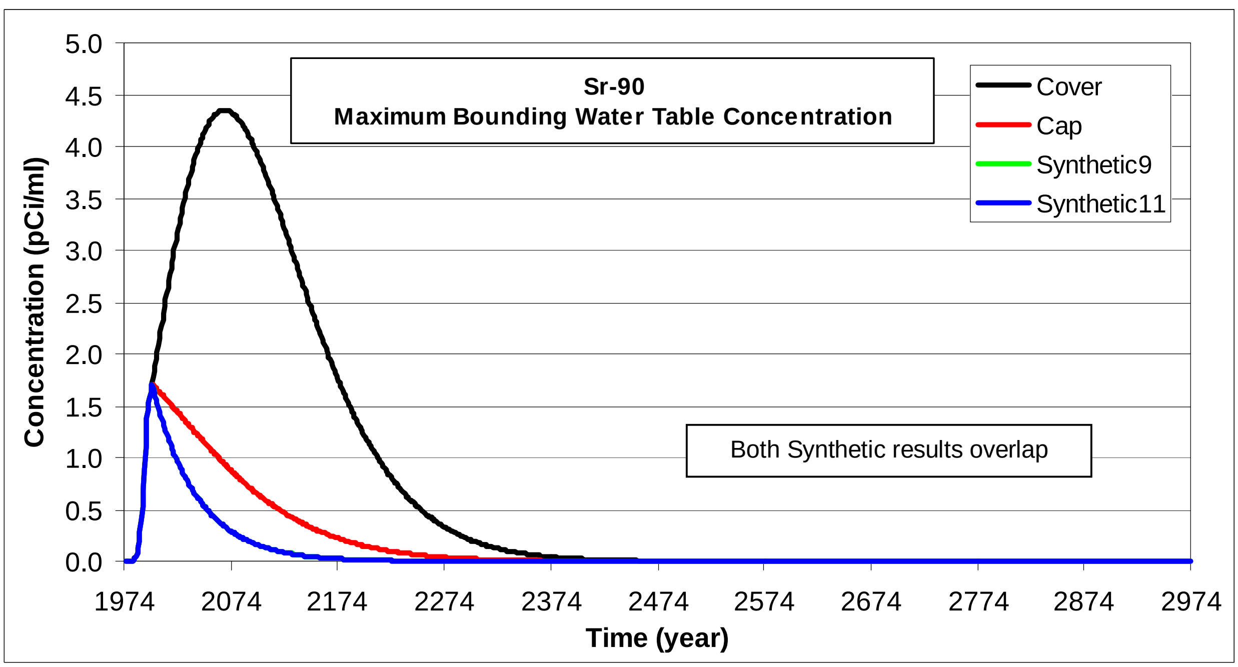


h) uranium-235

Figure 4-3 (con't). Maximum Bounding Water Table Concentrations for each COI

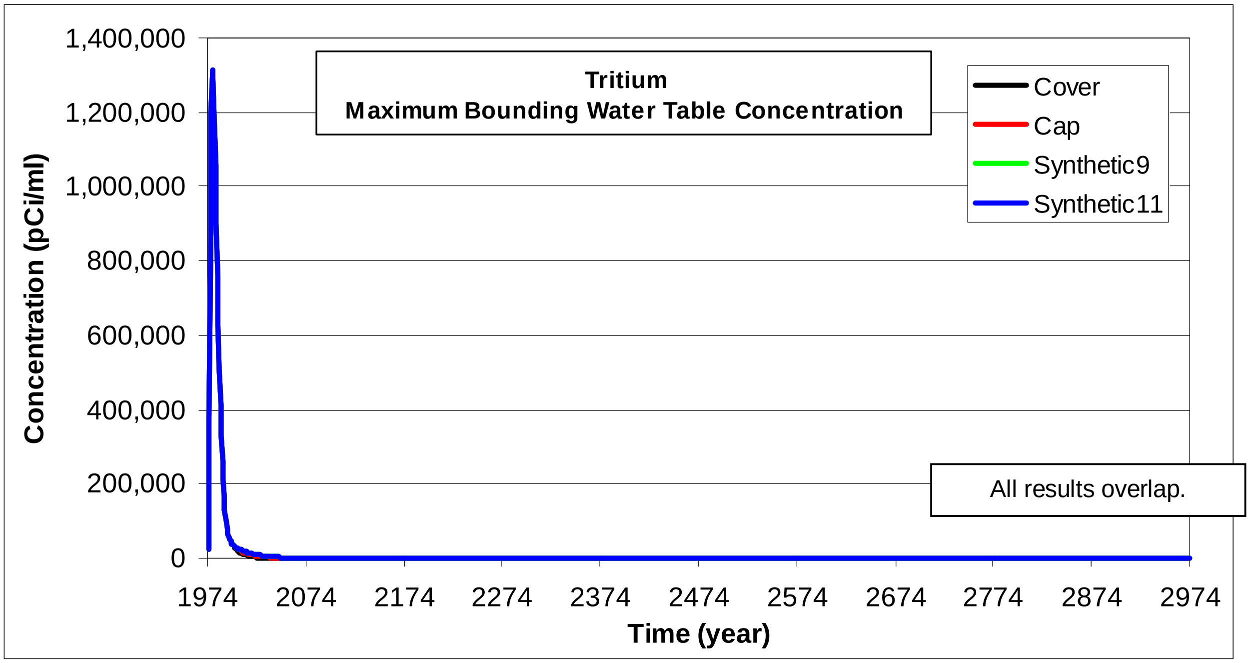


i) cesium-137

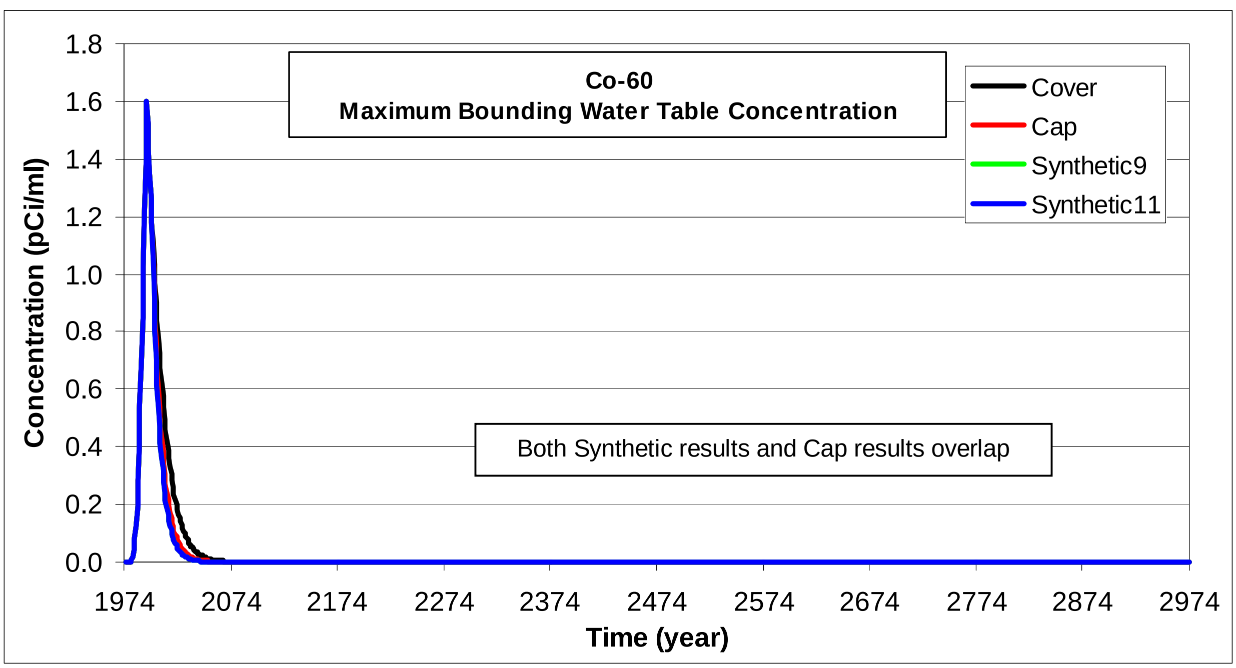


j) strontium-90

Figure 4-3 (con't). Maximum Bounding Water Table Concentrations for each COI

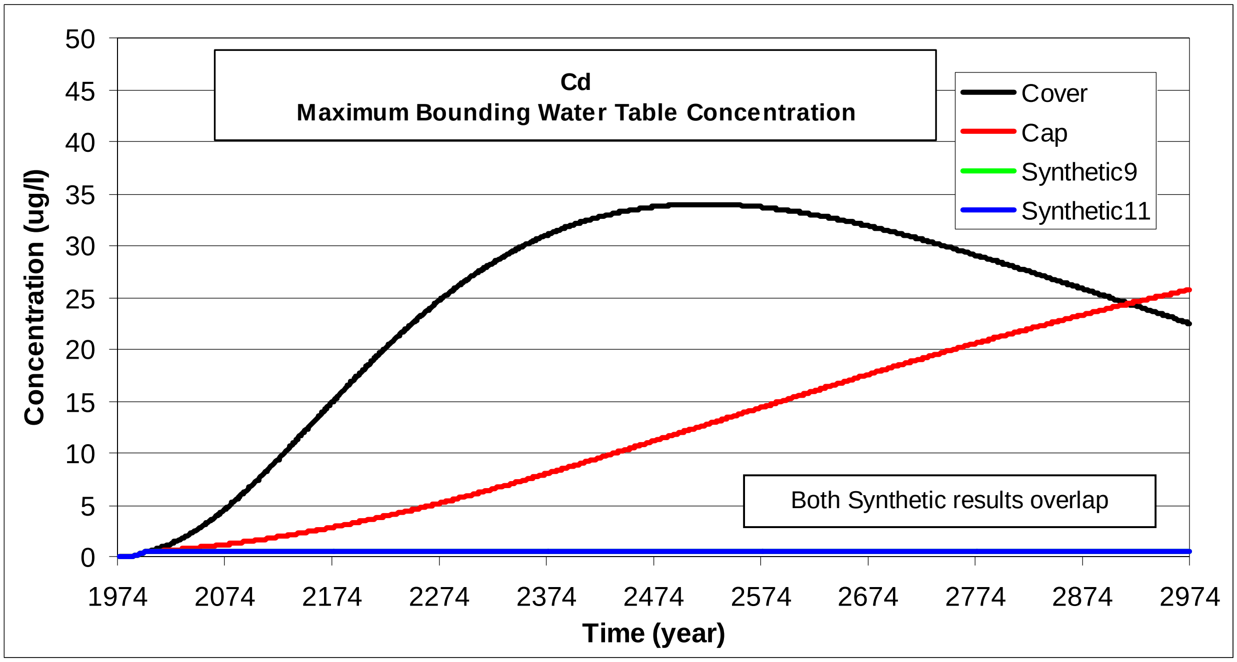


k) tritium

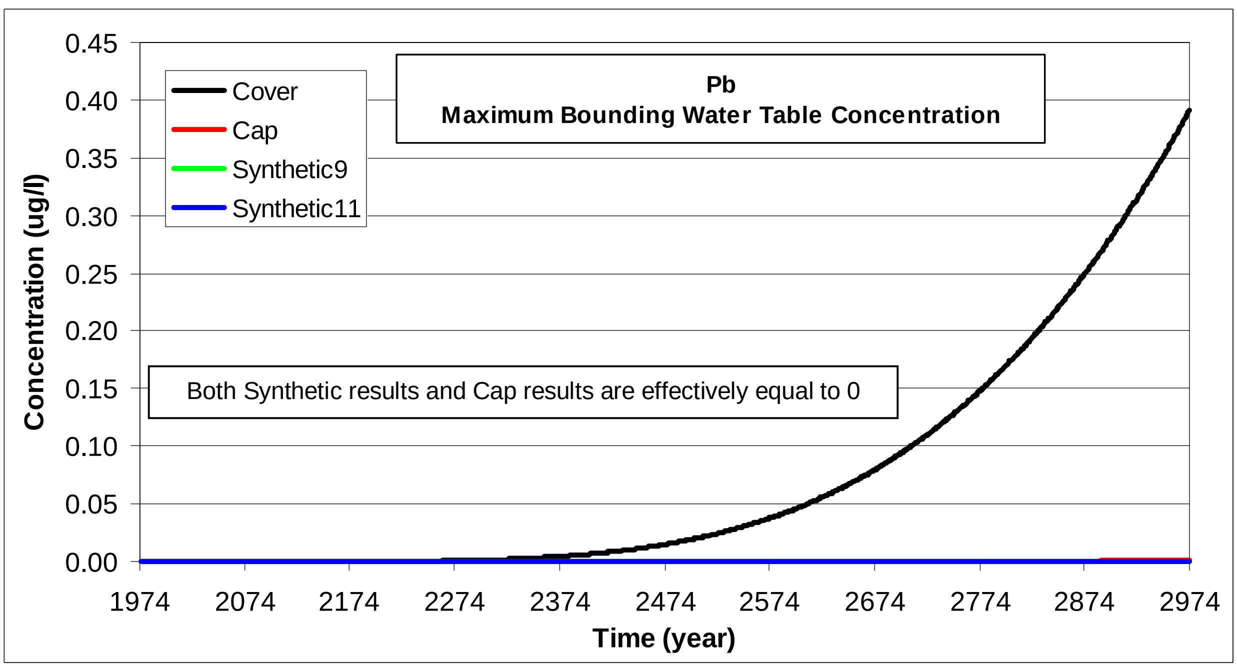


l) cobalt-60

Figure 4-3 (con't). Maximum Bounding Water Table Concentrations for each COI

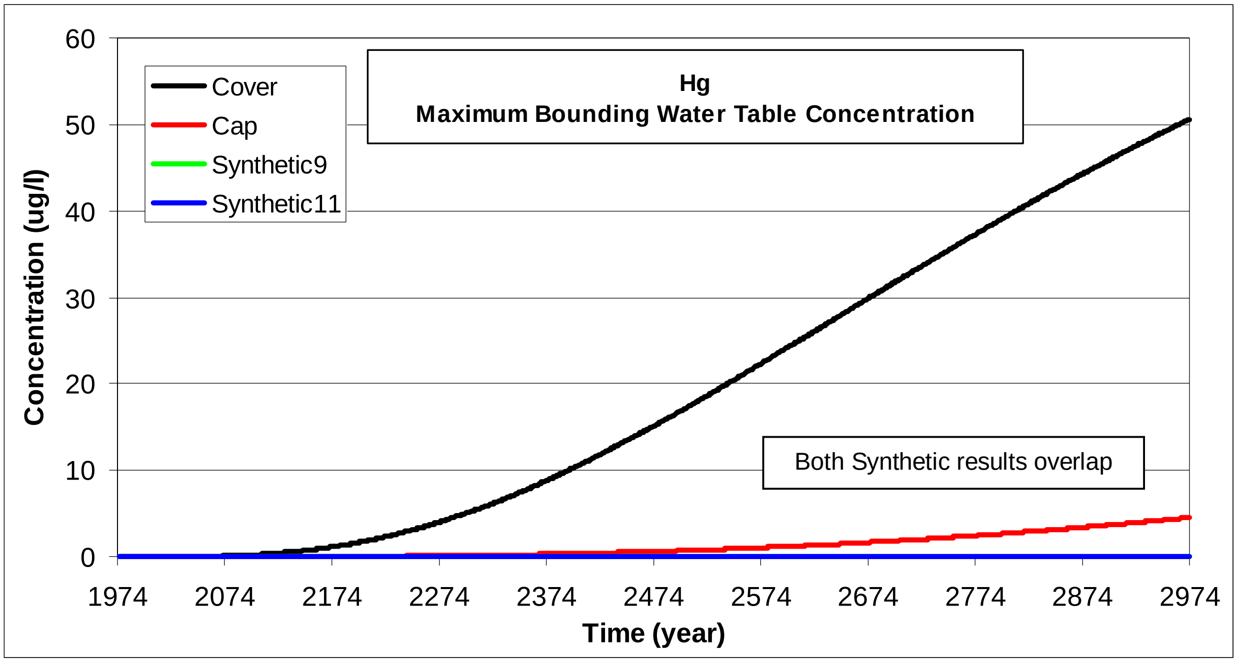


m) cadmium

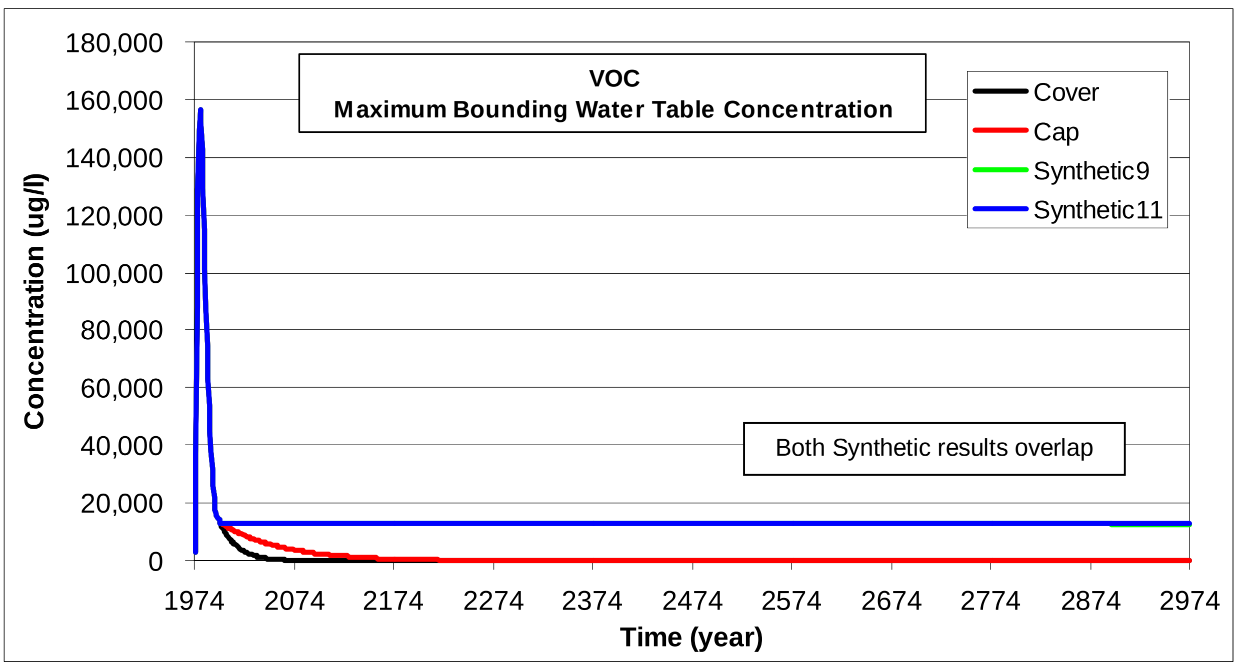


n) lead

Figure 4-3 (con’t). Maximum Bounding Water Table Concentrations for each COI



o) mercury



p) VOC

Figure 4-3 (con't). Maximum Bounding Water Table Concentrations for each COI

Table 1-1. Remedial Alternatives

Alternative	System Type	Effective Infiltration Rate (m/yr)
Cover	Compacted Soil Cover	0.139000
Cap	RCRA Clay Cap	0.041000
Synthetic (10^{-9})	Geomembrane System	0.000100
Synthetic (10^{-11})	Geomembrane System	0.000008

Note: Effective infiltration rates determined from HELP model calculations.

Table 1-2. Initial Inventory of Constituents

Constituent	Initial Mass/activity (Ci or kg)
C14	3,778
Pu239	1,475
Pu238	20,514
U238	14.8
Tc99	12
I129	10.6
Np237	1.99
U235	0.6
Cs137	58,657
Sr90	58,657
H3	3,014,457
Co60	1,960,400
Cd	1,588
Pb	45,359
Hg	10,975
VOC	262,000

Table 2-1. Infiltration Rates Summary for Each Remedial Alternative

Year	Cover (m/yr)	Clay (m/yr)	Synthetic (10^{-9}) (m/yr)	Synthetic (10^{-11}) (m/yr)
1974	0.48	0.48	0.48	0.48
1995	0.139	0.139	0.139	0.139
2000	0.139	0.041	0.0001	0.000008
2974	0.139	0.041	0.0001	0.000008

Note: Infiltration rates for 1974 to 1995 reflects “natural” infiltration.
Infiltration rates for 1995 to 2000 reflects Cover system that currently exists.

Table 4-1 COI Standard Values

Constituent	Standard Value (pCi/ml or ug/L)
C14	2
Pu239	0.015
Pu238	0.015
U238	0.0071
Tc99	0.9
I129	0.001
Np237	0.015
U235	0.00033
Cs137	0.2
Sr90	0.008
H3	20
Co60	0.1
Cd	5
Pb	15
Hg	2
VOC	5

Table 4-2 COIs Exceeding Standards at Water Table Using Maximum Bounding Concentrations

ORWBG COIs Exceeding Standards and/or Values (Water table maximum bounding concentrations)

Cover/Cap System	30 Years	100 Years	300 Years	500 Years
Soil Cover	C14, Tc99, I129, Sr90, H3, Co60, VOC	C14, I129, Sr90, VOC	C14, I129, Sr90, Cd, Hg	C14, I129, Cd, Hg
Cap	C14, Tc99, I129, Sr90, H3, Co60, VOC	C14, Tc99, I129, Sr90, H3, VOC	C14, I129, Sr90, Cd, VOC	C14, I129, Cd
Synthetic Cap (10^{-9})	C14, Tc99, I129, Sr90, H3, Co60, VOC	C14, Tc99, I129, Sr90, H3, VOC	C14, Tc99, I129, VOC	C14, Tc99, I129, VOC
Synthetic Cap (10^{-11})	C14, Tc99, I129, Sr90, H3, Co60, VOC	C14, Tc99, I129, Sr90, H3, VOC	C14, Tc99, I129, VOC	C14, Tc99, I129, VOC

Note: Maximum bounding concentrations assume no-mixing of leaching fluid with groundwater.

Table 4-3 COIs Exceeding Standards at Water Table Using Minimum Bounding Concentrations

ORWBG COIs Exceeding Standards and/or Values (Water table minimum bounding concentrations)				
Cover/Cap System	**30 Years**	**100 Years**	**300 Years**	**500 Years**
Soil Cover	I129, Sr90, H3, Co60, VOC	C14, I129, Sr90, VOC	C14, I129, Sr90, Cd	Cd, Hg
Cap	I129, Sr90, H3, VOC	I129, Sr90, VOC	I129, VOC	I129
Synthetic Cap (10^{-9})	*see note Φ*	*see note Φ*	*see note Φ*	*see note Φ*
Synthetic Cap (10^{-11})	*see note Φ*	*see note Φ*	*see note Φ*	*see note Φ*

Notes:

Φ – For the two Synthetic Cap alternatives, no COIs are above standards and/or values from year 27 to 1000 (i.e., during the time of simulated final cover/cap system emplacement). Prior to year 21 (i.e., prior to existing cover placement), C14 and Tc99 exceeded standards/values. Additionally, I129, Sr90, H3, Co60, and VOC exceeded standards/values out to year 26 (i.e., up to simulated final system placement).

Minimum bounding concentrations assume full-mixing of leaching fluid with non-reduced groundwater flow.

Table 4-4 Cumulative Mass (Activity) Fluxes for Each Remedial Alternative, Sum of All Elements, to Top of Water Table

	Initial Mass	**Cumulative Mass (Activity) Flux (kg or Ci) to Water Table**							
	(Activity)	**Cover**		**Cap**		**Synthetic (10^{-9})**		**Synthetic (10^{-11})**	
COI	**(kg or Ci)**	**30 yrs**	**300 yrs**	**30 yrs**	**300 yrs**	**30 yrs**	**300 yrs**	**30 yrs**	**300 yrs**
C14	3,778	5	139	5	35	5	5	5	5
Pu239	1,475	-	-	-	-	-	-	-	-
Pu238	20,514	-	-	-	-	-	-	-	-
U238	14.8	-	-	-	-	-	-	-	-
Tc99	12	7	12	6	11	6	6	6	6
I129	10.6	3	10.6	3	8	3	3	3	3
Np237	1.99	-	<1	-	-	-	-	-	-
U235	0.6	-	-	-	-	-	-	-	-
Cs137	58,657	-	-	-	-	-	-	-	-
Sr90	58,657	2	30	1	3	1	1	1	1
H3	3,014,457	1,796,400	1,804,400	1,793,300	1,797,700	1,791,800	1,791,800	1,791,800	1,791,800
Co60	1,960,400	2	2	2	2	2	2	1	2
Cd	1,588	<1	136	<1	9	<1	<1	<1	<1
Pb	45,359	-	-	-	-	-	-	-	-
Hg	10,975	-	13	-	<1	-	-	-	-
VOC	262,000	254,700	262,000	253,300	262,000	252,600	252,800	252,600	252,600

Note: <1 denotes values that are less than 1, but greater than or equal to 0.01.

Appendix A. HELP Model Simulation for Synthetic (10^{-11}) Remedial Alternative

Introduction

A new remedial alternative configuration for the ORWBG streamtube fate and transport modeling required the determination of infiltration rate for the alternative. The new alternative, a Synthetic Cap System with a 10^{-11} barrier layer, was requested for evaluation the by ORWBG Core Team (US DOE, US EPA, SCDHEC). To calculate the infiltration rate, the Hydrologic Evaluation of Landfill Performance (HELP) model version 3.07 (Schroeder et al., 1994) was used.

Assumptions

The configuration for the Synthetic (10^{-11}) Cap System was assumed to be identical to that used previously for the Synthetic (10^{-9}) Cap System. The only difference between the two systems was the alteration of vertical permeability of the Barrier Layer from 3.0E-9 to 3.0E-11. No effort was made to assess whether the layer configuration or permeability values were practical, or whether a system with this configuration (and parameters) could be constructed.

Input Data

The pertinent input data for this calculation is given in Table A-1. The default values provided by the HELP model were used when appropriate.

Analytical Methods and Calculations

The HELP model is a quasi-two-dimensional hydrologic model of water movement across, into, through, and out of landfill cover systems. The model uses cover system information in conjunction with weather data, and accounts for surface storage, snowmelt, runoff, infiltration, vegetative growth, evapotranspiration, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. A number of hydrologic values are generated along with infiltration rate information. However, in this calculation, only the resulting infiltration rate estimate through the barrier layer was needed.

Results

The abbreviated output listing from the HELP model run is given in Listing A-1. The listing shows that the infiltration (percolation/leakage) through Layer 5 (the barrier layer) is a yearly annual 0.00033 in. Converting this value into metric units results in an infiltration rate of 0.000008 m/yr.

References

Schroeder, P.R. Aziz, N.M., Lloyd. C.M. and Zappi, P.A. 1994. The Hydrologic Evaluation of Landfill Performance (HELP) Model: User’s Guide for Version 3, EPA/600/R-94/168a, September 1994, U.S. Environmental Protection Agency Office of Research and Development, Washington, D.C.

Table A-1. HELP Model Input Parameters for Synthetic (10^{-11}) Alternative

Weather and General Parameters

Item	Value
Nearby City	AUGUSTA
State	GEORGIA
Latitude	33.22
Evaporative zone depth	22. IN
Maximum leaf area index	3.5
Growing season start day	82
Growing season end day	323
Average wind speed	6.5 MPH
First quarter relative humidity	68.0 %
Second quarter relative humidity	70.0 %
Third quarter relative humidity	77.0 %
Fourth quarter relative humidity	73.0 %
Landfill area	80 ACRES
Percent of area where runoff is possible	100 %
Runoff curve number (user specified)	58.8
Number of simulated years	20

Soil and Design Parameters

Layer No.	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (vol/vol)	Field Capacity (vol/vol)	Wilting Point (vol/vol)
1	1	24	3	.457	.083	.033
2	1	12	21	.397	.032	.013
3	2	12	1	.417	.045	.018
4	4	.04				
5	1	.5		.75	.747	.4

Layer No.	Layer Type	Sat. Hyd. Conductivity (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality
1	1	0.0031					
2	1	0.3					
3	2	0.01	900	4			
4	4	1E-12			1	4	3
5	1	3E-11					

Listing A-1. Abbreviated Output Listing from HELP Model Run.

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************

PRECIPITATION DATA FILE:    c:\help3\orwbg\CLAY.D4
TEMPERATURE DATA FILE:      c:\help3\orwbg\CLAY.D7
SOLAR RADIATION DATA FILE:  c:\help3\orwbg\CLAY.D13
EVAPOTRANSPIRATION DATA:    c:\help3\orwbg\CLAY.D11
SOIL AND DESIGN DATA FILE:  c:\help3\orwbg\SYNTH11.D10
OUTPUT DATA FILE:           C:\HELP3\orwbg\SYNTH11.OUT

TIME:   9: 7     DATE:   7/10/2000

******************************************************************************
     TITLE:  RCRA Synthetic Cap Simulation
******************************************************************************
     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.

                                   LAYER  1
                                   --------
                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   3
           THICKNESS                  =     24.00   INCHES
           POROSITY                   =      0.4570 VOL/VOL
           FIELD CAPACITY             =      0.0830 VOL/VOL
           WILTING POINT              =      0.0330 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.1612 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.310000009000E-02 CM/SEC
         NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.63
                  FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.

                                   LAYER  2
                                   --------
                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  21
           THICKNESS                  =     12.00   INCHES
           POROSITY                   =      0.3970 VOL/VOL
           FIELD CAPACITY             =      0.0320 VOL/VOL
           WILTING POINT              =      0.0130 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.0830 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.300000012000     CM/SEC

                                   LAYER  3
                                   --------
                       TYPE 2 - LATERAL DRAINAGE LAYER
                         MATERIAL TEXTURE NUMBER   1
```

```
   THICKNESS                  =     12.00   INCHES
   POROSITY                   =      0.4170 VOL/VOL
   FIELD CAPACITY             =      0.0450 VOL/VOL
   WILTING POINT              =      0.0180 VOL/VOL
   INITIAL SOIL WATER CONTENT =      0.1507 VOL/VOL
   EFFECTIVE SAT. HYD. COND.  = 0.999999978000E-02 CM/SEC
   SLOPE                      =      4.00   PERCENT
   DRAINAGE LENGTH            =    900.0    FEET

                        LAYER  4
                        --------
            TYPE 4 - FLEXIBLE MEMBRANE LINER
              MATERIAL TEXTURE NUMBER   0
   THICKNESS                  =      0.04   INCHES
   POROSITY                   =      0.0000 VOL/VOL
   FIELD CAPACITY             =      0.0000 VOL/VOL
   WILTING POINT              =      0.0000 VOL/VOL
   INITIAL SOIL WATER CONTENT =      0.0000 VOL/VOL
   EFFECTIVE SAT. HYD. COND.  = 0.999999996000E-12 CM/SEC
   FML PINHOLE DENSITY        =      1.00   HOLES/ACRE
   FML INSTALLATION DEFECTS   =      4.00   HOLES/ACRE
   FML PLACEMENT QUALITY      = 3 - GOOD

                        LAYER  5
                        --------
          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
   THICKNESS                  =      0.50   INCHES
   POROSITY                   =      0.7500 VOL/VOL
   FIELD CAPACITY             =      0.7470 VOL/VOL
   WILTING POINT              =      0.4000 VOL/VOL
   INITIAL SOIL WATER CONTENT =      0.7465 VOL/VOL
   EFFECTIVE SAT. HYD. COND.  = 0.299999990000E-10 CM/SEC

          GENERAL DESIGN AND EVAPORATIVE ZONE DATA
          ----------------------------------------
  NOTE:  SCS RUNOFF CURVE NUMBER WAS USER-SPECIFIED.

SCS RUNOFF CURVE NUMBER            =     58.76
FRACTION OF AREA ALLOWING RUNOFF   =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE =     80.000  ACRES
EVAPORATIVE ZONE DEPTH             =     22.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE  =      3.479  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE =     10.054  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE =      0.726  INCHES
INITIAL SNOW WATER                 =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS   =      7.046  INCHES
TOTAL INITIAL WATER                =      7.046  INCHES
TOTAL SUBSURFACE INFLOW            =      0.00   INCHES/YEAR

           EVAPOTRANSPIRATION AND WEATHER DATA
           -----------------------------------
  NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
           AUGUSTA               GEORGIA

    STATION LATITUDE                         =  33.22 DEGREES
    MAXIMUM LEAF AREA INDEX                  =   3.50
    START OF GROWING SEASON (JULIAN DATE)    =     82
    END OF GROWING SEASON (JULIAN DATE)      =    323
    EVAPORATIVE ZONE DEPTH                   =  22.0  INCHES
    AVERAGE ANNUAL WIND SPEED                =   6.50 MPH
    AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  68.00 %
```

```
          AVERAGE 2ND QUARTER RELATIVE HUMIDITY  =  70.00 %
          AVERAGE 3RD QUARTER RELATIVE HUMIDITY  =  77.00 %
          AVERAGE 4TH QUARTER RELATIVE HUMIDITY  =  73.00 %

      NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
               COEFFICIENTS FOR    AUGUSTA             GEORGIA

               NORMAL MEAN MONTHLY PRECIPITATION (INCHES)
  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------
    3.99        4.04        4.92        3.31        3.73        3.88
    4.40        3.98        3.53        2.02        2.07        3.20

      NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
               COEFFICIENTS FOR    AUGUSTA             GEORGIA

          NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)
  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------
   46.00       47.50       54.80       63.20       71.00       77.40
   80.60       79.90       74.60       63.50       53.90       46.90

      NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
               COEFFICIENTS FOR    AUGUSTA             GEORGIA
                 AND STATION LATITUDE  =  33.22 DEGREES

*******************************************************************************
      AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH   20
-------------------------------------------------------------------------------
                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS                  4.10     3.43     5.57     2.63     3.33     3.59
                           5.54     3.49     4.42     1.90     1.72     2.86
   STD. DEVIATIONS         2.33     1.62     3.22     1.58     2.10     2.09
                           2.87     2.06     2.47     1.37     1.30     1.34
 RUNOFF
 ------
   TOTALS                  0.000    0.000    0.000    0.000    0.000    0.000
                           0.000    0.000    0.000    0.000    0.000    0.000
   STD. DEVIATIONS         0.000    0.000    0.002    0.001    0.000    0.000
                           0.001    0.000    0.000    0.000    0.000    0.000
 EVAPOTRANSPIRATION
 ------------------
   TOTALS                  1.513    1.841    2.591    2.649    3.522    3.225
                           4.479    3.236    3.053    1.422    0.894    1.078
   STD. DEVIATIONS         0.167    0.214    0.565    0.863    1.477    1.373
                           1.566    1.548    1.134    0.586    0.243    0.227
 LATERAL DRAINAGE COLLECTED FROM LAYER  3
 ----------------------------------------
   TOTALS                  1.5691   1.2590   2.8198   1.2361   0.8731   0.8684
                           0.8098   0.6896   0.6868   0.6660   0.6673   0.7635
   STD. DEVIATIONS         1.5193   0.9169   2.6429   0.9361   0.2274   0.5198
                           0.5245   0.1477   0.2949   0.2577   0.5452   0.6249
 PERCOLATION/LEAKAGE THROUGH LAYER  4
 ------------------------------------
   TOTALS                  0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   STD. DEVIATIONS         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
 PERCOLATION/LEAKAGE THROUGH LAYER  5
```

```
  ------------------------------------
    TOTALS              0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
                        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
    STD. DEVIATIONS     0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
                        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
-------------------------------------------------------------------------------
               AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------
  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES            9.4348 10.5376 11.5808 11.0698 10.3877  9.5526
                        8.7908  8.8432  8.2334  8.1075  7.5575  7.7260
    STD. DEVIATIONS     2.9259  2.4576  2.7043  1.9636  1.6860  1.7983
                        1.9516  1.8941  1.9456  2.3663  2.4428  2.5543
*******************************************************************************

*******************************************************************************
     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   20
-------------------------------------------------------------------------------
                                     INCHES           CU. FEET       PERCENT
                                -------------------  -------------   ---------
 PRECIPITATION                   42.58    (   7.367)  12364942.0     100.00
 RUNOFF                           0.001   (  0.0025)       302.73      0.002
 EVAPOTRANSPIRATION              29.502   (  3.6327)   8567453.00     69.288
 LATERAL DRAINAGE COLLECTED      12.90862 (  4.42815)  3748661.750   30.31686
   FROM LAYER  3
 PERCOLATION/LEAKAGE THROUGH      0.00037 (  0.00000)       108.241     0.00088
   LAYER  4
 AVERAGE HEAD ON TOP              9.318 (    1.508)
   OF LAYER  4
 PERCOLATION/LEAKAGE THROUGH      0.00033 (  0.00001)        97.056     0.00078
   LAYER  5
 CHANGE IN WATER STORAGE          0.167   (  1.8886)     48427.13      0.392

******************************************************************************
                PEAK DAILY VALUES FOR YEARS    1 THROUGH   20
   ------------------------------------------------------------------------
                                                 (INCHES)      (CU. FT.)
                                                ----------   -------------
      PRECIPITATION                                3.80       1103520.000
      RUNOFF                                       0.009         2591.1011
      DRAINAGE COLLECTED FROM LAYER  3             0.69343     201373.34400
      PERCOLATION/LEAKAGE THROUGH LAYER  4         0.000001         0.29635
      AVERAGE HEAD ON TOP OF LAYER  4             20.788
      MAXIMUM HEAD ON TOP OF LAYER  4             34.854
      LOCATION OF MAXIMUM HEAD IN LAYER  3
            (DISTANCE FROM DRAIN)                144.3 FEET
      PERCOLATION/LEAKAGE THROUGH LAYER  5         0.000001         0.27355
      SNOW WATER                                   2.14        621547.5000
      MAXIMUM VEG. SOIL WATER (VOL/VOL)                   0.2748
      MINIMUM VEG. SOIL WATER (VOL/VOL)                   0.0330

       ***  Maximum heads are computed using McEnroe’s equations.  ***
            Reference:  Maximum Saturated Depth over Landfill Liner
                        by Bruce M. McEnroe, University of Kansas
                        ASCE Journal of Environmental Engineering
                        Vol. 119, No. 2, March 1993, pp. 262-270.
******************************************************************************

******************************************************************************
                   FINAL WATER STORAGE AT END OF YEAR   20
    ----------------------------------------------------------------------
```

```
           LAYER        (INCHES)       (VOL/VOL)
           -----        --------       ---------
             1            3.6949         0.1540
             2            1.3082         0.1090
             3            5.0040         0.4170
             4            0.0000         0.0000
             5            0.3740         0.7480
         SNOW WATER       0.000
******************************************************************************
******************************************************************************
```