

CLOSURE PLAN REVIEW GUIDANCE FOR RCRA FACILITIES

“THIS POLICY DOES NOT HAVE THE FORCE OF LAW”

Ohio Environmental Protection Agency
Division of Hazardous Waste Management

October 2009

<http://www.epa.ohio.gov/dhwm>



Ohio EPA Offices

Northwest District Office
347 North Dunbridge Road
Bowling Green, Ohio 43402
Phone: (419) 352-8461
Fax: (419) 352-8468

Central District Office
50 W. Town St. Suite 700
PO Box 1049
Columbus, Ohio 43216-1049
Phone: (614) 728-3778
Fax: (614) 728-3898

Northeast District Office
2110 East Aurora Road
Twinsburg, Ohio 44087
Phone: (330) 963-1200
Fax: (330) 487-0769

Southwest District Office
401 East Fifth Street
Dayton, Ohio 45402-2911
Phone: (937) 285-6357
Fax: (937) 285-6249

Central Office
50 W. Town St. Suite 700
PO Box 1049
Columbus, Ohio 43216-1049
Phone: (614) 644-2917
Fax: (614) 728-1245

Southeast District Office
2195 Front Street
Logan, Ohio 43138
Phone: (740) 385-8501
Fax: (740) 385-6490

See also Ohio EPA's Web-site: <http://www.epa.ohio.gov/directions.aspx>

Table of Contents

Table of Contents.....	Pg. ii
------------------------	--------

Acronyms.....	Pg. ix
---------------	--------

Overview and Chapters

Overview of the Closure Plan Review Guidance.....	Pg. 0-1
--	----------------

Description of the Closure Plan Review Guidance (CPRG).....	Pg. 0-1
---	---------

Difference Between Statements in the CPRG and Ohio EPA Statutory Requirements.....	Pg. 0-2
---	---------

Origin of the Policies Contained in the CPRG.....	Pg. 0-3
---	---------

Additional Resources Available for Closure.....	Pg. 0-3
---	---------

Chapter 1 - Regulatory Considerations for Reviewing and Approving Closure and Post-Closure Plans.....	Pg. 1-1
--	----------------

1.1 Rules Associated with Closure and Post-Closure Plans.....	Pg. 1-1
---	---------

1.2 When and Where to Submit a Closure and/or Post-Closure Plan.....	Pg. 1-8
--	---------

1.3 Closure Plan Designations.....	Pg. 1-10
------------------------------------	----------

1.4 Public Participation in the Closure and Post-Closure Process.....	Pg. 1-11
---	----------

1.5 Administrative Framework of Closure and/or Post-Closure Plan Review ..	Pg. 1-12
--	----------

1.6 Objective of a Closure and/or Post-Closure Plan Review	Pg. 1-14
--	----------

1.7 Notice of Deficiency and Director's Approval/Modification/ Disapproval Letters	Pg. 1-15
---	----------

1.8 Closure and/or Post-Closure Plan Amendments and Extension of Closure Time Period.....	Pg. 1-19
--	----------

1.9 Completion of Closure and/or Post-Closure Care	Pg. 1-22
--	----------

1.10 Generator Closure.....	Pg. 1-25
-----------------------------	----------

Chapter 2 - Other Cleanup Programs.....	Pg. 2-1
--	----------------

2.1 RCRA Corrective Action Program	Pg. 2-1
--	---------

2.2 Corrective Action Management Unit (CAMU) Rule	Pg. 2-1
---	---------

2.3 Clean Ohio Fund	Pg. 2-2
---------------------------	---------

2.4 Ohio Voluntary Action Program.....	Pg. 2-5
--	---------

Chapter 3 - Required Components of All Closure Plans.....	Pg. 3-1
--	----------------

3.1 Description of Facility	Pg. 3-1
-----------------------------------	---------

3.2 Maps of Facility	Pg. 3-1
----------------------------	---------

3.3 Description of Hazardous Waste Management Unit to be Closed	Pg. 3-1
---	---------

3.4 Detailed Drawing of Hazardous Waste Management Unit to be Closed	Pg. 3-2
--	---------

3.5 List of Hazardous Waste	Pg. 3-2
-----------------------------------	---------

3.6 Management of Waste	Pg. 3-2
-------------------------------	---------

3.7 Schedule for Closure.....	Pg. 3-5
-------------------------------	---------

3.8 Air Emissions and Wastewater.....	Pg. 3-6
---------------------------------------	---------

3.9 Personnel Health and Safety.....	Pg. 3-6
--------------------------------------	---------

3.10 Decontamination Efforts	Pg. 3-7
------------------------------------	---------

3.11 Soil Sampling and Analysis	Pg. 3-14
---------------------------------------	----------

3.12 Ground Water Sampling and Analysis	Pg. 3-23
---	----------

3.13 Surface Water Sampling and Analysis	Pg. 3-30
--	----------

3.14 Sediment Sampling and Analysis.....	Pg. 3-30
--	----------

3.15 Background and Soil	Pg. 3-31
--------------------------------	----------

3.16	Background and Ground Water.....	Pg. 3-33
3.17	Background and Sediment	Pg. 3-37
3.18	Background and Surface Water	Pg. 3-37
3.19	Use of Historical Data.....	Pg. 3-38
3.20	Financial Assurance Requirements.....	Pg. 3-41

Chapter 4 - Components for Closure by Removal Plans Pg. 4-1

4.1	Remediation Standards for Soils and Ground Water	Pg. 4-1
4.2	Statistical Evaluation of Soil	Pg. 4-6
4.3	Statistical Evaluation of Ground Water.....	Pg. 4-7
4.4	Description of Removal Efforts and Treatment Processes.....	Pg. 4-7
4.5	Status of Facility After Closure by Removal	Pg. 4-9

Chapter 5 - Components for Waste in Place Closure Plans, Post-Closure Plans and Certifications Pg. 5-1

5.1	Components for Waste in Place Closure Plans	Pg. 5-1
5.2	Components of a Closure Certification	Pg. 5-2
5.3	Components for Post-Closure Plans	Pg. 5-4
5.4	Components of a Post-Closure Certification	Pg. 5-13

Chapter 6 - Risk Assessment in Closure Pg. 6-1

6.1	Introduction.....	Pg. 6-1
6.2	Human Health Risk Assessments	Pg. 6-2
6.3	Ecological Risk Assessments.....	Pg. 6-12

Chapter 7 - General Concepts in Human Health Risk Assessments Pg. 7-1

7.1	Data Collection/Evaluation	Pg. 7-1
7.2	Exposure Assessment.....	Pg. 7-8
7.3	Toxicity Assessment.....	Pg. 7-21
7.4	Risk Characterization	Pg. 7-27

Chapter 8 - Special Contaminants..... Pg. 8-1

8.1	Benzene	Pg. 8-1
8.2	Dioxin and Furan	Pg. 8-2
8.3	Lead	Pg. 8-7
8.4	Polychlorinated Biphenyls	Pg. 8-8
8.5	Polycyclic Aromatic Hydrocarbons	Pg. 8-12

Chapter 9 - Glossary Pg. 9-1

Chapter 10 - References Pg. 10-1

Appendices

Note: Previous appendices that contain correspondence on the closure program and US EPA guidance documents have been removed from the CPRG in an effort to save paper, they can be found on-line at:

http://epa.ohio.gov/portals/32/pdf/Removed_CPRG_Appendices.pdf

Appendix A: Generic Cleanup Numbers – Technical Background and ValuesPg. A-1

Appendix B: Development of Alternate Metal Standards.....Pg. B-1

Appendix C: Guidance for Statistical Evaluation of Hazardous Waste Constituent Levels in Soils	Pg. C-1
Appendix D: Grid Spacing Determination	Pg. D-1
Appendix E: Ground Water Scoring Matrix	Pg. E-1
Appendix F: Mobile Laboratory Guidance	Pg. F-1
Appendix G: Final Covers for Hazardous Waste Surface Impoundments, Waste Piles, and Landfills.....	Pg. G-1
Appendix H: Soil Permeability Data Evaluation	Pg. H-1

List of Tables

Table 0-1: Applicability of Closure.....	0-2
Table 4-1: List of Alternate Metal Standards (AMS).....	4-3
Table 6-1: Summary of Responsibilities for Environmental Covenants	6-7
Table 6-2: Default Exposure Parameters for Outdoor Workers	6-11
Table 8-1: Toxicity Equivalence Factors	8-6
Table 8-2: PCB Toxicity Values Summary	8-12
Table 8-3: Sixteen Environmentally Common PAHs.....	8-14
Table 8-4: Summary Table of PAHs for Which Relative Potency Factors (RPFs) Were Used to Derive the Carcinogenic Slope Factor Toxicity Value	8-15
Table A-1: Input Variables for Calculating GCNs for Benzene	A-26
Table A-2: Default Exposure Factors for Residential and Industrial Land Use	A-36
Table A-3: Risk-Based Generic Cleanup Numbers.....	A-42
Table A-4: MCL-Based Generic Cleanup Numbers	A-46
Table A-5: Chemical Specific Values for the Generic Cleanup Numbers	A-47
Table B-1: List of Alternate Metal Standards	B-2
Table B-2: Partial Statistics Used in the Data Evaluation Process of Developing the AMS.....	B-3
Table B-3: Comparison of the Mean Values of Metal Concentrations Used to Establish AMS to the Results of Some Other Studies	B-4
Table C-1: t Distribution Critical Values for 95% Confidence Level	C-12
Table C-2: How to Handle Non-Detects in Statistics.....	C-14
Table D-1: Slope Factor Score.....	D-1
Table D-2: Reference Dose Score	D-1
Table D-3: Risk of Exposure (ROE) Matrix	D-2
Table D-4: Soil Sampling Intensity Matrix	D-2
Table D-5: Grid Intervals for Soil Sampling in a “Hot Spot” Contamination Scenario ...	D-3
Table D-6: Number of Samples for Soil Sampling in a Homogeneous Contamination Scenario	D-4
Table D-7: Weighted Average for the Potency of the Carcinogens	D-5
Table D-8: Weighted Average for the Potency of the Systemic Toxicants.....	D-5
Table D-9: Calculation of Kd Score.....	D-6
Table D-10: Risk of Exposure (ROE) Matrix	D-6
Table D-11: Soil Sampling Intensity Matrix	D-7
Table E-1: Ground Water Scoring Matrix / Leaching Evaluation Scoring Sheet	E-2
Table E-2: Low-Nonpersistent Compounds	E-3

Table E-3: Moderate-Persistent to Somewhat Persistent Compounds.....	E-3
Table E-4: High-Highly Persistent Compounds.....	E-3
Table E-5: Default Hydraulic Conductivity Values.....	E-5
Table E-6: Determining if a Ground Water Investigation Should be Performed.....	E-7
Table H-1: Typical Particle Sizes	H-2
Table H-2: Soil Types and Plasticity	H-6
Table H-3: Range of Hydraulic Conductivities in Soils.....	H-7

List of Figures

Figure 1-1: Administrative Procedures for Ohio EPA Review and Approval for Interim Standard Closures.....	1-4
Figure 3-1: Hazardous Waste Management Flowchart.....	3-4
Figure 3-2: Decontamination Pad Elements	3-13
Figure 7-1: Screening Flowchart	7-30
Figure A-1: Correct and Incorrect Uses of GCNs.....	A-3
Figure A-2: A Flowchart of How GCNs Can Be Applied	A-5
Figure A-3: Decision Tree for Choosing GCNs for a Site.....	A-7
Figure A-4: Steps for Screening Chemicals from a Risk Assessment	A-30
Figure A-5: Steps for Using GCNs to Determine that No Further Action is Necessary at a Unit	A-34
Figure C-1: Probability Plot (left) and Box Plot (right)	C-3
Figure C-2: Histograms by Transformation	C-4
Figure C-3: Probability Plot (left) and Box Plot (right)	C-4
Figure E-1: Soil Leaching Flowchart	E-8
Figure E-2: Land Based Units Flowchart	E-9
Figure E-3: Non-Land Based Units Flowchart.....	E-10
Figure G-1: Type 1 Cover Example	G-11
Figure G-2: Type 2 Cover Example	G-13
Figure G-3: Type 3 Cover Example A.....	G-14
Figure G-4: Type 3 Cover Example B.....	G-15
Figure H-1: Example of a Grain-Sized Distribution Test	H-4
Figure H-2: Soil Properties on the United States Department of Agriculture's Soil Classification Triangle	H-5
Figure H-3: Demonstration of Difference of Flow in Large and Small Diameter Pipes .	H-8
Figure H-4: Moisture-Density Relationships.....	H-10
Figure H-5: Degree of Saturation Lines	H-11
Figure H-6: Line of Optimums Criterion	H-12
Figure H-7: Acceptable Zone Criterion.....	H-13
Figure H-8: Example of Lab Test Results	H-17
Figure H-9: Example of Field Test Results	H-19

List of Equations

Equation 3-1: Decision Rule for Composite Sampling	3-19
Equation 3-2: Relative Percent Difference	3-20
Equation 4-1: Calculation of Background Remediation Standard (BRS)	4-2
Equation 6-1: Ingestion of Chemicals in Soils and Dust for Construction/General Outdoor Worker Scenario.....	6-12
Equation 6-2: Dermal Contact with Chemicals in Soil for Construction/General Outdoor Worker Scenario.....	6-12

Equation 6-3: Inhalation of Volatiles and Particulates from Contaminated Soil for Construction/General Outdoor Worker Scenario	6-12
Equation 7-1: Conversion of Inhalation Reference Concentration to Inhalation Reference Doses.....	7-24
Equation 7-2: Conversion of Unit Risk to Inhalation Slope Factor	7-25
Equation 7-3: Calculation of Carcinogenic Risk Estimate	7-31
Equation 7-4: Calculation of Dermal Slope Factor	7-31
Equation 7-5: Calculation of Total Cancer Risk	7-31
Equation 7-6: Calculation of Total Exposure Cancer Risk	7-32
Equation 7-7: Calculation of Hazard Quotient.....	7-33
Equation 7-8: Calculation of Dermal Reference Dose	7-33
Equation 7-9: Calculation of Hazard Index.....	7-33
Equation 7-10: Calculation of Total Exposure Hazard Index	7-34
Equation 8-1: Calculation of Toxicity Equivalent.....	8-5
Equation A-1: Ingestion of Chemicals in Drinking Water Residential Scenario - Noncancer	A-8
Equation A-2: Ingestion of Chemicals in Drinking Water Residential Scenario - Cancer.....	A-9
Equation A-3: Dermal Contact with Chemicals While Showering Residential Scenario - Noncancer.....	A-9
Equation A-4: Dermal Contact with Chemicals While Showering Residential Scenario - Cancer	A-9
Equation A-5: Calculation of Volatilization Factor for Water (Vfw)	A-10
Equation A-6: Calculation of Concentration of Contaminant in Air.....	A-10
Equation A-7: Inhalation of Airborne Chemicals While Showering Residential Scenario - Noncancer.....	A-10
Equation A-8: Inhalation of Airborne Chemicals While Showering Residential Scenario - Cancer	A-10
Equation A-9: Calculation of Ground Water Noncancer GCN for a Volatile Constituent that has Both a RFD _o and RFD _i	A-11
Equation A-10: Calculation of Ground Water Noncancer GCN for a Constituent that has a RFD _o and is either Non-Volatile or does not have a RFD _i	A-11
Equation A-11: Calculation of Ground Water Noncancer GCN for a Constituent that is Volatile, Has a RFD _i , and does not have a RFD _o	A-11
Equation A-12: Calculation of Ground Water Cancer GCN for a Volatile Constituent that has both a Sfo and Sfi.....	A-12
Equation A-13: Calculation of Ground Water Cancer GCN for a Constituent that has a Sfo and is either Non-Volatile or does not have a Sfi	A-12
Equation A-14: Calculation of Ground Water Cancer GCN for a Constituent that is Volatile, has a Sfi, and does not have a Sfo.....	A-12
Equation A-15: Soil-Water Partition Equation for Inorganic Contaminants	A-15
Equation A-16: Soil-Water Partition Equation for Organic Contaminants	A-15
Equation A-17: Calculation of 20 DAF Generic Cleanup Number.....	A-16
Equation A-18: Ingestion of Chemicals in Soils and Dust Residential Scenario - Noncancer.....	A-17
Equation A-19: Ingestion of Chemicals in Soils and Dust Residential Scenario - Cancer	A-17
Equation A-20: Dermal Contact with Chemicals in Soil Residential Scenario - Noncancer.....	A-18
Equation A-21: Dermal Contact with Chemicals in Soil Residential Scenario - Cancer	A-18
Equation A-22: Calculation of Apparent Diffusivities (DA)	A-19
Equation A-23: Calculation of Volatilization Factor (VF)	A-20

Equation A-24: Calculation of Particulate Emission Factor (PEF)	A-21
Equation A-25: Inhalation of Volatiles and Particulates from Contaminated Soil Residential Scenario - Noncancer	A-21
Equation A-26: Inhalation of Volatiles and Particulates from Contaminated Soil Residential Scenario - Cancer	A-21
Equation A-27: Calculation of Soil Saturation Concentration	A-22
Equation A-28: Calculation of Direct Contact Noncancer GCN for a Constituent that has both a RFD _o and RFD _i	A-23
Equation A-29: Calculation of Direct Contact Noncancer GCN for a Constituent that has a RFD _o and does not have a RFD _i	A-23
Equation A-30: Calculation of Direct Contact Noncancer GCN for a Constituent that is Volatile, has a RFD _i and does not have a RFD _o	A-23
Equation A-31: Calculation of Direct Contact Cancer GCN for a Constituent that has a Sfo and a Sfi	A-24
Equation A-32: Calculation of Direct Contact Cancer GCN for a Constituent that has a Sfo and does not have a Sfi	A-24
Equation A-33: Calculation of Direct Contact GCN for a Constituent that has a Sfi and does not have a Sfo	A-24
Equation A-34: Ingestion of Chemicals in Soils and Dust Industrial Scenario	A-25
Equation A-35: Dermal Contact with Chemicals in Soil Industrial Scenario	A-25
Equation A-36: Inhalation of Volatiles and Particulates from Contaminated Soil Industrial Scenario	A-25
Equation C-1: Calculation of Upper Fence	C-6
Equation C-2: Calculation of Lower Fence	C-6
Equation C-3: Calculation of Upper Cutoff	C-8
Equation C-4: Calculation of Lower Cutoff	C-8
Equation C-5: Comparison of 95% Upper Confidence Limit to the Background Remediation Standard through the t-test	C-11
Equation C-6: Comparison of 95% Upper Confidence Limit to the Background Remediation Standard through the t-test	C-11
Equation D-1: Calculation of Grid Interval	D-4
Equation D-2: Calculation of Weighted Average	D-4
Equation H-1: Water Content at 100% Saturation	H-14
Equation H-2: Degree of Saturation	H-14

List of Exhibits

Exhibit 7-1: Example: Adjustment of an Administered to an Absorbed Dose RfD	7-26
Exhibit 7-2: Example: Adjustment of an Administered to an Absorbed Dose Slope Factor	7-26
Exhibit A-1: Calculation of Ground Water Noncancer GCN for Benzene	A-27
Exhibit A-2: Calculation of Ground Water Cancer GCN for Benzene	A-27
Exhibit A-3: Calculation of Direct Contact Noncancer GCN for Benzene	A-28
Exhibit A-4: Calculation of Direct Contact Cancer GCN for Benzene	A-29
Exhibit A-5: Example - How GCNs Can Be Used to Screen a Chemical From a Risk Assessment	A-31
Exhibit A-6: Example - How GCNs Can Be Used as Cleanup Standards	A-33
Exhibit A-7: Example - How GCNs Can Be Used to Demonstrate That No Further Action is Required	A-35
Exhibit C-1: Determining Outliers - Example for even number of background data	C-9
Exhibit C-2: Determining Outliers - Example for odd number of background data	C-10

Exhibit C-3: Comparison of 95% Upper Confidence Limit to the Background Remediation Standard through the t-test	C-12
Exhibit C-4: Comparison of 95% Upper Confidence Limit to the Background Remediation Standard through the t-test	C-13
Exhibit D-1: Calculation of Grid Interval	D-4
Exhibit H-1: Example: Reviewing Soil Test Results from Lab Testing	H-16
Exhibit H-2: Example: Reviewing Soil Test Results from Field Testing	H-18

Acronyms

Acronym	Description
ACL	Alternate Concentration Limit
AGO	Attorney General's Office
AMS	Alternate Metal Standard
AOC	Area of Concern
ASTM	American Society for Testing and Materials
atm-m ³ /mol	Atmospheres-cubic meters/mol
ATSDR	Agency for Toxic Substances and Disease Registry
BCF	Bioconcentration Factors
BRS	Background Remediation Standard
CAMU	Corrective Action Management Unit
CDD	Chlorinated Dibenzodioxins
CDF	Chlorinated Dibenzofurans
CERCLA	Comprehensive Environmental Recovery Compensation Liability Act
CFR	Code of Federal Regulations
cm ²	Squared Centimeters
cm ³	Cubic Centimeters
CO	Central Office
COC	Constituent of Concern
CPRG	Closure Plan Review Guidance
CPS	Closure Performance Standard
CQA	Construction Quality Assurance
CQC	Construction Quality Control
CRO	Cessation of Regulated Operations
Csat	Soil Saturation Concentration
CSM	Conceptual Site Model
D	Day(s)
DAF	Dilution Attenuation Factor
DDAGW	Division of Drinking and Ground Water
DERR	Division of Emergency and Remedial Response
DHWM	Division of Hazardous Waste Management
DL	Detection Limit
DNAPL	Dense, Non-Aqueous Phase Liquid
DO	District Office
DQO	Data Quality Objectives
EQL	Estimated Quantitation Limit
ERAC	Environmental Review Appeals Commission
ERAS	Engineering and Remediation Assistance Section
FI	Fraction Ingested
FR	Federal Register
GCN	Generic Cleanup Number
gpm	Gallons per minute
GWPS	Ground Water Protection Standard
g/mol	Grams per mole
hr	Hour(s)
HI	Hazardous Index

Acronym	Description
HQ	Hazardous Quotient
HEAST	Health Effects Assessment Summary Tables
HSWA	Hazardous and Solid Waste Amendments of 1984
HWMU	Hazardous Waste Management Unit
I	Intake
IEUBK	Integrated Exposure Uptake Biokentic
IGWMP	Integrated Ground Water Monitoring Plan
IQR	Inter-quartile Range
IRIS	Integrated Risk Information System
kg	Kilogram
L	Liters
LCS	Laboratory Control Sample
LDR	Land Disposal Restriction
LNAPL	Light Non-Aqueous Phase Liquid
LQG	Large Quantity Generator
m ³	Cubic Meters
MCL	Maximum Contaminant Level
MDL	Method Detection Limit
mg	Milligrams
MOA	Memorandum of Agreement
MRL	Minimal Risk Level
NAPL	Non-Aqueous Phase Liquid
NCAPS	National Corrective Action Prioritization System
NCEA	National Center for Environmental Assessment
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
ND	Non-Detect
NFA	No Further Action
NOD	Notice of Deficiency
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	National Research Council
NTIS	National Technical Information Service
OABS	Oral Absorption Factor
OAC	Ohio Administrative Code
ODNR	Ohio Department of Natural Resources
Ohio DOD	Ohio Department of Development
Ohio EPA	Ohio Environmental Protection Agency
ORC	Ohio Revised Code
OSHA	Occupation Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response (U.S. EPA)
PAH	Polycyclic Aromatic Hydrocarbon
PBT	Persistent, Bioaccumulative and Toxic
PCB	Polychlorinated Biphenyls
PCOC	Potential Constituent of Concern
PE	Performance Evaluation
PE	Professional Engineer
PEF	Particulate Emission Factor

Acronym	Description
POC	Point of Compliance
PPB	Parts Per Billion
PPM	Parts Per Million
PQL	Practical Quantitation Limit
PRF	Plan Review Form
PRG	Preliminary Remediation Goal
QAPjP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RAGS	Risk Assessment Guidance for Superfund
RBS	Risk-Based Standard
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfDi	Inhalation Reference Dose
RfDo	Oral Reference Dose
ROE	Risk of Exposure
SEAM	Superfund Exposure Assessment Manual
SFi	Inhalation Slope Factor
SFo	Oral Slope Factor
SIF	Sampling Intensity Factor
SOP	Standard Operating Procedure
SPLP	Synthetic Precipitation Leaching Procedure
SQG	Small Quantity Generator
SVOC	Semivolatile Organic Compound
SWMU	Solid Waste Management Unit
TCDD	Tetra-Chlorinated Dioxin
TCLP	Toxicity Characteristic Leaching Procedure
TEF	Toxic Equivalent Factor
TGM	Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring
TIC	Tentatively Identified Compound
TOC	Total Organic Carbon
TOX	Total Organic Halogens
TSCA	Toxic Substances Control Act
TSDF	Treatment, Storage, and Disposal Facility
UCL	Upper Confidence Limit
mg	Micrograms
UIC	Underground Injection Control
U.S. EPA	United States Environmental Protection Agency
UR	Unit Risk
VAP	Voluntary Action Program
VF	Volatilization Factor
VOC	Volatile Organic Compound
WMU	Waste Management Unit
WQS	Water Quality Standard
Y	Year(s)

Overview of the Closure Plan Review Guidance

Description of the Closure Plan Review Guidance (CPRG)

As described in United States Environmental Protection Agency's (U.S. EPA) *Resource Conservation and Recovery Act (RCRA) Orientation Manual*,¹ treatment, storage, and disposal facilities (TSDFs) are the last link in the cradle-to-grave hazardous waste management system. All hazardous waste TSDFs will eventually stop generating and/or receiving waste for treatment, storage or disposal. At that time, the owner/operator must either remove all waste that has accumulated in [hazardous waste management units](#) (units) at the facility, or leave the waste in place while maintaining the units in such a way that ensures they will not pose an unacceptable future threat to human health and the environment.

Closure plans are documents required by federal and state law to ensure that a hazardous waste management unit is closed properly. TSDF closure plans are subject to review and approval by Ohio Environmental Protection Agency (Ohio EPA) - the delegated authority to implement and oversee RCRA Subtitle C in the state. Ohio EPA reviews closure plans to ensure an environmentally acceptable closure at facilities and to ensure all statutory requirements for closure are met. A component of the review and approval process includes an opportunity for public participation. Closure plans successfully completed through the state's review of the closure certification also provide documentation that a hazardous waste management unit or facility has been properly closed prior to subsequent use or sale of the property.

The Closure Plan Review Guidance (CPRG) is primarily designed to assist technical staff in the Division of Hazardous Waste Management (DHWM) with their evaluation of closure plans for hazardous waste management units. This document supplements U.S. EPA guidance documents, including closure and/or post-closure plan review checklists. Secondly, facility owner/operators may find it helpful in preparing closure plans for Ohio EPA review.

The applicability of this document to areas other than RCRA closures is limited. While similar activities may be required at facilities regulated under RCRA Corrective Action, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Ohio Voluntary Action Program (VAP), or authorities granted under Ohio Revised Code (ORC) Chapters 3734.20 and 6111, the statutory basis and regulatory development for these programs are independent (see [Chapter 2](#) of this guidance for further information on other clean-up programs). Similarly, guidance developed for other programs (*i.e.*, VAP) may not be applicable to RCRA closures. Therefore, a good understanding of those provisions is required in determining the applicability of the ideas discussed in this guidance. Ohio EPA strives for consistency in regulation of solid and hazardous waste wherever possible. However, inherent differences in the federal statutes and regulations upon which Ohio's regulatory programs are based make total uniformity impossible at this time.

The CPRG generally applies to facilities whose activities are subject to: (1) the hazardous waste facility interim standards chapters (Ohio Administrative Code (OAC) Chapter 3745-65 et seq.), which are generally equivalent to U.S. EPA's Interim Status facility standards (40 Code of Federal Regulations (CFR) Part 265); and (2) the hazardous waste facility standards chapters (OAC Chapter 3745-54 et seq.), which are generally equivalent to U.S. EPA's facility standards (40 CFR Part 264). This document may be used to review closure plans that are submitted as part of the process for terminating a Part A permit (or interim standards permit), or as part of a facility's Part B application. Portions of this guidance may also be applicable for use in

¹ Refer to U.S. EPA's *RCRA Orientation Manual* for a complete overview of RCRA Subtitle C and the hazardous waste management system.

conducting "generator closures" (see [Section 1.10, Generator Closure](#)); for closure of units found at unpermitted hazardous waste treatment, storage, or disposal facilities; and for closures required through a Director's Orders. Table 0-1 aids in determining closure applicability.

Please note that the content of the CPRG is subject to periodic revision. CPRG users are encouraged to check for the latest version on DHWM's web page at: www.epa.ohio.gov/dhwm.

Table 0-1: Applicability of RCRA Closure

Type of Hazardous Waste Facility	How RCRA Closure Occurs
Illegal TSDF, <i>a facility that began treating, storing or disposing hazardous waste in a manner that is regulated, but did not submit an application or obtain a permit.</i>	Enforcement action will be taken and the facility will be required to submit a closure plan through administrative orders.
Part A/Interim Standards Facility	A closure plan is required for termination of Part A Permit, or
	A closure plan will be used when the Ohio EPA requests a unit to be closed or upon cessation of use of unit.
Part B Permitted Facility	A closure plan is created as a component of the Part B application; it is approved before the facility obtains its permit. The facility can close at anytime following the closure plan with prior notification to Ohio EPA.
Large Quantity Generator	No closure plan is necessary, closure of unit occurs in accordance with generator requirements upon cessation of use.

Difference Between Statements in the CPRG and Ohio EPA Statutory Requirements

The CPRG provides guidance to the Ohio EPA closure plan reviewer (reviewer), as well as to owner/operators of facilities subject to hazardous waste closure requirements and to the general public. More specifically, the CPRG conveys how Ohio EPA generally expects to exercise its discretion in implementing Ohio statutory and regulatory provisions that concern hazardous waste closure. This guidance explains and clarifies issues related to Ohio's hazardous waste closure program.

The statutory provisions and regulations discussed in this guidance contain legally binding requirements. This guidance itself does not substitute for those provisions or regulations, nor is it regulation itself. As required by ORC Section 3745.30, this document has been stamped with the phrase "THIS POLICY DOES NOT HAVE THE FORCE OF LAW." Thus, the CPRG does not impose any new requirements. Ohio EPA retains discretion to use approaches on a case-by-case basis that differ from this guidance where appropriate. Ohio EPA will base closure decisions on the statute and regulations as applied to the specific facts of the closure.

Any person is free to raise questions and concerns about the substance contained in this guidance and the appropriateness of its application. Whether or not the recommendations in the CPRG are appropriate in a given situation will depend on site-specific circumstances.

Origin of the Policies Contained in the CPRG

Ohio EPA has had closure rules since 1981. In 1983, Ohio EPA received interim authorization from U.S. EPA for the base RCRA program and full authorization was granted to Ohio EPA in June of 1989. Since that time Ohio EPA has been implementing the hazardous waste closure program in lieu of U.S. EPA. In an effort to effectively administer the program, the DHWM began developing written guidance for closure plan reviewers in the late 1980's. In 1991, this guidance was gathered together and issued under the title of the Closure Plan Review Guidance (CPRG). The CPRG was reissued in September of 1993 as an *Interim Final* document and was used in that form until it was issued as a final document in March of 1999. In 2005 and again in 2006 the CPRG was revised and reissued to include additional information.

This guidance builds on the past versions and DHWM's collective knowledge of implementing the closure program for the past 20 plus years. Although this version of the CPRG is similar to the previous versions, areas of the text have been enriched to provide more guidance and formatted for electronic usage.

DHWM will provide updates to the CPRG when necessary. In general, updates are developed and recommended by DHWM staff, approved by DHWM management and many are posted on DHWM's web page. Changes to the CPRG that are considered to be administrative or informative and minor in nature do not go through the advertisement process before appearing on DHMW's web page.

CPRG users are encouraged to check DHWM's web page (www.epa.ohio.gov/dhwm) for the most up-to-date version of the CPRG. The public may comment on any part of the CPRG at anytime. Comments can be directed to DHWM's Engineering and Remediation Assistance Section (ERAS) Manager.

Additional Resources Available for Closure

Although the CPRG represents a significant tool for assisting the DHWM closure plan reviewer in conducting plan reviews, there are additional resources available. Implementing staff will initially look to their local office resources to address program concerns. If the issue cannot be resolved at the office level, staff can raise the issue directly to ERAS. In addition, quarterly "benchmarking" events will take place in two forms: 1) a conference call where staff suggest agenda items and call summaries are posted internally, or; 2) a "Get Together" where staff can also suggest agenda items, training can be offered, and where staff can present case studies/issues face-to-face with other staff.

The CO ERAS maintains a staff of engineers, risk assessors and remediation experts that can provide support in all facets of plan review including: risk assessment, cover or cap design, sampling and remedy evaluation/selection, data validation, and data assessment. ERAS staff will be reviewing and approving new closure plans, but District Office (DO) staff in charge of finalizing implementation of the plan are encouraged to contact Central Office (CO) ERAS staff if assistance is needed.

Lastly, there are other sources of assistance for plan reviews from outside of the division. DHWM maintains a Memorandum of Agreement (MOA) with the Division of Drinking and Ground Waters (DDAGW) and provides funding for hydrogeologic technical support for closure reviews. Plan reviewers should follow correct protocols for requesting assistance from DDAGW when closure plans include ground water components. The Office of Legal Services is also available to assist with closure plan reviews that involve environmental covenants or deed notices. Reviewers should work through management to request legal assistance.

Chapter 1

Regulatory Considerations for Reviewing and Approving Closure and Post-Closure Plans

A discussion about the review of closure and post-closure plans begins with an understanding of Ohio EPA's grant of statutory authority and the rules the Agency has adopted to implement closure and post-closure of hazardous waste management units and facilities. As an administrative agency, Ohio EPA can only exercise those hazardous waste program powers that have been clearly granted to it by the General Assembly in statute (see Ohio Revised Code (ORC) Section 3734.12). Under this statute, Ohio EPA is granted rule-making authority for, among other things, the closure and post-closure of hazardous waste storage, treatment and disposal units. These rules must also be consistent with and equivalent to the regulations adopted by U.S. EPA under the Resource Conservation and Recovery Act of 1976, as amended. Over the last twenty years, Ohio EPA has adopted closure and post-closure rules, which establish the state standard for acceptable closure and post-closure activity. The objective of an Agency closure plan review process is to ensure that each closure plan being reviewed complies with the applicable closure regulations, particularly the closure performance standard of Ohio Administrative Code (OAC) Rules 3745-55-11 and 3745-66-11. A discussion of this and the more significant closure and post-closure rules follows.

1.1 Rules Associated with Closure and Post-Closure Plans

Most of the rules relating to the closure and post-closure of hazardous waste management units (units) are found within OAC Chapters 3745-50 through 3745-256.

General Facility Standards vs. Interim Standards

Both OAC Rules 3745-54-01(B) and 3745-65-01(B) require owner/operators of facilities that store, treat or dispose of hazardous waste to be subject to, among other things, closure and post-closure requirements. The former rule is found in the General Facility Standards, while the later rule is in the Interim Standards-General Provisions. Historically, DHWM has required owner/operators of hazardous waste facilities, not operating pursuant to a Hazardous Waste Installation and Operation Part B permit (Part B permit), to comply solely with the Interim Standards, with the underlying premise that both sets of standards apply concurrently to owner/operators of facilities which treat, store, or dispose of hazardous waste. Refer to [U.S. EPA's RCRA Orientation Manual](#) for definitions of permitted and interim status facilities. At times, DHWM has also applied both standards to non-Part B permitted units that close with waste in place (and therefore needing post-closure care). In an August 2006 ERAC ruling,¹ the General Facility Standard and the Interim Standards have been found to be mutually exclusive. Thus, the General Facility Standards apply to all TSD unit owners and operators, except those qualifying to operate under the Interim Standards (OAC Rule 3745-50-40(C)(5)). Closure performed under the General Facility Standards entails a hazardous waste permit. While the permit is an option, it can be a time consuming process and DHWM may not wish to require facilities to obtain a Part B permit for closure of illegal units. The two different administrative processes may be utilized to close illegal units are a Director's Final Findings and Order (DFFO) or a Hazardous Waste Installation and Operation Permit.

¹ Textileather Corporation vs. Christopher Jones, ERAC Case No. 485045 issued August 22, 2006. The text of this decision can be found at <http://epaintra.epa.state.oh.us/dhwm/pdf/ERAC-Findings-ConclusionsAndOrder2006.pdf>

Facilities with permits will address their closure needs via their permit. Facilities qualifying to operate under the Interim Standards may be closed per the applicable Interim Standards Chapters.

Non-Part B permitted units, which should have been permitted, must be closed in accordance with the General Facility Standards using one of two vehicles:

- Director's Final Findings and Orders (DFFO) or
- A hazardous waste permit issued for the specific purpose of closure.

Newly discovered units may be addressed by the enforcement process since most facilities would prefer using the enforcement process rather than obtain a hazardous waste permit to close the unit. In this context, a DFFO is the formal administrative vehicle to allow closure in lieu of a permit. An agreed-to set of orders requiring the submission of a closure plan would include statements about which OAC Chapters to follow. The administrative requirements of OAC Chapters 3745-65 and 66 will be used to provide a procedural framework for acting on closure plans, while the substantive requirements of the closure plan are contained in applicable portions of OAC Chapters 3745-54 and 55 (including to the groundwater requirement in accordance with OAC rules 3745-54-90 through 3745-54-55).

An expedited permit can also be a vehicle to complete closure. It should be noted that this process will rarely be utilized and if a facility wishes to use an expedited permit the reviewer should contact their supervisor early in the process. For the sole purpose of accomplishing closure, a permit application would contain a closure/post-closure plan and the necessary financial assurance. The other elements including the Part A, Part B, siting criteria and the pre-application public participation requirements are not applicable or necessary.

Closure plans approved by the Agency before the August 2006 ERAC ruling and were approved pursuant to the Interim Standards will continue to be administered under the Interim Standards. There is no need to cite General Facility Standards or obtain a DFFO for these plans because the adoption of the post-closure rule, OAC Rule 3745-66-21, addresses the ground water concerns. For the same reason, facilities operating under an Interim Standards post-closure plan will also continue to be administered through the Interim Standards.

Example when DFFO/permit is not necessary:

A closure plan was approved using both the General Facility Standards and the Interim standards without DFFOs or a permit. The facility now wishes to amend the plan (See [Section 1.3, Closure Plan Designations](#)). There is no need to obtain DFFOs or a permit because the plan has already been approved using the both standards and the facility has already agreed to use both.

Examples when DFFO/permit is necessary:

- A closure plan that has not been approved by the director and has been submitted as part of an enforcement case should have DFFOs before the plan can be approved.
- In some cases, closure of unit will not require a penalty component for a newly discovered unit. These plans will need either DFFOs or a "closure-only" permit. This will also depend on if the facility must submit additional documentation such as a Facility Management Plan, DHWM's history with the facility, and the facility's preference.

Rule Elements

The general closure performance standard is found in OAC Rules 3745-55-11 and 3745-66-11. The several rules which follow (OAC Rules 3745-55-12 [or 3745-66-12] through 3745-55-16 [or 3745-66-16]) provide information about the content of a closure plan, how the plan is approved, disapproved, or modified, time allowed for closure, certification of closure and survey plats. For example, Section A of OAC Rule 3745-55-12 (the Part B permit standards) and 3745-66-12 (the Interim Standards) require owner/operators of hazardous waste facilities to have a written closure plan (and in the case of OAC Rule 3745-55-12, a written and approved closure plan), while section B of OAC Rules 3745-55-12 and 3745-66-12 sets forth the minimum information the closure plan should contain. Section D of these two rules requires closure of a facility in certain enumerated circumstances, such as, termination of a permit or termination of Interim Standards. These sections also set forth when notice of closure must be given to the director and when a closure plan must be submitted for those without an approved plan. Notice of when closure is expected to begin is important because it starts the closure process clock and allows the Agency the opportunity to conduct an inspection of the unit before closure of the unit begins.

Figure 1-1 is a simplified flow chart of the administrative procedures for facilities closing under the Interim Standards and utilizing the DFFO process. For more information on the administrative procedures for facilities submitting closure plans as part of the Part B permit application, the DHWM reviewer should refer to the [Unified Permitting Manual](#).

The requirements of post-closure care are covered under OAC Rules 3745-55-17 (or 3745-66-17) through 3745-55-20 (or 3745-66-21). These rules provide information about the monitoring and maintenance requirements during the post-closure care period, the content of a post-closure plan, how the plan is approved and modified, the length of the post-closure care period, the notice to the local land authority, and the certification of completion of post-closure care. [Chapter 5](#) has more information about post-closure plans and certifications.

Review and Approval for Interim Standards Closure Under DFFOs

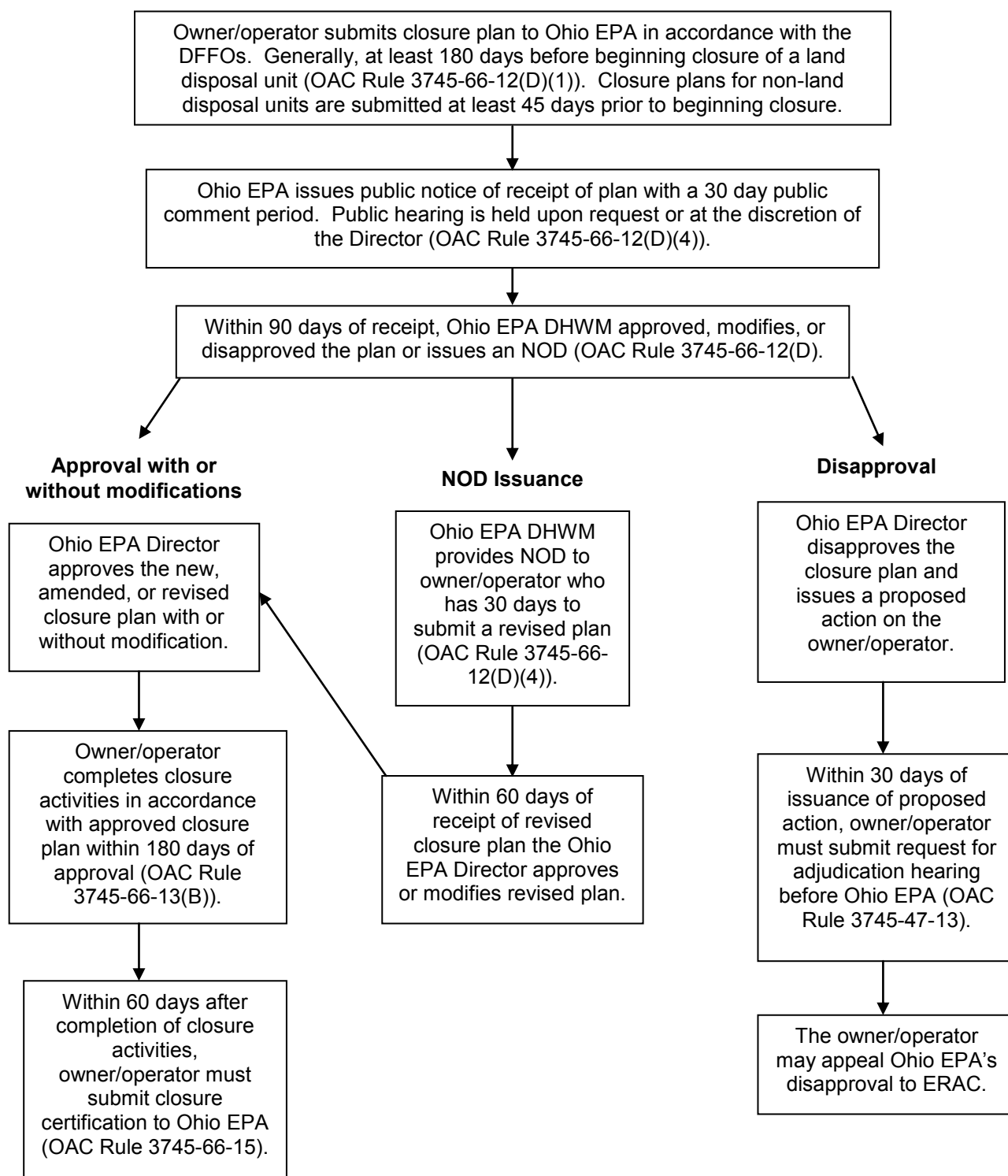


Figure 1-1: Administrative Procedures for Ohio EPA Review and Approval for Interim Standards Closure

The Closure Performance Standard - Closure by Removal or Decontamination, Waste in Place Closure, Completion of Closure and Post-Closure Care

During closure, facility owner/operators must comply with the closure performance standard in OAC Rules 3745-55-11 and 3745-66-11. According to these rules, closure must be completed in a manner that: (a) minimizes the need for further maintenance; (b) controls, minimizes or eliminates, to the extent necessary to protect human health and the environment, post-closure escape of hazardous waste, hazardous constituents, leachate, contaminated run-off, or hazardous waste decomposition products to ground or surface waters or to the atmosphere; and, (c) complies with the unit-specific closure requirements.

Generally, two types of closure are allowed - closure by removal or decontamination and closure with waste in place. The concept of closure by removal or decontamination requires that the hazardous waste be removed from the unit and waste residue be removed or decontaminated to such a degree that no additional regulatory control under the hazardous waste rules is required. Units that do not close by removal or decontamination remain subject to the requirements for post-closure care, including post-closure permitting or alternative authorities, such as a post-closure plan or Director's Orders, referred to in the post-closure rule.

For units closing with waste in place, the post-closure care period begins with the completion of closure. The term "completion of closure" as used in OAC Rules 3745-55-15 and 3745-66-15 refers to the completion of closure activities performed in accordance with the approved closure plan. A closure certification statement must be submitted within sixty (60) days of the completion of closure activities. The term "completion of closure" as used in this rule does not include activities such as the receipt and/or approval of the submitted certification documents or other activities that serve to verify the completion of closure activities has occurred.

The phrase "completion of closure" is also used in OAC Rules 3745-55-17 and 3745-66-17 to trigger the beginning of the thirty year post-closure care period. This means that the post-closure care activities specified within the approved post-closure plan commence upon the completion of closure activities but prior to submission of the certification of closure to Ohio EPA. In other words, post-closure care activities are not triggered by the submission of a closure certification statement. Refer to [Section 1.9, Completion of Closure and/or Post-Closure](#) for more detailed information on completion of closure.

The Post-Closure Rule and Corrective Action

Originally published in the Federal Register (FR) on October 22, 1998 (63 FR 56710), the post-closure rule, found in OAC Rule 3745-66-21, is composed of two parts. It first provides alternatives to post-closure permits, which were previously required for facilities that closed with waste in place. Secondly, it allows the regulating agency to use the facility-wide Corrective Action process to perform closure activities. More specifically, the post-closure rule gives the regulators the flexibility to issue a post-closure permit to a facility, or to impose the same regulatory requirements in an enforceable document issued under an alternate non-permit authority. This enforceable document would be in lieu of a post-closure permit. Facilities under an enforceable document instead of a post-closure permit must continue to meet all requirements of the regulations applicable to non-permitted facilities, as well as any additional requirements under facility-wide Corrective Action and ground water requirements applicable under a permit.

With respect to the closure of regulated units, the post-closure rule allows the regulating agency to replace the closure and ground water requirements at certain hazardous waste management

units with similar, site-specific requirements developed through the facility-wide Corrective Action process. This flexibility is available under the following conditions:

- The hazardous waste management unit is situated among Waste Management Units (WMU), or areas of concern, a release has occurred, and both the unit and the WMU(s) are likely contributors to the release; and
- The regulating authority determines that applying the hazardous waste closure and ground water monitoring requirements for post-closure care is not necessary because the clean-up remedy developed through the Corrective Action process is deemed to be protective; or
- The remedy selected will satisfy the RCRA closure performance standards.

Addressing Hazardous Constituents During the Closure Process

As indicated in previous sections, the closure rules require owner/operators of hazardous waste management units to close these units in a manner that is protective of human health and the environment. Based on the belief that “it is necessary to include hazardous constituents in the closure performance standard to ensure that all contamination is adequately addressed at closure,” U.S. EPA revised the language of 40 CFR Section 264.111(b) and 265.111(b) to require that closure must control, minimize or eliminate, to the extent necessary, escape of hazardous constituents, instead of only hazardous waste constituents as the previous regulation required. U.S. EPA further stated that this approach is consistent with the Hazardous and Solid Waste Amendments (HSWA) corrective action authority regarding solid waste management units.² Ohio adopted the hazardous constituent language contained in the federal standard in November of 1987 (see OAC Rules 3745-55-11 and 3745-66-11). As a result, owner/operators of closing facilities are required to make reasonable efforts to address all applicable hazardous constituents (Appendix VIII of 40 CFR Part 261) found at the unit. Reasonable efforts should be based on a site-specific review of waste managed or generated at the site or a record review of similar information.

The term hazardous constituent is defined to mean “... those constituents listed in the appendix to rule 3745-51-11 of the Administrative Code” (see OAC Rule 3745-50-10). This appendix is also known as, and equivalent to, Appendix VIII to 40 CFR Part 261. It is a list of chemicals developed by U.S. EPA and used by U.S. EPA and Ohio EPA in deciding whether to list a waste as hazardous. Specifically, under OAC Rule 3745-51-11 (Criteria for Listing Waste) the director must list a waste as a hazardous waste upon determining that the waste contains any of the toxic constituents listed in the Appendix (hereinafter referred to as Appendix VIII) and after considering the factors (found in OAC Rule 3745-51-11(A)(3)(a) through (k)), “the director concludes that the waste is capable of posing a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported or disposed of, or otherwise managed.”

Closures are unit-based activities where as Corrective Action is site-wide. In closure, it is important to define the physical boundaries of the hazardous waste management unit subject to closure based upon the hazardous waste, hazardous waste constituents, or breakdown products associated with hazardous waste managed at the unit. The applicable (Appendix VIII) hazardous constituents found within the boundary of the hazardous waste management unit must be addressed during closure (OAC Rules 3745-55-11 and 3745-66-11).

² Federal Register: May 2, 1986 (51 FR 16424)

In instances where hazardous constituents are found to be present at or near the closure unit but are not attributable to the unit activities, Ohio EPA has several alternatives. The hazardous constituents found within the unit boundary can be addressed as a part of the closure process; as such the unit will not be investigated during Corrective Action. Alternatively, the unit can be closed addressing only the hazardous waste managed at or attributable to the unit (without addressing the other hazardous constituents); the closed unit will then be subject to Corrective Action investigation.

Hazardous constituents outside the closure unit boundary may be addressed through Corrective Action or other programs available through the state. In cases where the closure unit has released hazardous waste or constituents into the surrounding soil or ground water and the closure units are located near Waste Management Units (WMUs) or Areas of Concern (AOCs) that also had releases to the environment, the clean-up of similar releases may be subject to two different set of standards and procedures.³ Therefore Ohio EPA may address the closure unit under Corrective Action by exempting the closure unit from certain closure requirements conditioned on the incorporation of the unit into the Corrective Action program through a permit or order.

There are practical difficulties with analyzing closure media for all Appendix VIII constituents. Appendix VIII is a composite of several other lists⁴ and includes many entries that are large categories of chemicals, which may be more appropriate for listing purposes. In a July 1987 rule making replacing the then current ground water monitoring requirement to analyze for all Appendix VIII constituents with a core list of chemicals (known as Appendix IX to 40 CFR Part 264 hereinafter referred to as Appendix IX) plus chemicals specified by the Regional Administrator on a site-specific basis, U.S. EPA found that while appropriate for listing purposes, Appendix VIII presented a number of problems for the purposes of ground water monitoring. U.S. EPA recognized that Appendix VIII analysis could be extremely difficult or impossible for many constituents. Therefore in the ground water context, U.S. EPA proposed a list of chemicals (Appendix IX, for which Ohio EPA's equivalent is the Appendix to OAC Rule 3745-54-98) made up of those compounds on Appendix VIII which it deemed feasible to analyze for in ground water samples, plus a small number of compounds routinely monitored in the Superfund program. This experience documents the practical difficulty of identifying or monitoring all Appendix VIII constituents.

Although owner/operators of closing facilities are required to make reasonable efforts to address all Appendix VIII constituents, judgement needs to be exercised in addressing Appendix VIII

³ In the case of post-closure ground water monitoring for a closed unit, the action level triggering corrective action could be any statistically significant increase over the background level of the constituent in the ground water below the closure unit. This approach (known also as the "no increase over background" strategy) is supported by the fundamental closure notion that the owner/operator is responsible for responding to constituents migrating from the closed unit. This approach is also consistent with U.S. EPA's ground water protection strategy that seeks to maintain ground water quality necessary for current and future uses. Background ground water quality, independent of the effects of hazardous waste disposal, will define the highest use to which a particular aquifer may be put. U.S. EPA's "no increase over background" strategy is meant to assure that the existing and potential uses of the aquifer will be maintained. See Federal Register: July 26, 1982 (47 FR 32285).

⁴ Appendix VIII includes priority pollutants under Clean Water Act, chemicals identified by U.S. Department of Transportation as hazardous to transport, carcinogens identified by U.S. EPA, and chemicals high acute toxicity as listed in the National Institute for Occupational Safety and Health Registry of Toxic Effects of Chemical Substances.

contamination through informed sampling based upon knowledge of the site. This can be done through a closure or closure/Corrective Action.

Unit Specific and Other Relevant Closure Rules

In addition to the closure performance standard, the rules also provide unit-specific closure and post-closure requirements, which are found in the Ohio rules:

- Containers - OAC Rule 3745-55-78,
- Tanks - OAC Rule 3745-55-97,
- Surface Impoundments - OAC Rule 3745-56-28,
- Waste Piles - OAC Rule 3745-56-58,
- Land Treatment - OAC Rule 3745-56-80,
- Landfills - OAC Rule 3745-57-10,
- Incinerators - OAC Rule 3745-57-51,
- Drip Pads - OAC Rule 3745-57-85,
- Miscellaneous Units - OAC Rules 3745-57-91 to 3745-57-93,
- Containment Buildings - OAC Rule 3745-205-102, and
- Hazardous Waste Munitions - OAC Rule 3745-205-202.

Similar rules exist in the Interim Standards closure and post-closure provisions. Many other relevant rules such as those, which apply to the Land Disposal Restrictions (LDR) program under OAC Chapter 3745-270 and to any new hazardous waste management units that may be created pursuant to an approved closure plan, should also be addressed. Any new units to be created during closure to handle remediation activities should be fully described and be in full compliance with applicable unit specific requirements.

1.2 When, Where and How to Submit a Closure and/or Post-Closure Plan

The submitted closure plan should be able to stand alone as a complete, independent document, with minimal reference to other documents. In practical terms, an independent, third party contractor should be able to make an accurate contract bid on the closure activities using the information in the closure plan. Similarly, the public should be able to ascertain the full scope of the project from the copy of the closure plan.

It is recommended that the owner/operator of the facility submit one (1) electronic⁵ copy of the closure and/or post-closure plan to Ohio EPA, however a paper copy will also be acceptable. The cover letter should be addressed to:

Director of Ohio EPA
c/o DHWM, Regulatory and Information Services Section
Attention: Manager
P.O. Box 1049
Columbus, Ohio 43216-1049.

It is also recommended that a paper copy be sent to the DHWM Supervisor at the appropriate Ohio EPA DO (See [Map of District](#) page for a list of the district offices, including addresses and phone numbers, and a map of their jurisdictions). If ground water monitoring is involved, two copies sent to the DO would expedite the review process.

⁵ DHWM is defining electronic copies in this situation to be Portable Document Format (.pdf) files submitted on compact disk (*i.e.*, CD).

Interim Standards or Unpermitted Treatment, Storage, or Disposal Facilities (TSDFs)

The DFFOs will contain a schedule of when the closure plan should be submitted. The OAC also contains schedules of how far in advance a closure plan must be submitted before the expected beginning of closure. In addition, Ohio EPA must first approve all closure activities before they may begin (or the owner/operator risks disapproval of an activity that they have already completed).

Timeframe in the OAC

The owner/operator of a land disposal facility (*i.e.*, landfill, surface impoundment, waste pile, land farm) must submit a closure plan to Ohio EPA at least one hundred eighty (180) days before the expected date to begin closure. Facilities with only tanks, container storage, or incinerator units are required to submit the closure plan at least forty-five (45) days prior to the date on which the owner/operator expects to begin closure of “any non-land disposal unit at a facility” (refer to OAC Rule 3745-66-12(D)).

The owner/operator of an Interim Standards unit subject to post-closure must submit a post-closure plan to Ohio EPA at least one hundred eighty (180) days before the date the owner/operator expects to begin partial or final closure of the first hazardous waste disposal unit (refer to OAC Rule 3745-66-18). Facilities with the intention of closing surface impoundments or waste piles units by removal or decontamination must prepare and submit to Ohio EPA a written post-closure plan within ninety (90) days of the date that the owner/operator determined the hazardous waste management unit must be closed with waste in place. Generally, if it is known that a unit will likely need to be closed with waste in place, a post-closure plan should be included with the initial closure plan submitted for review and approval.

Timeframe related to DFFOs

To address closure obligations mandated through the enforcement program, a case-by-case approach is being recommended. The key is to select a process that makes sense for the situation and will ultimately ensure achievement of the closure performance standard.

In certain instances, DHWM may elect to allow sampling (with prior review of the sampling and analysis plan by DHWM) before issuance of the DFFOs to expedite the closure process. Ultimately a DFFO will be issued, and the sampling will support and provide more information for the DFFO and is not used as a means to replace the DFFO.

Ohio EPA also has the option to write the DFFOs to allow sampling (with prior review of the sampling and analysis plan by DHWM) before a closure plan approval. The sampling information can then be used to supplement the closure plan. The DFFOs may have a timeframe for the sampling, analysis, and subsequent submittal of the closure plan.

The DFFOs can also be written compelling the facility to submit a closure plan to be approved by the director before any sampling or closure activities take place at the facility.

Although likely to be a rare occurrence, it is conceivable that prolonged discussions unrelated to the closure plan could delay issuance of the DFFOs and consequently the creation of the framework needed for plan approval. In such situations, it is recommended that a separate closure framework-specific DFFO be drafted and issued in order to prevent delay of closure and cleanup activities that are not in dispute.

Each case will be different and the processes will vary, it is Ohio EPA's discretion as to the approach that will be used.

Closure-only Permits (Non-Part B)

Facilities utilizing the "closure only" permits will submit the closure plan as part of the permit application. Due to the fact that the owner/operator will already have an approved closure and/or post-closure plan as part of the Part B permit application, the owner/operator may begin closure once the permit is issued. Note that Ohio EPA generally requests that the owner/operator contact the appropriate district office inspector at least five (5) business days in advance of certain critical activities, such as soil sampling or removal, so that the inspector may be present to observe these activities or obtain split samples.

Part B Permitted Facilities

Each Part B permit should contain a written, complete and adequate closure and/or post-closure plan because these plans must, by rule, be submitted with the permit application, and reviewed and approved by Ohio EPA (refer to OAC Rule 3745-55-12). In accordance with ORC Section 3734.05(D) and (H), the approved closure and/or post-closure plan will become a condition of any RCRA Part B permit. Therefore, it is **critical** to have complete and adequate closure plan details when a Part B permit is granted or being considered for renewal. A closure and/or post-closure plan in a Part B permit application should be written and reviewed with detail and scrutiny. It should be approached as if the facility was closing soon after permit issuance. It should not assume that substantive details, such as "clean" levels or a list of hazardous constituents of concern, can be left for later resolution.

Due to the fact that the owner/operator will already have an approved closure and/or post-closure plan as part of the Part B permit application, the owner/operator must provide written notice sixty (60) days prior to the date closure is expected to begin for a land unit and forty-five (45) days prior to the date on which final closure of a facility with only non-land treatment or storage units is expected to begin (OAC Rule 3745-55-12).

As a general rule, all disposal units should have post-closure plans. Also certain surface impoundments, waste piles and tanks or tank systems are required to have contingent post-closure plans even if the original intent is to remove or decontaminate the hazardous waste at closure.⁶ Unless otherwise required by rule as discussed above, an owner/operator must submit a post-closure plan to Ohio EPA within ninety (90) days from the date that the owner/operator or the Ohio EPA determines that the hazardous waste management unit must be closed as a landfill (OAC Rule 3745-55-18(A)).

1.3 Closure Plan Designations

The rules do not define the terms "new" or "revised" for Interim Standards closure plans. The terms "revise" or "revised" do not appear in OAC Rule 3745-66-12 and only appear in OAC Rule 3745-66-13 (E)(7)(c) in a generic sense (and probably means to amend the plan). The terms "amend", "amended" or "amendment" appear in the title as well as the body of OAC Rule 3745-66-12 and refers to closure plans whether or not approved by the director. Owner/operators can amend the closure plan at any time prior to notification of final closure (see OAC Rule 3745-66-12(C)). Those with approved closure plans are required to follow the prescribed procedure in OAC Rule 3745-66-12(C)(3):

⁶ Refer to OAC Rules 3745-55-12, 3745-55-97, 3745-56-28, 3745-56-58, and 3745-66-97.

"If the amendment to the plan is a modification according to the criteria in rules 3745-50-51 of the Administrative Code, the modification to the plan will be approved according to the procedures in paragraph (D)(4) of this rule." (Note: This does not mean comply with OAC Rule 3745-50-51 unless the facility has a Part B Permit.)

The term "new" is used in OAC Rule 3745-66-12(D)(4) as follows:

"If the director does not approve the plan he will provide the owner or operator with a detailed written statement of reasons for the refusal and the owner or operator must modify the plan or submit a new plan for approval within thirty days after receiving such written statement."

In order to have a usable internal nomenclature that would convey, in a general sense, the version of the closure plan being considered, DHWM developed a somewhat unique lexicon. For the purpose of an internal tracking number, there are three distinct designations for the different types of closure plan submittals; *new*, *amended* and *revised*.

- **New closure plans** are the original (first) closure plans submitted for a unit and are subject to the public notice procedures as outlined in [Section 1.4, Public Participation in the Closure and Post-Closure Process](#).
- **Amended closure plans** are those plans submitted *after* a director's approval has been issued on a previous closure plan. Some amended closure plans are also subject to the public notice procedure. [Section 1.8, Closure and/or Post-Closure Plan Amendments and Extension of Closure Time Period](#), discusses closure plan amendments in more detail.
- **Revised closure plans** are those plans submitted to Ohio EPA in response to a NOD. Ordinarily, Ohio EPA does not public notice revised closure plans. However, if the revised plan is fundamentally different than the original closure plan (e.g., changing from closure by complete removal of all contaminated soil to a risk-based soil cleanup standard), the district reviewer, in consultation with ERAS, should request a supplemental public notice of the revised closure plan.

1.4 Public Participation in the Closure and Post-Closure Process

Prior to Agency action on an Interim Standards closure and/or post-closure plan, Ohio EPA, by law, is required to provide the general public with both a notice and an opportunity for public comment during the mandatory thirty (30) day public comment period (OAC Rule 3745-66-12(D)(4) and 3745-66-18(E) and (F)). The Agency's public notice also provides information as to why a closure and/or post-closure plan has been submitted, where a copy of the plan is available for review, and finally, when and how to submit written comments.

For all new, amended, and revised if applicable, closure and/or post-closure plans, Ohio EPA's public notice appears in the "Ohio EPA Weekly Review" and in a newspaper of general circulation in the county in which the facility is located. A letter indicating that the closure and/or post-closure plan has been received and information about the public comment period is sent to the facility owner/operator and the DO.

In response to a request or at the discretion of Ohio EPA, the Agency may hold a public meeting to give an overview of the plan and accept oral comments. The public notice for the meeting may be included with the initial public notice of receipt of the plan or in a separate public notice 30 days before the meeting. The Public Involvement Coordinator (PIC) will arrange the meeting

and help prepare the reviewer, who may be expected to give a presentation summarizing the closure and/or post-closure plan.

DHWM Regulatory and Information Services Section receives all public comments, which are then forwarded to the DHWM personnel for consideration. It is the reviewer's responsibility to develop a response to any substantive public comments in the form of a *responsiveness summary* explaining the Agency's action relative to the comments received. Copies of the responsiveness summary, along with the approval letter, will then be sent to the facility and to those who submitted comments. It is important to note that the thirty (30) day public comment period must end before the director of Ohio EPA can issue an action for the closure plan.

Avenues for public participation on Part B closure plans manifest themselves in either the renewal process (OAC Rule 3745-50-40 (D)) or the permit modification process (OAC Rule 3745-50-51). In a renewal, the closure and/or post-closure plan is contained in the Part B permit application and there is a public comment period as a part of the issuance of the draft renewal permit. Once Ohio EPA issues a final renewal permit, the closure and/or post-closure plan becomes an element of the renewal permit. Changes to Part B closure plans are reviewed and approved, disapproved or modified by Ohio EPA as a permit modification. See OAC Rules 3745-55-12 and 3745-50-51 and [DHWM's internal web page](#) for the most current guidance on permit modifications.

For more information on public participation during the closure and post-closure process, refer to OAC Rules 3745-50-40, 3745-50-51, 3745-55-12, 3745-55-18, 3745-66-12, and 3745-66-18.

1.5 Administrative Framework of Closure and/or Post-Closure Plan Review

In 2006, DHWM formed a Closure Improvement Workgroup to analyze the efficacy of DO review of closure plans. The group determined that a significant amount of resources were allocated to keep DO staff trained and ready to review closure plans, but DHWM was receiving and taking final action on significantly fewer plans. This trend was expected to continue. It was decided to change the closure plan review process. The new process is designed to incorporate a level of flexibility with the approach. In general, CO ERAS staff conduct new and amended plan reviews and DO staff provide plan implementation oversight and certification review. However, flexibility in the process can be exercised, for example, when the DO has a long history with a site and is better positioned to review the plan, or if the certification review will be extensive and CO is better positioned to review the certification, or in other situations where it makes sense to assign tasks based on specific expertise or resources.

Outlined below are the steps in the revised closure process (Implemented July 1, 2007):

General framework of the closure process

CO ERAS will be responsible for the closure plan review until approval by the director. DO personnel will be responsible for overseeing closure plan implementation; reviewing closure certification reports and preparing appropriate Notices of Deficiency (NOD) or acceptance letters for the closure certifications.

While no concurrent or dual review is contemplated in this process, a DO led review of the closure plan can occur upon a mutual agreement between the CO and DO management. For example, a DO-led review could be conducted when a particular technical expertise resides in the DO, or there is something unique about history of the closure making it more efficient for the DO to conduct the review or there is a resource issue.

Case-by-case flexibility is of key importance. Equally important is the interest of the state in efficiently processing the closure plans to completion. Once a decision is made about where the review will be conducted, it is that office's responsibility to complete the review (NOD and/or Approval); if for some reason the review cannot be completed, the CO and DO supervisors need to meet and resolve the issue.

The general approach for the process is outlined in the following steps. It may change if review of the closure plan is assigned to the DO or if the review of the certification is assigned to the CO.

Step 1 – Pre-submittal: Permitted facilities will submit their plans in their Part B application. For unpermitted facilities, closure plans will be submitted in response to orders. If a closure plan is submitted due to enforcement actions, the CO Enforcement Coordinator may notify ERAS.

Step 2 – Closure Plan Receipt: Once a closure plan is received in CO with a copy to the DO, CO will public notice the receipt of a closure plan. The ERAS supervisor will notify the DO supervisor that a closure plan has been received (with basic information about the nature of the closure plan) and request a planning conference call.

Step 3 – Planning Conference Call: The call will be initiated by the ERAS supervisor. Staff involved with the project will participate in the call, including the DO supervisor. The objectives of the planning call are as follows:

- Identify CO plan reviewer to DO
- Identify DO plan implementer to CO
- Define CO/DO communication and coordination strategy during process (participation in meetings/calls, copied on correspondence).
- Discuss unique circumstances/issues for the review/oversight of the plan
- If applicable, assign the DO as closure plan review lead, with the basis for this determination

The results of the call will be captured in an e-mail summation from the ERAS supervisor to the DO supervisor.

Step 4 – Plan Review & Site Visit: CO staff will conduct a preliminary review of the plan prior to an initial site visit. DO staff participation is determined by the coordination strategy defined in Step 2. Plan review will follow the general NOD/response process, outlined in this guidance, including use of review tools (*i.e.*, Plan Review Forms). If a Division of Drinking and Ground Water (DDAGW) review is required, CO staff will submit review requests to DDAGW CO who will coordinate reviews with DDAGW DO staff as per the DHWM-DDAGW Memorandum of Agreement.

Step 5 – Plan Approval & Project Transition: CO staff will prepare the closure plan approval letter and response to comments (if comments are received) and forward these items to the director's office for signature. Concurrently, CO review staff will prepare and forward a project transition memo to the DO. The transition memo will act as the mechanism to formally transfer the project to the DO and will include a copy of the signed approval letter and identify key aspects of closure plan approval for evaluation

during oversight. If needed, a conference call or meeting between CO and DO staff can be scheduled to go over the transition memo.

Step 6 – Plan Oversight & Certification Review: In conjunction with DO management, DO oversight staff will develop a strategy for overseeing compliance with the plan, identifying critical events, dates for visits, etc. DO oversight staff will authorize any minor changes to the plan (of a Class 1 permit mod nature). Changes that are of a Class 2 or 3 nature should will be reviewed and processed by CO-ERAS. Amendment procedures can also be found in [Section 1.8, Closure and/or Post-Closure Plan Amendments and Extension of Closure Time Period](#). Extensions of the approved closure period are final actions and are processed by DO staff in accordance with the procedures in Section 1.8.

DO staff will conduct a review of the closure certification and in conjunction with site visits, make a determination of whether the closure was conducted in accordance with the approved plan. DO staff may be responsible for completing data validation plan review forms, risk assessment plan review forms as closure plan certification reports often contain new information collected as part of the implementation process. The DO will prepare either a NOD or a final closure letter following the process outlined in [Section 1.7, Notice of Deficiency and Director's Approval/Modification/Disapproval Letters](#).

Previously submitted closure plans

Closure plans being reviewed in the DO on or before the date of transition will remain the responsibility of the DO. After July 1, 2007, closure plans received will be processed under the new administrative process with CO staff to generally conduct closure plan reviews with the DO providing closure plan implementation oversight and certification review.

DDAGW Involvement

For land disposal units or others with potential ground water contamination, the DDAGW district staff will review ground water monitoring, contamination and site suitability issues. CO staff will submit review requests to DDAGW CO who will coordinate reviews with DDAGW DO staff as per the DHWM-DDAGW Memorandum of Agreement. DDAGW comments should then be incorporated into closure plan review comments and referenced to specific hazardous waste rules where possible. That said, the DDAGW role is to provide technical assistance and support services to the DHWM. The comments and reports provided by DDAGW in response to DHWM work requests are advisory in nature. DHWM staff have both the lead role and the final responsibility in making regulatory compliance determinations. As the leader, DHWM staff also have the responsibility for coordinating the completion of the project including meetings and communications with involved parties, determining how to proceed with DDAGW's recommendations, and understanding the ground water issues.

1.6 Objective of a Closure and/or Post-Closure Plan Review

The closure and/or post-closure plan review must verify that the plan complies with all appropriate regulations, particularly the general closure performance standard of OAC Rule 3745-55-11 or 3745-66-11 and OAC Rules 3745-55-17 through 20 (or 3745-66-17 through 21) for post-closure. Many other relevant regulations, such as unit-specific requirements, ground water monitoring and response rules, and the Land Disposal Restrictions program under OAC Chapter 3745-270 also need to be addressed. Any new units to be created during closure to handle remediation activities should be fully described and be in full compliance with applicable unit-specific requirements.

Generally speaking, a plan that adequately addresses all relevant items in [Chapter 3](#), [Chapter 4](#), and [Chapter 5](#) can be considered to meet the closure performance standard. This guidance should be used in the preparation and review of closure and post-closure plans to help determine whether the plan adequately demonstrates that the owner/operator will close or conduct post-closure at the facility/unit in a way that meets the applicable performance standard. The owner/operator is responsible for justifying any deviation from the recommended Chapter 3, Chapter 4 and/or Chapter 5 of this guidance. The most critical items in the closure plan are the remediation standards and their accompanying risk assessment (if appropriate), the sampling plan, and in the case of landfills or units needing post-closure care, isolation of waste from ground water, the cap and cover design, and ground water monitoring and response programs.

In accordance with OAC Rules 3745-66-12(D) and 3745-66-18(F), Ohio EPA is required to complete a review of an Interim Standards closure or post-closure plan within ninety (90) days of receipt.

Numerous documents are available to assist in the review of a closure plan. In addition to U.S. EPA checklists, DHWM has developed [closure Plan Review Forms \(PRF\)](#) for different types of RCRA units to more adequately reflect RCRA closures in Ohio. The PRFs can be used for a general or initial review of a plan. Do not use the PRFs alone to evaluate a closure plan. Reviewers should go beyond the level of detail in a form to address the specific detail in a plan for an individual site. While the CPRG reiterates many points of the PRFs, it also expands upon and explains additional items of concern. Because the CPRG is continually updated, check the DHWM's web site, <http://www.epa.ohio.gov/dhwm>.

1.7 Notice of Deficiency and Director's Approval/Modification/Disapproval Letters

The director of Ohio EPA must “approve, modify or disapprove” the Interim Standards closure or post-closure plan within ninety (90) days of its receipt (OAC Rule 3745-66-12(D)(4) and 3745-66-18(F)). Furthermore, “if the director does not approve the plan he will provide the owner or operator a detailed written statement of reasons for the refusal...” The rule presents the following four options to Ohio EPA:

- (1) Approve the plan as received;
- (2) Modify the plan (*i.e.*, approval with modifications);
- (3) Disapprove the plan; or
- (4) Neither approve nor disapprove the plan but, rather, issue a NOD letter within ninety (90) days of receipt. This is to be followed by the owner/operator's obligation to modify the plan or submit a new plan for approval within thirty (30) days of receipt of the NOD. Ohio EPA must then approve or modify the plan within sixty (60) days of receipt.

The total period of time allowed by OAC Rule 3745-66-12 for review and final action on a closure plan is 180 days. Figure 1-1 also explains the closure plan review process.

In terms of procedure, closure and post-closure plan approvals or modifications (*i.e.*, an approval with modifications) are issued under the director's signature as final actions (appealable to the Environmental Review Appeals Commission) while disapprovals are issued under director's signature as proposed actions (which are appealable before Ohio EPA hearing

examiners). NODs would not be an approval, modification or disapproval and consequently will not need to be characterized as a final or proposed action. Instead, the NODs are letters or correspondences communicate Ohio EPA's comments on the closure or post-closure plan. Since the NOD letters do not contain a statement concerning the approval or disapproval of a closure plan, the NOD letters can be prepared and sent to the facility directly from the reviewer's supervisor.

Notice of Deficiency

In most cases, when an unacceptable plan is received from the owner/operator, a NOD letter from Ohio EPA will be used to communicate the deficiencies to the owner/operator. The NOD letter must be accompanied by a detailed list of plan deficiencies, citing specific rules and rule interpretations, as appropriate, and referenced to specific locations in the text. (Refer to the [DHW's internal web page](#) for the NOD boilerplate letter.) The NOD should identify all items that must be upgraded or corrected in order to gain approval of the revised plan. The burden of preparation of a revised plan is on the owner/operator.

In those instances where the review is conducted jointly with the DO, the DO reviewer will discuss the results of any review with the CO reviewer and resolve any differences prior to releasing the NOD letter.

The NOD letter must specify a time for a response by the owner/operator. Keeping in mind that the standard for many things that Ohio EPA does is the "lawful and reasonable standard," every effort should be made to require an NOD response within 30 days, as required by OAC Rules 3745-66-12 and 3745-66-18. However, in those instances where the number or complexity of NOD comments makes it impossible to respond within the regulatory time frame, the parties can, through mutual agreement and Ohio EPA's enforcement discretion, establish a reasonable time in which to accomplish the needed tasks. For example, if the NOD requires an extensive collection of soil and ground water samples in order to characterize the site and, of necessity, it will take more than 30 days, then a reasonable time should be mutually agreed to in order to allow the tasks to be completed. There is no reason that the Ohio Attorney General's Office (AGO), or any attorney, needs to be involved since the issues are usually technical.⁷ Deadlines can be imposed by the division. However if the owner/operator repeatedly misses a deadline, or is otherwise uncooperative, enforcement action can be taken.

If, in response to an NOD, a revised closure plan (see [Section 1.3, Closure Plan Designations](#)) proposing a fundamentally different means of closure (e.g., risk assessment versus complete excavation and removal) is submitted, the law requires that the "director will approve or modify this plan in writing within sixty days." (See OAC Rule 3745-66-12(D)(4) and 3745-66-18(F)).

Alternatively, nothing in the rules prevent the parties, via mutual consent, from withdrawing the original plan from further consideration and agreeing to submit, by a certain date, a new plan for approval. A withdrawal of a closure or post-closure plan must be a mutually agreed to course of action that would be appropriate when it is virtually impossible for Ohio EPA (while using all reasonable efforts) to meet its review timelines as set forth in the rules. The impossibility should arise from the content or

⁷

The reviewer should exercise judgement on this matter as the AGO should be involved in issues involving closure plans submitted in accordance with a pending enforcement negotiation, a court order or settlement agreement, especially when there are penalties for late or non-responsive performance.

substance contained in a closure plan that is subject to Ohio EPA's review. For example, the submission (in response to an NOD) of a fundamentally different means of closure from a previous submittal may be a situation where withdrawal is warranted. This could involve a different means of treatment or methodology to demonstrate closure by removal. As a discretionary procedure, the decision to withdrawal will depend on whether this approach will result in an overall more timely and efficient review and approval of a closure plan that can ultimately be implemented to a successful conclusion. The new plan should go through the public notice procedures and be subject to the procedural and substantive requirements of OAC Rule 3745-66-12 or 3745-66-18.

Closure and/or post-closure plan reviewers should use standard language for deficiencies whenever possible. The comment should be written in the "owner/operator will provide..." style and contain specific, detailed and clear directives telling the owner/operator what Ohio EPA wants to see in the plan, not just what the plan is lacking or fails to provide. Reviewers should make an effort to communicate to the owner/operator the required content of a closure and/or post-closure plan before plan submittal and also communicate the content of comments that may be in NODs prior to these NODs being sent. A tool the reviewer can use in this regard is the appropriate [closure PRF](#). PRFs may also be used by the owner/operator as an aid in preparing an approvable closure plan.

Technical meetings between the reviewer(s) and the owner/operator and their representatives prior to and after submittal of the plan are encouraged. If the owner/operator disagrees with the deficiencies in the NOD letter or wishes to discuss the comments in greater detail, he/she should contact the CO ERAS staff responsible for the closure plan review as soon as possible. In most cases, basic, fundamental, substantive components of a plan should be required through the NOD process.

Ohio EPA can, and often does, impose modifications through the closure plan approval letter that *become part of the approved closure plan*. In certain instances, it may be necessary to add numerous modifications in order for the requirements of the closure performance standard to be met. Although OAC Rules 3745-66-12(D)(4) and 3745-66-18(F) do not place limitations or restrictions on the type or number of modifications that can be imposed, the number of modifications to the plan should be limited to a reasonable number given the facts surrounding the closure. The situation will determine how many and what type of modifications will be included in the closure approval. For example, if multiple NOD letters were sent and the revisions to a closure plan are not sufficient, this may warrant an approval with substantial and/or many modifications. DHWM staff should consult with their supervisors if they feel it is necessary to recommend a significant number of modifications in order for a closure plan to be approved.

It is essential that the reviewer be explicit and use standard requirements whenever possible in order to get the best response in the revised plan. Again, reviewers and owner/operators are encouraged to communicate with each other as much as possible prior to and after submittal of a plan in order to eliminate any misunderstanding and information gaps.

Approval of the Closure and/or Post-Closure Plan

Approval, modification or disapproval of a closure plan may only be granted by a letter from the director of Ohio EPA. Refer to the [DHWM's internal web page](#) for the most current version of the closure plan approval boilerplate letter. These letters are prepared

by ERAS staff and then sent to the director's office for his/her signature. In preparing approval or approval with modifications letters, reviewers should make sure that the essential or critical parts (e.g., remediation standards and lists of hazardous constituents) of a closure and/or post-closure plan are addressed and documented before or in, and not after, issuance of the director's letter. For example, the approval letter could state that "The owner/operator must notify the appropriate DO of Ohio EPA at least five (5) business days in advance of soil sampling activities so that Ohio EPA may be present to approve sample points." However, an approval letter should avoid, whenever possible, requiring major items (e.g., landfill cover (cap) design, list of constituents to be analyzed, risk assessment calculation methods) to be submitted after issuance of the director's approval or approval with modification letter. It is important to note that the conditions included in the closure plan approval with modifications letter should not be questions. The following general guidelines should be considered when writing additional conditions for an approval with modifications letter:

- Comprehensiveness - are all the pertinent regulations applied to the facility through complete closure plan conditions?
- Protectiveness - if implemented, will the closure plan conditions effectively protect human health and the environment?
- Consistency - do the requirements in the closure plan conditions agree with each other?
- Clarity - do the regulations, facts, and supporting documents provide a clear basis for the closure plan conditions? Are the conditions organized in a manner that makes them readily understandable?
- Technical Soundness - are the overall provisions of the closure plan technically feasible?
- Enforceability - can compliance with the closure plan conditions be ascertained and measured by the inspector?

The reviewer is responsible for reviewing the owner/operator's responses to any modifications contained in a closure plan approval letter to ensure compliance with the closure performance standard.

It is important to note that for Interim Standard closure plans, the closure period begins with the date of the director's approval, not the date the reviewer approves the owner/operator's responses to the approval with modifications letter. Where necessary, the reviewer may require changes to the responses to ensure compliance with OAC Rule 3745-66-12. Delays in reaching a final agreement on the responses cannot be used to delay closure without an extension of time being granted pursuant to OAC Rule 3745-66-13. For more information on extensions to the closure time period, see Section 1.8.

Upon the director's approval or approval with modifications, Ohio EPA issues a public notice of this final action of the director in the "Ohio EPA Weekly Review" and in a newspaper of general circulation in the affected county. The final action may be appealed within 30 days of issuance to the Environmental Review Appeals Commission in accordance with ORC Chapter 3745.

1.8 Closure/Post-Closure Plan Amendments and Extension of Closure Time Period

Owner/operators must make every effort to complete closure as specified in the approved plan within the specified time limit (usually 180 days). If it is not possible to complete closure in the approved time, the owner/operator must request and the director approve an extension to the time allowed for closure under OAC Rule 3745-66-13(B) (or OAC Rule 3745-55-13 for permitted facilities). This typically will not involve an amendment of a closure plan (see discussion below for mechanism/procedure to approve or deny extension of time requests). Note that the director's authority to grant an extension of time is separate from the closure plan amendment authority found in OAC Rule 3745-66-12. However there may be instances where the two authorities will need to be invoked together.

PLEASE NOTE:

The laws on closure and post-closure (OAC Rules 3745-66-12(C) and 3745-66-18(D)) require:

(1) The owner or operator must amend the closure (or post-closure) plan whenever:

(c) In conducting partial or final closure activities, unexpected events require a modification of the closure (or post-closure) plan.

Extensions

Ohio EPA recognizes that occasionally completion within this time period may be impossible due to extenuating circumstances, such as inclement weather or an unexpected event occurring during closure that warrants extension of the closure period. Alternatively, there may be instances where an owner/operator finds it necessary to amend the closure plan because unexpected events encountered during closure require changes in the plan, in addition to requesting an extension of time to complete closure. Amendments to a closure plan are handled under OAC Rule 3745-66-12(C) (or OAC Rule 3745-50-51 for permitted units).

For example, the owner/operator may determine that removal of all contaminated soil is not possible. Within 30 days of the determination, the owner/operator must submit an amended closure plan to the director of Ohio EPA for review and approval when an unexpected event prohibits completion of closure as originally approved. In this instance, the owner/operator may also need to make a request to the director of Ohio EPA for an extension of time allowed for closure under OAC Rule 3745-66-13(B). CO will notify the appropriate DO when an extension request is received but a copy of the request should also be submitted to the DO at the same time it is submitted to the director.

For extensions of time needed to complete closure, the request must *justify* the need for an extension and should *specify* the new completion date. While the owner/operator is waiting for a response from Ohio EPA, they should continue to conduct closure activities as directed by the plan, as appropriate and reasonable in light of circumstances (*e.g.*, defining the full extent of contamination).

In order to determine whether to grant or deny a request for an extension to the closure period, consider the requirements of the rule. According to the relevant portions of OAC Rule 3745-66-13(B), "The director may approve an extension to the closure period if the owner or operator demonstrates, among other things, that:

(1)(a) The partial or final closure activities will, of necessity, take longer than 180 days to complete; . . . and . . .

(2) He has taken and will continue to take all steps to prevent threats to human health and the environment from the unclosed but not operating hazardous waste management unit or facility, including compliance with all applicable Interim Standards requirements.”

If the owner/operator demonstrates that his/her circumstances meet these two criteria, an approval letter can be issued. Conversely, if he/she cannot make this demonstration, a denial letter should be issued. Under this reasoning, an owner/operator who failed to file the extension request in a timely manner (*i.e.*, 30 days prior to the expiration of the 180 day time period) may be recommended for an extension approval if he/she can make the other necessary demonstrations.

Once a decision is made, the proper administrative processing procedure must be used. Denial letters (*i.e.*, a letter denying a request for an extension of time to complete closure) should be issued under the signature of the Division or District Chief or Assistant Chief. The denial of a request for extension of closure is neither a final action nor a proposed action of the director. The denial letters should contain a short statement as to why a denial is appropriate and the letter should not contain appeal rights. Refer to the [DHWM's internal web page](#) for the denial of an extension request boilerplate letter.

Approval letters (*i.e.*, letters approving a request for an extension of time to complete closure) will be issued as final actions under the director's signature. Similarly the approval of an extension request boilerplate letter can be found on the [DHWM's internal web page](#).

In terms of compliance, no rule provision automatically suspends or extends the requirement to close in a timely manner. For example, the subsequent submittal of an amended closure plan alone will not automatically suspend or somehow remove the requirement to close under the originally approved closure plan. Additionally, submittal of an amended closure plan does not exempt the facility from the closure schedule as specified in the approved closure plan. Affirmative action (*i.e.*, director's approval of a request for extension of time required for closure) must be taken by Ohio EPA in order to make such a change.

An owner/operator who has not completed closure activities within the time allotted for closure and has not received an extension approval in accordance with OAC Rule 3745-66-13 is in violation of the regulatory requirement to close in a timely manner and should be notified of such in a notice of violation letter. In terms of enforcement issues, the reviewer should evaluate whether an enforcement referral is necessary using guidance found on [DHWM's internal web page](#).

If the closure project requires major construction, waste treatment, ground water monitoring, etc. and it is known at the time the closure plan is submitted that these activities will require more than 180 days to complete, the owner/operator may request and the director may approve more than 180 days as part of the original approval. To avoid unnecessary processing of subsequent extension requests, owner/operators should be encouraged to be reasonable in their extension requests and allow for contingencies.

Amendments

Any proposed changes to an approved closure and/or post-closure plan should be discussed with an Ohio EPA representative before they are attempted. All changes made to an approved closure and/or post-closure plan are *amendments*. OAC Rules 3745-55-12(C), 3745-55-18(D), 3745-66-12(C) and 3745-66-18(D) direct the owner/operator to

submit and the Agency to evaluate all proposed amendments using the criteria promulgated in OAC Rules 3745-50-51 and 3745-50-52.

For cases requiring an amended plan, such as when a closure by removal is changed to a waste in place closure, an owner/operator subject to Interim Standards, must submit a detailed plan describing all necessary activities to comply with the closure performance standards and appropriate closure and post-closure rules (OAC Rules 3745-66-10 through 3745-66-20, and any applicable OAC Rules 3745-54-90 through 3745-54-101). Interim Standards post-closure plans may also be amended to contain the more comprehensive ground water monitoring and response program found in the General Facility Standards, if necessary.

For Interim Standards closure and/or post-closure plans, it should be determined if a proposed change or amendment would constitute a Class 2 or Class 3 type of modification according to the criteria in OAC Rule 3745-50-51. Proposed changes that would constitute a Class 2 or 3 modification are required to be processed following the formal decision-making procedure culminating with a director's action as set forth in OAC Rule 3745-66-12(D)(4) or 3745-66-18(F). They will be reviewed and processed in CO-ERAS. Minor amendments consistent with Class 1 type of modifications may be authorized directly, in writing, by the DO Chief or Assistant Chief. (Refer to the [DHWM's internal web page](#) for the boilerplate letter.) Finally, in every instance the director has the regulatory authority to, with cause, request an amendment to a closure and/or post-closure plan in accordance with OAC Rules 3745-66-12(C)(4) and 3745-66-18(D)(4), respectively.

Any permitted facility contemplating undergoing full or partial closure in a manner inconsistent with the approved closure and/or post-closure plan must submit a request for a permit modification to:

Director of Ohio EPA
c/o DHWM, Regulatory and Information Services Section
Attention: Manager
P.O. Box 1049
Columbus, Ohio 43216-1049.

Changes to closure and/or post-closure plans for permitted facilities are to be handled in accordance with the permit modification requirements of OAC Rules 3745-50-51, 3745-55-12(C), and 3745-55-18(D). The approved modified plan will then become a condition to the Ohio hazardous waste permit. Finally, in every instance the director has the authority to, with cause, request a modification to a closure and/or post-closure plan in accordance with OAC Rules 3745-55-12(D) and 3745-55-18(D)(4), respectively. Refer to the [DHWM's internal web page](#) for the most current guidance on permit modifications.

For more information on closure and/or post closure plan amendments and extension of the closure time period, refer to OAC Rules 3745-66-12, 3745-66-13, and 3745-66-18 for Interim Standards and OAC Rules 3745-55-12, 3745-55-13, 3745-55-18 and 3745-50-51 for Part B permitted facilities.

1.9 Completion of Closure and/or Post-Closure Care

Completion of Closure

The “completion of closure” phrase, as used in OAC Rules 3745-55-15, 3745-55-17, 3745-66-15, and 3745-66-17, does not include the receipt and/or approval of the certification documents that must be submitted to Ohio EPA. The phrase “completion of closure” refers more to the owner/operator’s view of the closure activities (thus triggering the certification process) than to Ohio EPA’s concurrence that closure has been completed in accordance with the approved closure plan. As used here, “completion of closure” means that the activities included in the approved closure plan have finally been completed and this serves to trigger both the submission of the closure certification as well as the commencement of post-closure care requirements. In other words, post-closure care activities begin immediately following the completion of approved closure activities.

Facilities closing units with waste in place must begin post-closure care once “completion of closure” (in accordance with the approved closure plan) has occurred. Such a facility may begin post-closure care activities prior to submitting the certification of closure to Ohio EPA because post-closure care activities are triggered by “completion of closure” and not the submission of closure certification statement or Ohio EPA’s acceptance of that certification. Generally, if it is known that a unit will likely need to be closed with waste in place, a post-closure plan should be included with the initial closure plan submitted for review and approval.

Certification of Completion of Closure

OAC Rules 3745-55-15 and 3745-66-15 require the submission of a closure certification “(w)ithin sixty days of completion of closure of each hazardous waste surface impoundment, waste pile, land treatment, landfill unit, and storage area, and within sixty days of completion of final closure.” The certification should be sent to the director, by registered mail, certifying that the hazardous waste management unit or facility, as applicable, has been closed in accordance with the specifications in the approved closure plan. All closures of hazardous waste management units must be certified by both the owner/operator and an independent registered professional engineer licensed (or otherwise authorized; see ORC Section 4733.18) to practice in the state of Ohio. The registered professional engineer must be independent, meaning he/she cannot be directly employed by the owner/operator’s corporation or any of the corporation’s subsidiaries.

If an owner/operator has closed a hazardous waste disposal unit, then in accordance with OAC Rules 3745-55-16 and 3745-66-16, they must submit to the local zoning authority, or the authority with jurisdiction over local land use, and the director, a survey plat indicating the location and dimensions of landfill cells or other hazardous waste disposal units with respect to permanently surveyed benchmarks. This survey plat must be submitted no later than the submittal of the certification of closure. The survey plat must be prepared and certified by a professional land surveyor. Lastly the survey plat must contain a note, prominently displayed, which states the owner/operator’s obligation to restrict disturbance of the hazardous waste disposal unit in accordance with the applicable provisions in OAC Rules 3745-55-10 through 3745-55-20 or OAC Rules 3745-66-10 through 3745-66-21.

Additionally, if an owner/operator is closing a hazardous waste disposal unit, then in accordance with OAC Rules 3745-55-19 and 3745-66-19, they must submit to the local zoning authority, or the authority with jurisdiction over local land use, and to the director, a record of the type, location, and quantity of hazardous waste disposed of within each cell or other disposal unit of the facility. This record must be submitted no later than sixty days after the certification of closure of each hazardous waste disposal unit. Also, within sixty days of certification of closure

of the first hazardous waste disposal unit and within sixty days of certification of closure of the last hazardous waste disposal unit, the owner/operator must:

- (1) Record a notation on the deed to the facility property which is normally examined during a title search, that will notify in perpetuity the potential purchasers of the property that the land has been used to manage hazardous wastes, its use is restricted, and that the survey plat has been filed with the local zoning authority and the director; and
- (2) Submit a certification, signed by the owner/operator, that he has recorded the notation, including a copy of the document in which the notation has been placed, to the director.

Review of Closure Certification and Post-Certification Inspection

Although a facility may often be inspected by Ohio EPA prior to or during closure of a unit, Ohio EPA practice also requires an inspection of the closed hazardous waste management unit at the completion of all closure activities or when a closure certification is received from the owner/operator. ERAS will send a courtesy e-mail memo to the DO requesting the post-certification inspection and a review of the received certification document. Refer to the [closure certification PRF](#) when reviewing the certification.

The post-certification inspection must be documented. The documentation should describe, at a minimum, the date of the inspection, appearance of the area of the closed unit(s), review of documents such as manifests, environmental measures (*i.e.*, amount of waste generated, shipped off-site, closed in place, etc.), status of facility after closure (Treatment, Storage, or Disposal Facility (TSDF), Large Quantity Generator (LQG), Small Quantity Generator (SQG), etc.) and any other relevant factors. The reviewer (inspector) should determine as part of the review of the closure certification whether, to the best of his/her knowledge, the unit(s) has been closed in accordance with the approved closure plan and all appropriate hazardous waste rules and document that conclusion. The DO will then issue a letter to the facility acknowledging successful completion of closure activities. Refer to the [DHWM's internal web page](#) for the boilerplate letter. However if the reviewer does not agree with the certification documents, appropriate action, including possible referral for enforcement, should be taken immediately. Refer to DHWM's internal web page for available options and procedures.

Post-Closure Care Period

OAC Rule 3745-66-17(A)(1) states the following, "(p)ost-closure care of each hazardous waste management unit subject to the requirements of rules 3745-66-17 to 3745-66-21 of the Administrative Code must begin after completion of closure of the unit and continue for thirty years after that date."

The post-closure care period continues for thirty years after completion of closure, unless otherwise shortened or extended. The petitioning process for Interim Standards outlined in OAC Rule 3745-66-18(G), as well as the post-closure plan amendment procedure in OAC Rule 3745-66-18(D), create avenues to extend or reduce the post-closure care period. Similarly OAC Rules 3745-50-51 and 3745-55-18(D) outline the procedures for extending or reducing the post-closure care period for permitted facilities.

Post-closure care should continue to the extent it is necessary to protect human health and the environment from potential migration of hazardous waste from the unit at levels harmful to human health or the environment regardless of whether the actual time length is more or less than 30 years. Information to consider includes leachate or ground water monitoring results, characteristics of hazardous wastes present, application of advanced technology, alternative disposal, treatment, or re-use techniques, or other data that would tend to indicate whether or not the facility is secure from potential migration of hazardous waste at harmful levels.

It is important to note though, before the end of the post-closure period, Ohio EPA should make a separate determination on whether post-closure care is required to continue for a facility. To do this, Ohio EPA should use its authority to request existing post-closure plans be modified to include a re-opener condition in the post-closure plan requiring the owner/operator to present a demonstration in year 28 of the post-closure care period that continued post-closure care is not likely to be required after year 30. Ohio EPA would also need to include such a re-opener in all post-closure plan (and post-closure permit) approvals. For owner/operators not willing to agree with such a re-opener, a post-closure permit and use of the omnibus authority could be appropriate means to continue needed post-closure care activities.

Certification of Completion of Post-Closure Care

OAC Rules 3745-55-20 and 3745-66-20 require the submission of a certification of completion of post-closure care “(n)o later than sixty days after the completion of the established post-closure care period for each hazardous waste disposal unit.” The certification is sent to the director, by registered mail, certifying that the post-closure care period for the hazardous waste disposal unit was performed in accordance with specifications in the approved post-closure plan. All certifications must be signed by both the owner/operator and an independent registered professional engineer licensed, or otherwise authorized to practice, in the state of Ohio (see ORC Section 4733.18).

Review of Post-Closure Certification

The certification of completion of the post-closure care period focuses on whether the post-closure activities were performed in accordance with the approved post-closure plan not whether the post-closure care period should continue. Verification of this certification can be accomplished in a manner very similar to the verification process used to accept closure certifications.

Permit Withdrawal

Once a permitted hazardous waste management unit has completed closure and post-closure, if necessary, and Ohio EPA has accepted the certification(s) from the facility, then the owner/operator should submit a permit modification requesting the closed unit be removed from the permit. Permit modifications removing units that have closed are not granted by Ohio EPA until certification of closure is received and accepted.

When Ohio EPA has accepted the final facility closure certification and post-closure certification, if necessary, and has determined that the facility has fulfilled their corrective action obligations under OAC Rules 3745-54-100 and 3745-54-101, then the owner/operator should submit a permit withdrawal request in accordance with OAC Rule 3745-50-47.

Ohio EPA charges each owner/operator a hazardous waste permit fee for each type of hazardous waste management unit on a graduated scale, according to OAC Rule 3745-50-36. Obviously, since fees are assessed for each type of RCRA unit, it is imperative that the owner/operator submit permit modification or withdrawal requests in a timely manner to avoid additional charges for units with certified closures. The fee system is detailed in OAC Chapter 3745-50.

1.10 Generator Closure

Because generator management⁸ practices vary from facility to facility, how a generator will meet the closure performance standard will also vary. OAC Rule 3745-52-34 requires that the generator meet the closure performance standard of OAC Rule 3745-66-11, as well as the applicable disposal or decontamination requirements of OAC Rule 3745-66-14. However, OAC Rule 3745-52-34 also specifically exempts certain generators from the rule requirements regarding time allowed for closure, having a written closure plan, certification of closure, cost estimates for closure, and financial assurance for closure. Further OAC Rule 3745-52-34 does not impose an obligation or duty on Ohio EPA to approve the closure measures either before or after the generator closure activity takes place.

The generator closure process is self-implementing. Generators should be aware of the closure performance standard, the requirements of OAC Rule 3745-52-34 and make a good faith effort to meet that standard. The law then presumes that the standard has been met. There is no pre-existing legal requirement that a generator submit a certification as a step in the process of demonstrating that the closure performance standard is met. Ohio EPA would have the burden of demonstrating that the generator did not in fact meet the closure performance standard.

Ohio EPA recommends that generator accumulation areas (particularly hazardous waste accumulation areas which are comprised of or are located directly on soil) be closed as soon as possible in order to avoid future problems. If a generator decides not to close an accumulation area when it is no longer used to store hazardous waste, any future contamination, which occurs in that area, may be attributed to the accumulation of hazardous waste. The longer a generator waits to close a hazardous waste accumulation area, the more complicated the closure may become due to the possibility of contamination spreading into or out of the unit. Therefore, in the best interest of the generator and the environment, the accumulation area should be closed as soon as possible when hazardous wastes are no longer managed in the area.

If a generator has conducted activities that would constitute treatment, storage or disposal practices in the accumulation area without a hazardous waste permit, the generator closure rules do not apply to the closure of the accumulation area because of the unlawful treatment, storage and/or disposal of hazardous waste. Under such circumstances, the generator would be subject to and may be required to close the hazardous waste management unit in accordance with the requirements of OAC Chapter 3745-66. A generator that needs information regarding formal closure should consult later chapters of this guidance document and his/her DO DHWM contact.

Requirements for Generator Closure⁹

Container Storage Areas - Impermeable Surface (sealed pads)

- (a) If the container pad has not had any leaks or releases to it from containers of hazardous waste, and this fact can be corroborated by inspection logs for the life of the pad as a hazardous waste accumulation area, then this type of pad can be

⁸ Certain generators who treat or store hazardous waste are subject to closure, but when a generator handles other regulated materials, they may be subject to the Cessation of Regulated Operations (CRO) Rules under [OAC Chapter 3745-352](#). Visit DHWM's web-site for more information on complying with the [Generator Requirements](#) and the [CRO Rules](#).

⁹ All final generator closure decisions are left to the inspector's best professional judgment. This guidance is to assist inspectors on how to handle different generator closure situations.

closed with a signed statement by the generator of the facility stating there have not been any releases of hazardous waste to this pad. The log and statement would be reviewed by the inspector and documented on the generator closure portion of the Large Quantity Generator (LQG) checklist.

- (b) If there have been leaks or releases to the pad, or it cannot be corroborated that no leaks, spills or releases have occurred, then the generator should compile detailed documentation of the decontamination and/or removal process(es) that were conducted to meet the closure performance standard. The generator can then provide a statement that the closure performance standard was met per the procedures mentioned directly above in (a).

Container Storage Areas - *Potentially Permeable Surface (e.g. Concrete Pads)*

- (a) If the generator provides documentation equivalent to that described above in (a) for impermeable surfaces, then the accumulation area may be closed using those same procedures. To satisfy any doubts the inspector has, sufficient photo and written documentation (including but not limited to physical descriptions and drawings of the accumulation area) attesting to the structure's pre-accumulation condition should be available to compare with the physical description after the generator has finished accumulating hazardous waste in that area. This can be done either by the inspector during an inspection or done by the generator prior to storing any hazardous waste on the pad.
- (b) If a spill occurred in the accumulation area and there were no constituents of concern released that could potentially permeate the pad/floor (e.g., concrete pad), then the generator can follow the guidance described above in (b) for impermeable surfaces.

Container Storage Area with Permeable Surface or Located on Soil

If a generator has stored containers of hazardous waste on either one of these types of accumulation areas, it is recommended that the generator close the unit per applicable portions of this guidance document and maintain detailed documentation that the closure performance standard was met.

Tank Systems

Generators storing in tank systems must meet the closure requirements of OAC Rule 3745-66-97(A) and (B). This may include following the decontamination ([see Section 3.10, Decontamination Efforts](#)) procedures in this guidance document as a means of meeting the closure performance standard in OAC Rule 3745-66-11(A) and (B) and demonstrating compliance with the Disposal or Decontamination of Equipment, Structures and Soils requirement in OAC Rule 3745-66-14.

Generators utilizing hazardous waste tank systems that do not have adequate secondary containment are recommended to follow the closure procedures listed above for containment areas to close out the pad/foundation/soil on which the tank system is located. If the generator does have adequate secondary containment in the form of a liner or vault, the requirements to close these structures would be to follow the requirements presented above in (a) and (b) for impermeable surfaces. Closure of tanks with double walls would not need to follow the guidance presented above for containment areas as long as the secondary containment was never breached.

Prior to determining that the closure performance standard has been met, generators utilizing hazardous waste tank systems that have secondary containment installed during the life of the system are recommended to properly assess the area that may have been exposed to possible releases from the tank system prior to installing the secondary containment. If the generator's findings sufficiently demonstrate that there were not any releases from the tank system, then only the installed secondary containment and tank system would have to be closed in accordance with the tank closure requirements.

However, if the generator demonstrates that not all contaminated soils can be practicably removed or decontaminated or meet risk goals found in later chapters of this guidance document, then OAC Rule 3745-66-97(B) requires a generator to perform closure and post-closure in accordance with requirements that apply to landfills in OAC Rule 3745-68-10. Guidance for this type of closure and post-closure can be found in [Chapter 5, Components for Waste in Place Closure Plans, Post-Closure Plans and Certifications](#).

Chapter 2

Other Cleanup Programs

While working on closures of hazardous waste management units, staff may encounter the requirements of broader state cleanup programs such as RCRA Corrective Action, Clean Ohio Fund, and the Voluntary Action Program (VAP).

2.1 RCRA Corrective Action Program

Most frequently encountered by DHWM staff, the RCRA Corrective Action program investigates and remediates waste management units (WMUs) on a site-wide basis, as necessary, which are typically permit or order driven. Unlike the closure process, which provides two options (closure by removal and closure with waste in place), the Corrective Action process provides considerable flexibility to Ohio EPA to choose a remedy that reflects the conditions and the complexities of each facility. For example, depending on the site-specific circumstances, remedies may attain media cleanup standards through various combinations of removal, treatment, and engineering and institutional controls.

Where a collection of adjacent WMUs and a hazardous waste management unit undergoing closure are releasing hazardous constituents to the environment, two separate remedial processes would apply to the cleanup of the respective releases. Many times, the regulatory distinction between the WMU and the closure unit cannot be maintained because unit boundaries overlap, contaminant plumes are commingled, or it is difficult to identify the exact source of the contamination. The post-closure rule (previously discussed in [Section 1.1, Rules Associated with Closure and Post-Closure Plans](#)) developed by U.S. EPA, and effective in Ohio as of December 7, 2004, addresses this situation by allowing the hazardous waste management unit to be addressed under Corrective Action. This rule allows the regulating agency to choose whether to apply current 40 CFR Parts 264 and 265 (or OAC Chapters 3745-54 to 3745-205 and 3745-65 to 3745-256) to hazardous waste management units closed as a part of a broader Corrective Action or to address them through the Corrective Action cleanup requirements. However this rule was not intended as a way to bring WMUs under the unit-specific closure standards. For more information on RCRA Corrective Action, DHWM staff should refer to the [DHWM's internal web page](#), while owner/operators and the general public should refer to DHWM's web site at <http://www.epa.ohio.gov/dhwm>.

2.2 Corrective Action Management Unit (CAMU) Rule

This rule, which is part of a larger body of rules and policies¹ used to address the special circumstances of hazardous cleanup (or remediation) wastes, is designed specifically for hazardous wastes managed while implementing cleanup. U.S. EPA felt this rule was needed in order “to remove the disincentives to cleanup that the application of RCRA to these wastes can sometimes impose.”² Since, for a given site, the rules on the management of cleanup waste must apply at the same time as the rules for the closure of RCRA units, overlap is quite possible. Obviously, for the overall goal of protective and effective cleanups to be maintained, Ohio EPA staff must be prepared to interact with or coordinate the two approaches to cleanups. Fortunately, the Corrective Action Management Unit (CAMU) rule provides for inclusion of a closure unit into a CAMU, as long as the applicable post-closure rule requirements are met.

¹ In general, refer to U.S. EPA's (1998) *Management of Remediation Waste Under RCRA*.

² Federal Register: January 22, 2002 (67 FR 2962)

The CAMU rule³ establishes standards defining which hazardous wastes are eligible for placement into a CAMU. The rule further creates design and treatment standards for waste management which differ slightly from the minimum technology standards for land disposal units and the treatment standards under the Land Disposal Restrictions. Like the post-closure rule, the CAMU rules, which are OAC Rules 3745-57-70 through 3745-57-75, became effective in Ohio EPA on December 7, 2004.

Generally, waste managed during the closure of a non-permanent unit (such as a container or tank storage unit) will not be eligible for placement into a CAMU because removal is a part of the “operating life cycle of the unit.”⁴ Wastes removed from a closed or closing land disposal unit (landfill or surface impoundment) are CAMU eligible because the waste is managed for implementation of cleanup.

Staff should be aware of the distinction between removal of waste from a closed or closing unit for placement into a CAMU and incorporation of a unit into a CAMU. U.S. EPA’s position that wastes removed from non-permanent land-based units are generally not CAMU eligible does not preclude incorporation of such units into a CAMU under appropriate circumstances (see OAC Rule 3745-57-72(B)). As with any hazardous waste management unit that is incorporated into a CAMU, the ground water protection standard, closure and post-closure, financial assurance requirements and the unit specific requirements⁵ that applied to the hazardous waste management unit will continue to apply to that portion of the CAMU (*i.e.*, the portion encompassing the former hazardous waste management unit) after incorporation into the CAMU (see OAC Rule 3745-57-72(B)). Under the requirements of the post-closure rule, however, the director may defer any of these standards to the facility’s Corrective Action requirements, if certain conditions are met. These conditions may include, most importantly, that the hazardous waste management unit is situated among waste management units or areas of concern, a release has occurred, and the hazardous waste management unit and the waste management units or areas of concern are likely to have contributed to the release.

More information about the CAMU rule is available in the following Federal Registers: January 22, 2002 (67 FR 2962 (final rule)); August 22, 2000 (65 FR 51080 (proposed rule)); and November 20, 2001 (66 FR 58085 (supplemental proposed rule)), which can be found online at <http://www.epa.gov/fedrgstr/>.

2.3 Clean Ohio Fund

Another program that DHWM staff may encounter is Ohio’s recently adopted brownfield cleanup funding program known as the Clean Ohio Fund. It was approved by voters in 2000 and became law as House Bill 3 of the same year. It provides four competitive funds which serve to preserve green space, retain farmland, create recreational trails, and clean up brownfields and return them to productive use.

Through an elaborate screening process (implemented by integrating committees or executive committees of integrating committees), selected applications are forwarded to the Clean Ohio Council which must approve or disapprove, in writing, applications for grants or loans from the Clean Ohio Revitalization Fund. The council is prohibited from approving a project that fails to

³ Federal Register: January 22, 2002 (67 FR 2962)

⁴ Federal Register: January 22, 2002 (67 FR 2962)

⁵ OAC Rules 3745-54-90 through 3745-54-101, OAC Chapters 3745-54 to 3745-57 and 3745-205, and OAC Chapters 3745-65 to 3745-69 and 3745-256, respectively.

comply with the requirements established under ORC Section 122.65.8 and policies and requirements established under ORC Section 122.65.7. The council also must not approve a project if the applicant caused or contributed to the contamination at the property (refer to ORC Section 122.65.3).

Ohio EPA assists the Ohio Department of Development (Ohio DOD) with the management of the Clean Ohio Revitalization Fund (CORF) and the Clean Ohio Assistance Fund (COAF). Ohio EPA staff provide technical assistance to applicants during the application process and project implementation, assist in the review of applications with regard to proposed remedies and applicable standards, and review completed cleanups for compliance with applicable standards.

Clean Ohio Fund and DHWM

The Clean Ohio Fund (COF) requires that applicants include a completed Applicable Regulatory Program Statement (ARPS) from Ohio EPA in their application indicating what regulatory programs apply to the site. Therefore the following streamlined procedure was developed to provide COF applicants with this statement in a timely manner. The goal is to issue the ARPS to the applicant within thirty days after receipt of their ARPS Request Form.⁶ The procedure will also apply to and be available for Voluntary Action Program (VAP) eligibility determinations even if the requester is not planning to apply for COF funding.

Potential COF applicants will request an ARPS by submitting a completed ARPS Request Form to the Site Assessment and Brownfields Remediation (SABR) Section in the Division of Emergency and Remedial Response (DERR). The SABR Section will log in the request and track its progress. The ARPS Request Form will be sent to Ohio EPA Legal for assignment to a DERR attorney. If the form indicates potential RCRA hazardous waste management applicability, then the DERR attorney will forward it to a DHWM attorney.

The DHWM attorney will hand-deliver three copies of the submitted ARPS Request Form to DHWM's COF contact in CO for review. The CO-DHWM COF contact will ensure that a copy of the submitted form is faxed to the appropriate DO DHWM manager, who will then assign a staff member to work with CO-DHWM and the assigned DHWM attorney in reviewing the form. CO-DHWM and the DO staff will review all available DHWM CO and DO records in conjunction with the assigned attorney and discuss the results of their collective review. Input from other DHWM personnel will be sought as necessary. Once the review is complete and an agreement is reached on the findings, the CO-DHWM COF contact will e-mail the findings to the assigned DHWM attorney. This information is then incorporated into the final ARPS issued by Ohio EPA through the SABR section. Copies of the ARPS are provided to the DHWM staff and attorneys who were involved.

Brownfields With Units Subject to Closure

For brownfields containing units subject to hazardous waste closure requirements under ORC Chapter 3734, an applicant for closure funding must include, with the application, a cleanup plan that is consistent with [Chapter 3](#) of this guidance, including a description of the facility, map of the facility, description of the hazardous waste management unit to be closed, detailed drawing of the unit to be closed, list of hazardous waste, and sampling and analysis of environmental media. The cleanup plan must be designed to

⁶ The ARPS request form can be found on Ohio EPA, Division of Emergency and Remedial Response's (DERR) web page at http://www.epa.ohio.gov/derr/SABR/ohfund/required_forms.aspx.

achieve the objectives of a closure by removal or a risk-based closure as described in this guidance. A closure cost estimate developed pursuant to OAC Rule 3745-66-42 must also be included with the application. The cleanup plan and the closure cost estimate must be included with the application at the time the application is filed at the library to satisfy the COF public participation requirements. If funded, the applicant must prepare, submit for approval by the director of Ohio EPA, and implement a closure plan that is consistent with OAC Chapter 3745-66 and this guidance.

If an applicant has a closure plan that has been approved by the director of Ohio EPA, the approved closure plan must be included with the application at the time the application is filed at the library. If funded, the applicant must implement the applicable portions of the approved closure plan in accordance with applicable rules adopted under ORC Chapter 3734 and applicable Ohio EPA guidance.

For brownfields subject to generator closure requirements under OAC Rule 3745-52-34 and OAC Chapter 3745-66, an applicant for generator closure funding must include, with the application, a cleanup plan for each generator accumulation area which should be sufficient to support and justify the selection of a closure that is consistent with [Section 1.10, Generator Closure](#), of this guidance. If funded, the applicant must implement the closure in accordance with OAC Rule 3745-52-34 and Section 1.10 of this guidance.

DHWM Review of Applications Forwarded by the Public Works Integrating Committees to the Clean Ohio Council

CO-DHWM will forward the package to the appropriate DO DHWM supervisor to review the portion of an applicant's cleanup plan that addresses the closure unit. When DO resources or priorities do not allow the plan to be reviewed within the necessary time frame, CO-DHWM will then task one staff member (and designate a backup) in DHWM's CO ERAS to review the information. This guidance document should be used as a reference to review that portion of the application to determine if the unit was identified and addressed properly in terms of the type of closure the applicant proposes to perform. The assigned staff person will consult with DHWM financial assurance staff to determine if the estimated cost of the unit's closure is realistic in terms of the type of closure to be performed.

The assigned DO or ERAS staff member will provide the results of his/her review to DHWM's Chief. DHWM's Chief will brief the SABR Section in writing on the substance of the review.

DHWM Review of Completion of Cleanup

It is the responsibility of the recipient of Clean Ohio funding to determine if the property cleanup was protective of human health and the environment (*i.e.*, if the project was successfully completed) within the time period designated by the Clean Ohio Council. Once the cleanup of the hazardous waste management unit that was the subject of the closure plan approval is completed pursuant to the schedule contained in the approved plan, the recipient must submit to the director a certification that the unit was closed/cleaned up in accordance with the specifications in the approved plan (see OAC Rule 3745-66-15). The certification must be signed by the recipient and by an independent, registered professional engineer.

The DHWM DO staff person who reviewed the closure plan and recommended its approval will be assigned the task of reviewing the closure certification. The staff person will work directly with the recipient if revisions to the certification are needed. The results

of his/her review will then be provided to DHWM's Chief. DHWM's Chief will brief the Brownfield and Cleanup Oversight Program in writing on the results of the review.

Further information on the Clean Ohio Fund can be found at <http://www.clean.ohio.gov/>.

2.4 Ohio Voluntary Action Program

Ohio's Voluntary Action Program (VAP) was created in September 1994 with the passage of Senate Bill 221, the implementing legislation for the program. The VAP was fully implemented by Ohio EPA, DERR in early 1997. The program was created to give companies a way to investigate possible environmental contamination, clean it up if necessary and receive a promise from the State of Ohio that no more cleanup is needed.

If someone wants to clean up a piece of property, it may be done following specific standards developed by DERR. If done according to these standards, the company can ask Ohio EPA to release the owner (volunteer) from the responsibility to conduct further investigation and cleanup. When a certified professional, such as a scientist or engineer certified by Ohio EPA, believes that a site has been investigated and, if necessary, cleaned up to the standards contained in the VAP rules (OAC Chapter 3745-300), he or she can prepare what is called a No Further Action (NFA) Letter. This document, which must be submitted in a prescribed format developed by VAP, describes the environmental problems found at the site, how those environmental problems were investigated and how the site was cleaned up. If the volunteer wants a legal release from Ohio, then the certified professional submits the NFA letter to Ohio EPA for review. When a NFA letter is received by Ohio EPA, DERR technical staff review the document to determine if all of the standards (*i.e.*, investigation and cleanup rules contained in OAC Chapter 3745-300) have been met and then accordingly issue or deny the covenant not to sue.

As originally designed, compliance with the VAP and a covenant not to sue gave the volunteer no assurance that U.S. EPA would not later seek additional cleanup. In order to provide such assurance, Ohio EPA and U.S. EPA entered into a Memorandum of Agreement (MOA) in 2000, specifying additional measures needed to raise the Ohio VAP program to meet the federal needs. The primary differences between the Ohio VAP (or classic VAP) and the MOA Track VAP are that investigation and cleanup activities of the MOA Track VAP projects will be overseen directly by Ohio EPA personnel and include opportunities for public review and comment of site documents as they are produced by the cleanup volunteer.

Not every property can take advantage of VAP. Properties subject to federal or state corrective action through current permit obligations or enforcement orders are ineligible for VAP. However those facilities that are subject to RCRA corrective action but have not yet been issued a permit or an order requiring corrective action, are eligible for VAP. However, any portion of a property where closure of a hazardous waste management unit is required under ORC Chapter 3734 is ineligible for VAP, regardless of whether a closure and/or post-closure plan has been approved.

For more information regarding the Voluntary Action Program, refer to DERR's web site at <http://www.epa.ohio.gov/derr/volunt/volunt.aspx>.

Chapter 3

Required Components of All Closure Plans

There are several elements that should be included in a closure plan, regardless of the type of closure that is to be performed (see OAC Rules 3745-55-12 and 3745-66-12). This chapter outlines this expected content for all closure plans. The closure plan should be of sufficient detail to address all appropriate items in the rules, including the closure performance standard in OAC Rules 3745-55-11 and 3745-66-11 and it should be able to be comprehended by the public. A closure plan should also be written in such detail that an outside, third party contractor could make an accurate bid to provide the services required. The [plan review forms \(PRFs\)](#) mentioned throughout this guidance can be used to assist in the preparation and review of closure plan, post-closure plan, and/or certification content.

The reviewer should be aware that [Chapter 5](#) outlines the components of a closure certification. After completion of all partial and full closures, an owner/operator is required to submit a certification stating that the closure was completed in accordance with the approved plan. The closure plan reviewer should verify that a statement acknowledging this requirement is included in the closure plan. The closure plan reviewer should also be aware of these requirements and determine whether or not they are achievable based on the closure plan that is submitted.

3.1 Description of Facility

The plan should include details on the type of industry, products, location, size and other general, summarized information. This does not have to be an extensive description. Processes or activities which generate and manage hazardous waste should be described, especially those processes related to the hazardous waste management unit (unit) under-going closure.

3.2 Maps of Facility

The facility's geographic location should be provided on a clearly legible topographic (U.S. Geological Services 7.5 minute) or county map. A more detailed map (with a scale of no more than 1 inch = 200 feet) or diagram of the facility, with each hazardous waste management unit and ground water monitoring well(s) clearly located and identified, should also be included in the closure plan. All maps and diagrams should provide a specified scale, legend, and north arrows.

3.3 Description of Hazardous Waste Management Unit to be Closed

The closure plan must describe each hazardous waste management unit (e.g., storage area, tank, waste pile, surface impoundment, landfarm, landfill cell, incinerator, boiler or miscellaneous unit) individually. The description should include:

- waste types for each unit (by standard chemical name and U.S. EPA hazardous waste number),
- period of use,
- dimensions, construction details (e.g., materials, as-built drawings, etc.), and other structures associated with the unit (e.g., secondary containment),
- possible releases,
- topography,
- soil types (as appropriate),

- geologic and hydrogeologic information (as appropriate), and
- any other relevant matters.

The closure plan should also specify which units are to be closed (partial closure or final closure).¹ In the instance of a permitted facility, the closure plan in the Part B permit application should identify these units by reference to line numbers in the Part A portion of the application. For facilities operating under an Interim Standards Part A permit, closure plans should address the units in the Part A permit that are being closed. Plans for final closure should address all units in the Part A or Part B permit.

In addition to specifying the units covered by the submitted closure plan, the closure plan should also specify all hazardous waste management units subject to a hazardous waste permit which will remain unclosed and are not covered by the submitted closure plan.

3.4 Detailed Drawing of Hazardous Waste Management Unit to be Closed

The closure plan should include a sketch, diagram or blueprint drawing of the hazardous waste management unit(s), showing, at a minimum, dimensions and other construction details, appurtenant structures and relationship to other significant points or structures on the facility property. Blueprint drawings of landfill cells should also be provided. Again, drawings should provide a specified scale, legend, and north arrows.

3.5 List of Hazardous Waste

To meet the closure performance standard, the closure plan must include a complete detailed list of hazardous wastes and associated hazardous constituents (chemical name, EPA hazardous waste number, if applicable, and Chemical Abstracts Service Registry Number) treated, stored or disposed of at the hazardous waste management unit. Trade names should not be used; common, or preferably International Union of Pure and Applied Chemistry (IUPAC), chemical names should be given. Knowledge and/or sampling of the waste stream should be used to clearly indicate a waste's hazardous constituents (including the constituents that caused the waste to be corrosive, reactive, toxic, or ignitable). Because this list is the basis for all soil, ground water, and solid waste sampling, as well as the derivation of risk-based remediation standard(s), the list of hazardous waste should identify all hazardous constituents listed in the Appendix to OAC Rule 3745-51-11 associated with the wastes managed in the unit(s) undergoing closure. Along with the types of waste managed in the unit, the methods used to characterize the waste should also be included in the closure plan.

OAC Rules 3745-55-12 and 3745-66-12 require an estimate of the maximum inventory of waste ever on-site, at one time, in storage or treatment over the active life of the facility for each unit. In addition, the closure plan should include an estimate of the inventory of hazardous waste that will be present when closure begins. Inventories should be broken down by waste code.

3.6 Management of Waste

The closure plan should also specify the methods for handling hazardous waste, such as:

- Removal of waste and contaminated media, including the type of equipment and removal protocol, where appropriate (e.g., removal may not be necessary for landfill closures);

¹ Refer to [Chapter 9, Glossary](#) for the definition of partial closure and final closure.

- Staging, loading, and transportation of waste and contaminated media;
- Storage, treatment and disposal; and
- Land disposal restriction (LDR) status of each waste stream relative to treatment and disposal.

For off-site management, the plan should specify the type of facility each waste is expected to be sent to and the reviewer should verify the appropriateness of the proposed management. The reviewer may request to be informed in advance of shipments to off-site facilities and may also request verification of these shipments (e.g., hazardous waste manifests). Figure 3-1 generally describes the appropriate methods for hazardous waste management.

The contained-in policy, formulated by U.S. EPA, states that environmental media (*i.e.*, surface water, ground water, soil, and sediment) is defined as a hazardous waste and subject to regulation under the hazardous waste rules if it is contaminated with a listed hazardous waste or exhibits a hazardous waste characteristic. DHWM may determine that contaminated media no longer contains a hazardous waste on a case-by-case basis and in coordination with guidance provided by DHWM's CO.

Determining How to Handle Wastes

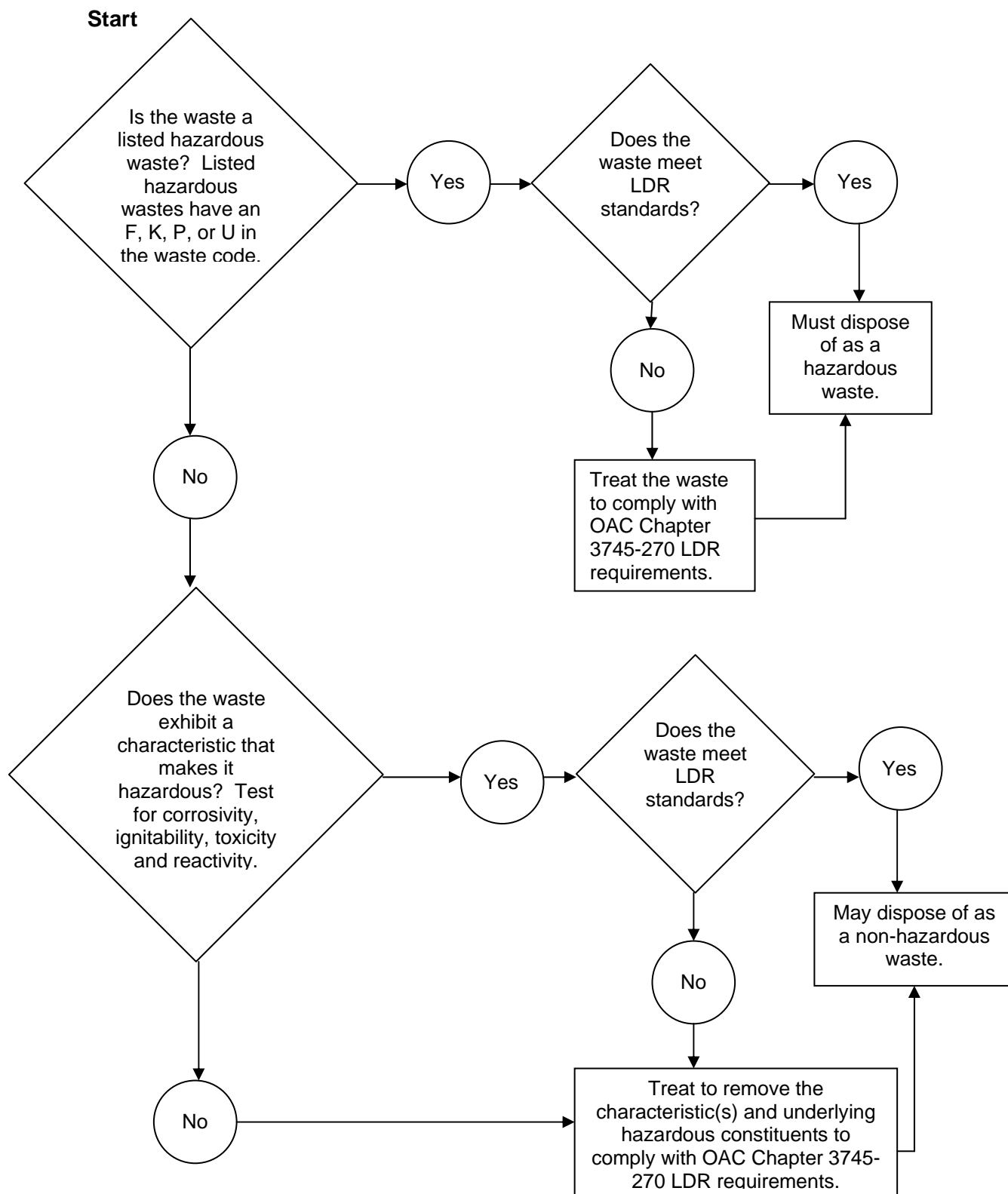


Figure 3-1: Hazardous Waste Management Flowchart

3.7 Schedule for Closure

OAC Rules 3745-55-13(A) and 3745-66-13(A) require an owner/operator to treat, remove, or dispose of all inventoried hazardous waste in accordance with the approved closure plan within ninety (90) days after receiving the final volume of hazardous wastes or within ninety (90) days after approval by the director of Ohio EPA, whichever is later. Also, the owner/operator must complete partial and final closure activities in accordance with the approved closure plan within one hundred eighty (180) days after receiving the final volume of hazardous wastes or within one hundred eighty (180) days after approval of the closure plan, if that is later. A longer time period to complete closure activities may be approved by the director of Ohio EPA pursuant to OAC Rule 3745-66-13(B) or 3745-55-13(B) for interim or permitted facilities, respectively. Refer to [Section 1.8, Closure and/or Post-Closure Plan Amendments and Extension of Closure Time Period](#), for more information.

Closures requiring time periods longer than one hundred eighty (180) days, including extensions after the director's closure plan approval, must be reviewed by Ohio EPA and approved by the director. For major closure projects (e.g., waste in place), Ohio EPA may require the owner/operator to submit a regular (e.g., monthly) report to Ohio EPA which outlines the current closure activity(ies) for the unit, describes any special problems encountered during the closure proceedings, and identifies the next period's anticipated events to be performed during the closure activities. As an example, a monthly report would be due thirty (30) days from the date the closure plan is approved and thereafter on thirty (30) day intervals until the final closure certification report is submitted.

The plan must contain a schedule² which shows all critical dates for closure, including but not limited to the total time required to close each unit, waste removal, sampling, soil removal, critical points when the independent professional engineer or his/her representative will be present, independent professional engineer's certification, backfilling, cap construction, and other relevant activities. It is important to note that the schedule must start at the point of the director's approval or, in the case of a Part B permitted facility, upon notification of intent to close and not rely on calendar dates. Beware of sampling and waste or soil removal delays caused by inclement weather. This may result in the owner/operator being unable to meet the closure completion deadline and making it necessary to request an extension. It is advisable that the closure plan or director's approval letter incorporate any extensions beyond the one hundred eighty (180) day limit, if they are likely.

Ohio EPA may require that the owner/operator contact the appropriate DO inspector at least five (5) business days in advance of certain critical activities, such as soil sampling or removal, so that the reviewer may be present to observe these activities, obtain split samples, or for other reasons at Ohio EPA's discretion. Inspector notifications should also be included in the closure schedule.

When conducting the closure plan review, it is important to ensure that key field activities are identified. "Key" or "critical" activities associated with the closure plan schedule, which can serve as the basis for a reviewer's compliance monitoring strategy in the field, may consist of, yet not be limited to the following:

- initial day in which field activities are being implemented
- ground water sampling
- well installation and development
- soil sampling

² See OAC Rules 3745-55-12(B)(6) and 3745-66-12(B)(6).

- background sampling
- rinsate sampling
- decontamination activities
- sampling of treated wastes/waste residues/contaminated environmental media
- waste evaluation and associated waste management activities
- removal of tanks and associated secondary containment systems
- confirmation sampling
- start-up or “shakedown” activities associated with treatment systems
- field laboratory activities

Special considerations should be taken into account when conducting plan reviews for land-based disposal units. Staff are encouraged to consult their supervisor, ERAS or the cleanup discussion groups involving the DOs and CO in formulating the appropriate compliance monitoring strategy while conducting a technical review of proposed closure and/or post-closure plans for such units.

3.8 Air Emissions and Wastewater

When applicable, the plan should specify how air emissions related to closure, including nuisance problems such as fugitive dust or odors, will be minimized or eliminated. Examples include solvent emissions during staging and loading operations or dust problems related to solidification. In such cases, it may be appropriate for Ohio EPA's Division of Air Pollution Control and/or the local air agency (<http://www.epa.ohio.gov/dapc>) to assist in closure plan review. In some cases (e.g., air stripping operations, soil gas extraction, landfill venting), an air pollution permit may be required. Ohio air pollution control rules are found in OAC Chapters 3745-15 through 25 (Air Standards), OAC Chapter 3745-31 (Permits to Install New Sources), and OAC Chapter 3745-35 (Air Permits to Operate and Variances).

Other closures may require a water pollution control permit or permission to discharge from the local Publicly Owned Treatment Works (POTW). Examples of these situations include surface impoundment dewatering or rinsate management. The closure plan reviewer should ensure that such wastewater management is in accordance with Ohio water pollution control rules, including those found in OAC Chapters 3745-1 (Ohio Water Quality Standards), OAC 3745-3 (Pretreatment Rules), 3745-31 (Permits to Install New Sources of Pollution), 3745-33 (Ohio National Pollutant Discharge Elimination System Permits), and 3745-36 (Indirect Discharge Permits).

3.9 Personnel Health and Safety

A requirement for health and safety training for all workers at hazardous waste sites was promulgated by the Occupational Safety and Health Administration (OSHA) in the Federal Register: March 6, 1989 (29 CFR Part 1910, 54 FR 9294). In addition to obvious measures needed to protect the health of nearby residents, the owner/operator must have available, a health and safety plan which specifies the measures to be taken to protect all personnel (including contractors, Ohio EPA personnel, and visitors) involved in the closure or those possibly exposed to hazardous waste from the closure activity. It is important to note that the reviewer (or inspector) should be familiar with the health and safety plan before going on site and should comply with the health and safety plan while on site.

A complete, detailed description of the safety program is not necessary in a closure plan. Approval of health and safety programs can only be granted by OSHA. However, the health and safety plan should cite specific documents, including existing safety plans specific to site operations, and list appropriate items of concern. These items may include monitoring

equipment, hazard evaluation, site safety plans, standard operating procedures (SOPs), engineering controls, personal protective clothing and equipment, decontamination and emergency procedures. For further information, the following documents may be referenced:

- U.S. EPA. (1992) *Standard Operating Safety Guides*.
- U.S. EPA. (2000) *Hazardous Materials Incident Response Operations* (165.5).
- OSHA regulations such as 29 CFR Section 1910.120 (Hazardous Waste Operations and Emergency Response), 29 CFR Section 1910.132 through 1910.138 (Personal Protective Equipment), 29 CFR Section 1910.1000 (Air Contaminants), 29 CFR Section 1910.1200 (Hazard Communication), and 29 CFR Part 1926 (Safety and Health Regulations for Construction).
- U.S. Department of Health and Human Services. (1985) *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities*.

3.10 Decontamination Efforts

OAC Rules 3745-55-12(B)(4) and 3745-66-12(B)(4) require that a closure plan include:

“A detailed description of the steps needed to remove or decontaminate all hazardous waste residues and contaminated containment system components, equipment, structures, and soils during partial and final closure, including, but not limited to, procedures for cleaning equipment and removing contaminated soils, methods for sampling and testing surrounding soils, and criteria for determining the extent of decontamination necessary to satisfy the closure performance standard;”

Also refer to OAC Rules 3745-55-14 and 3745-66-14, titled Disposal or Decontamination of Equipment, Structures and Soils.

It may not be necessary to meet these decontamination standards if one of the following conditions is met:

- The unit and appurtenances are destined for recycling in a manner that will destroy residual contamination (e.g., sold as scrap metal and recycled by a secondary steel producer). In this case, the hazardous waste management unit and appurtenances must be rendered useless (usually by cutting into small pieces) and must have documentation (e.g., sales agreements, shipping papers, photos, etc.) proving the final destination and disposition of the material provided as part of the closure certification document, or
- The unit will be used for further accumulation of similar materials not regulated by RCRA or for the accumulation of hazardous waste for “less-than-90-day-storage” and the owner/operator qualifies as a large quantity generator. The owner/operator should then acknowledge in the closure plan and certification document the responsibility to close the hazardous waste management unit in accordance with Generator Requirements (See [Section 1.10, Generator Closure](#) and/or OAC Rules 3745-52-34, 3745-66-11, and 3745-66-14) before the facility is decommissioned.

If the hazardous waste management unit undergoing closure is without satisfactory secondary containment (as defined in OAC Rules 3745-55-75 and 3745-55-93 (B through F) or 3745-66-93 (B through F)) or is in direct contact with soil, then the soil sampling and analysis procedures

described in this document should be used regardless of the fact that the unit is to be reused or recycled to demonstrate that the underlying soil is not contaminated.

Decontamination Efforts

The closure plan should describe all efforts to clean or decontaminate hazardous waste residues and constituents from equipment, vehicles, tanks, paved areas, concrete, pipes, pumps, sumps and any other appurtenances to the hazardous waste management unit. This description should specify the use of chemical and/or physical methods to be used for decontamination purposes. For more information on physical and chemical decontamination techniques the Nuclear Energy Agency's report *Decontamination Techniques Used in Decommissioning Activities* has information that can be used at RCRA sites, it can be found at: <http://www.oecdnea.org/html/rwm/reports/1999/decontec.pdf>.

The plan should include a discussion/evaluation of how cleaning methods and the surfactants chosen are suitable for the contaminants. If detergent washing and water rinsing are selected, the closure plan should show that the detergent solution will remove the contaminants of concern. This may be demonstrated with solubility data from product specification sheets or standard chemical tables. The length of time solutions are in contact with the surface and whether or not scrubbing or other physical efforts are used will affect the accuracy of the decontamination demonstration. Other useful considerations might include the temperature of the wash water and the pressure/nozzle that would be used to apply it to clean the surface. The effectiveness of chemical and physical decontamination will also depend on the unit's design, the cleaning solutions, and the constituents to be removed.

The independent professional engineer should certify the decontamination methods used and that the hazardous waste residues have been removed to the maximum extent practicable. When using chemical methods, a triple wash/rinse procedure for the entire surface of the unit and associated structures should be followed to ensure adequate decontamination. While the wash solution may be site-specific, the wash and rinse steps mentioned below should be performed at least three times.

- (1) Physically remove all gross contamination.
- (2) Wash the surface(s) with a detergent solution. This may be accompanied by the use of a brush made of inert material, a steam cleaner, or high pressure washer to remove any particles or surface film.
- (3) Rinse thoroughly with water.

If appropriate, the detergent solution in the second and/or third wash step, may be replaced with an inorganic desorbing agent (*i.e.*, acid rinse) or an organic desorbing agent. Each step that involves washing the surface should be followed by rinsing the surface thoroughly with water. This triple wash/rinse method is typically used when decontaminating a container storage pad, walls, secondary containment for a tank, etc. All rinsate should be collected, handled, and disposed of as a hazardous waste, unless sampling results demonstrate that the rinsate is non-hazardous.

Demonstration of Decontamination

Depending on the potential future use of the unit, analytical data may be required to demonstrate that adequate decontamination has been achieved. In this case, a closure plan reviewer, should require the closure plan to specify an appropriate decontamination

standard for the final rinse water (e.g., Maximum Contaminant Levels for drinking water, a risk-based standard or other health based standard). For example, if a tank unit undergoing closure has a potential future use of storing food products or becoming a water supply tank, then the final rinse water should be analyzed to show that the tank unit has been adequately decontaminated.

In lieu of chemical methods, performance-based physical extraction methods may be used to demonstrate that a structure has been properly decontaminated. Physical extraction methods include abrasive blasting, scarification, grinding and planing, spalling, vibratory finishing, and high pressure steam and water sprays. This decontamination standard requires:

- Removal of at least 0.6 centimeters of the surface layer of porous materials (e.g., concrete, asphalt pavement, etc.), and
- Treatment to a "clean debris surface" pursuant to 40 CFR 268.45, Table 1 or OAC Rule 3745-270-45, Table 1.

Achievement of the 0.6 centimeter standard should be verified by reference to machinery design specifications and level of effort. A "clean debris surface" is a surface that, when viewed without magnification, should be free of all visible contaminated soil and hazardous waste, except that residual staining caused by waste consisting of light shadows, slight streaks, or minor discolorations, and waste in cracks, crevices, and pits may be present provided that such staining and waste in cracks, crevices, and pits must be limited to no more than 5% of the total surface area.³

The use of wipe samples to demonstrate decontamination is typically not acceptable due to the lack of surface area covered by the wipe samples, but may be advisable where triple washing/rinsing or other means of decontamination are impractical or dangerous (e.g., motorized or electrical equipment). Wipe tests are useful to qualitatively indicate the presence or absence of contaminants, but should not be used quantitatively. They can be used to help determine if further decontamination efforts should be made due to the presence of hazardous constituents. Ohio EPA does not accept wipe samples for verification of decontamination unless it is impossible or inadvisable to immerse the entire surface with water as is necessary for chemical decontamination methods. If total constituent analysis of the wipe sample results in a hazardous waste constituent to be detected (above the Method Detection Limit), then complete decontamination cannot be verified. It should also be shown that the solvent used in the wipe cloth is capable of removing the constituent from the contaminated equipment. For any additional assistance in the use of wipe samples to demonstrate decontamination, bring the issue to DHWM's cleanup group involving the DOs and CO or contact your supervisor.

Managing Wastes Generated During Decontamination

A description of how waste material (i.e., rinsate, debris, disposable equipment, etc.) from decontamination will be managed and an estimate of the volume of waste material which will be generated by decontamination efforts should also be provided in the closure plan. The owner/operator is obligated to characterize debris (see OAC Chapters

³

Federal Register: August 18, 1992 (FR 37229)

3745-51 and 3745-52) for land disposal restrictions.⁴ As an example, a concrete storage pad can be shown to be decontaminated (*i.e.*, was triple washed/rinsed) but because contaminants may have permeated the surface of the pad, the pad material will need to be properly characterized prior to any possible disposal.

Rinsate, residuals or contaminated debris containing hazardous constituents associated with listed hazardous waste or exhibiting a characteristic of a hazardous waste should be managed as hazardous waste. However, the wastes generated from decontamination activities can be characterized to show that they are non-hazardous and properly disposed of as such. Rinsates and other contaminated liquids may be managed as wastewater as long as such activity is managed in strict compliance with the Clean Water Act and Ohio Water Pollution Control Law (See ORC Chapter 6111 and [Section 3.8, Air Emissions and Wastewater](#) part of this document).

Decontamination Equipment

Reusable equipment (*e.g.*, earth moving equipment and stainless steel soil samplers) should also be decontaminated. This may be accomplished by brushing or scraping debris from the exposed surfaces followed by at least three separate rinses. Although no chemical or physical analysis of the rinsate is required, rinsate should be managed as hazardous waste unless sampling results demonstrate that the rinsate is "non-hazardous" (See discussion above). The solid debris should be managed as solid waste, hazardous waste, or decontaminated soil (meeting risk-based remediation standards) depending on the wastes in the unit and the sampling results. Again, in the absence of analytical data, debris is presumed to be hazardous waste. The equipment decontamination operation should be managed so that vehicles do not distribute contaminated debris outside of the waste management area.

Equipment Decontamination Area

In order to prevent the contaminated water/detergent solution (rinsate) generated by chemical extraction methods from contaminating other environmental media (*i.e.*, soil), the area surrounding the equipment or secondary containment should be prepared to capture rinsate and other wastes prior to initiation of decontamination activities. Such preparation may include, but is not limited to, the installation of a decontamination pad for contaminated equipment, the installation of absorbent booms along the edge of the secondary containment, the installation of a plastic liner around the secondary containment (with curbing to prevent run-off), or the installation of a drainage system around the secondary containment with a rinsate collection basin. The spent rinsate solution can be collected for sampling and disposal through gravitational drainage into a deeper area of the secondary containment or a sump and with the application of a wet/dry vacuum.

The closure plan should include design details for the equipment decontamination area (*e.g.*, decontamination pad). Information required should include, but not necessarily be limited to, a scaled map showing the location of the decontamination area, materials of construction, liner specifications, the method of rinsate collection, and decommissioning procedures.

⁴

Federal Register: August 18, 1992 (FR 37193) For more information on determining if LDRs are applicable see DHWM's guidance:
http://epa.ohio.gov/portals/32/pdf/Land_Disposal_Restrictions_Guidance.pdf

Decontamination Pad Basics

In general, decontamination pads (pads) are temporary structures. However, this “temporary” designation can stretch anywhere from a day or two, to a couple of years. For instance, a pad may be needed during a small repair on a landfill cap, versus a years-long service during a full closure of a facility, involving numerous units. In addition, pads may be subjected to a wide range of work loads and frequencies of use (for example: a one-time decontamination of hand tools as opposed to a repeated periodical decontamination of large machinery). Obviously, the design requirements will be different in each case.

Closure plans involving use of decontamination pads (regardless of the pad’s purpose or longevity) should generally include the following information:

- a scaled map showing the location of the pad;
- intended use of the pad;
- a plan drawing illustrating major features of the pad;
- a summary of materials used for construction of the pad;
- the method of rinsate and/or particulate waste collection and disposal;
- maintenance of the pad (inspections and repairs); and
- description of the pad decommissioning (removal) procedures.

The following are few important aspects of a decontamination pad design:

- 1) The pad needs to be able to bear the load of the equipment to be decontaminated and needs to be of sufficient size to accommodate the largest piece of equipment plus an appropriate space for conducting decontamination activities.
- 2) The pad needs to be designed to capture all rinsate generated and prevent release of contaminants to the environment. This may include shielding to protect from wind dispersion, over-spray, and precipitation events.
- 3) The pad needs to be designed in a manner that will prevent damage from intended use.
- 4) The design and construction of the pad should not pose or increase the threat to human health and the environment.
- 5) The pad and its construction material should be properly managed at all times (*i.e.*, treated as hazardous waste unless proven otherwise).

Decontamination Pad Elements (illustrated in Figure 3-2, below)

Engineered Sub-base:

The “engineered sub-base” is a constructed foundation for the pad. “Engineered” means that it is built in a controlled fashion to provide needed characteristics. When rinsing is employed as a decontamination method, a sub-base design may include an optional drainage layer. The bottom of the drainage layer should be sloped (1% to 3%) toward a collection point, and be isolated from any outside source of liquid (from around the pad). Its sole purpose is to take-in and convey any amount of rinsate that may escape through a somehow breached pad, before it makes its way into soil. It can be built from aggregate, gravel, or a

synthetic material such as geonet. The drainage layer needs to be underlined by a low permeability layer, which can also be built either from natural (clay), or geosynthetic (GCL or geomembrane) material. The thickness of each layer is function-dependant and varies from one design to another. As an alternative, the sub-base can be constructed from just about any available material, providing that it can support the weight of the pad and the equipment, without exhibiting significant deformation. Such simple designs may be quite adequate for “short-term” pads.

Pad:

The “pad” provides a working surface for decontamination. Due to the nature of a typical decontamination process (i.e., washing and scrubbing), this surface should be able to withstand a rather rough combination of chemical and physical assaults. The most popular material for construction of pads is concrete. Being a relatively porous material, it may be coated with some kind of a (non-slip!) sealant, to prevent permeation of rinsate and to ease maintenance. The surface of the pad should be sloped to allow efficient removal of rinsate and waste debris, and all joints need to be sealed. Collection gutters may be included to conduct rinsate to a collection point, usually a sump. There should be no run-on, or run-off allowed to occur. The entrance onto the pad should always be from the lower end.

Containment:

In order to prevent rinsate from escaping into the surrounding area, decontamination pads are typically equipped with curbs and/or walls. These are usually at least several inches high, and sealed to the pad surface.

Sump:

A sump should be situated at the lowest point of the pad to collect rinsate and/or rainwater. It may be equipped with a pump, or some other means for liquid removal. The sump should be easily accessible for an occasional sediment cleanup. When the pad is not covered, the sump should provide enough storage capacity to accommodate a significant storm event (such as 50 year/24 hour occurrence, for instance), without overflow. Since the liquid head could temporarily build up, the walls and the bottom of the sump should be made impermeable.

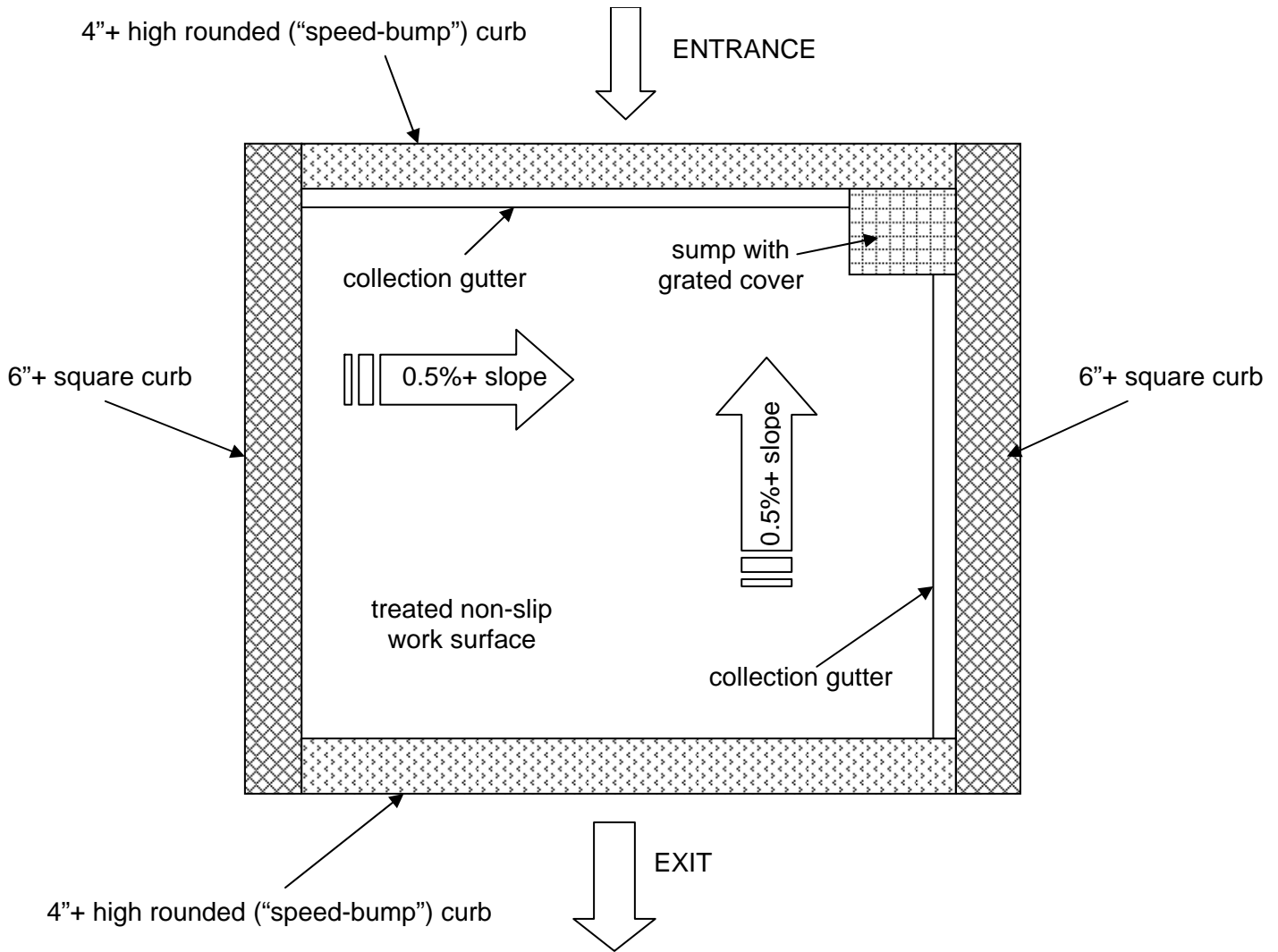
Enclosure (roof and walls):

When a prolonged service is expected, it may be a good idea to provide cover for a decontamination pad. A full enclosure is even better. The payoff for the initial investment is realized when a significant amount of decontamination work has to be done during inclement weather. If dust generation, over-spray and frequent windy conditions are anticipated, a complete enclosure will prevent the contaminant from spreading.

For further information on decontamination procedures, consult the following documents:

- U.S. EPA. (1985) *Guide for Decontaminating Buildings, Structures, and Equipment at Superfund Sites*.
- U.S. EPA. (1992) *Standard Operating Safety Guides*.
- American Society for Testing and Materials. (1990) *Standard Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites*.

Overhead View of Decontamination Pad



Cross Section View of Entrance to Decontamination Pad

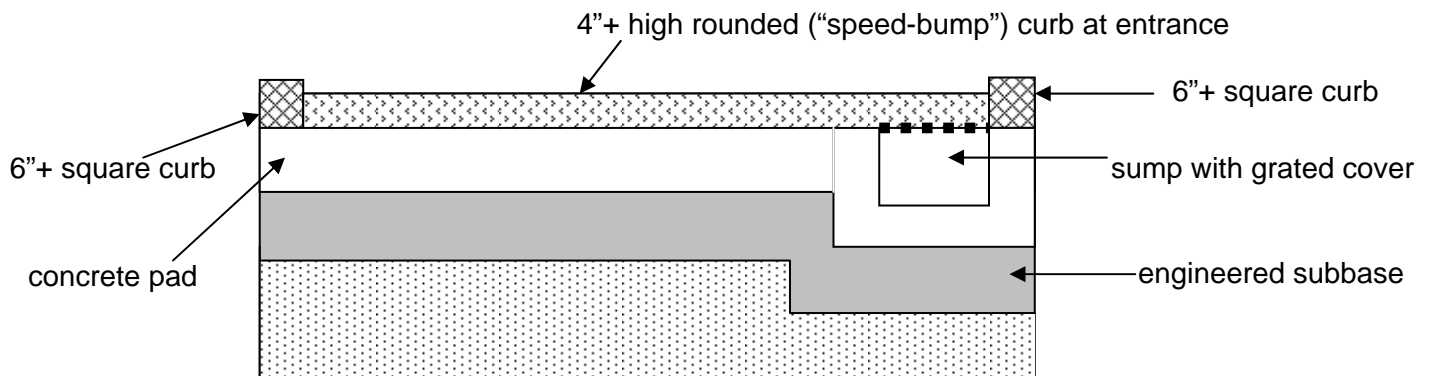


Figure 3-2: Decontamination Pad Elements

3.11 Soil Sampling and Analysis

Hazardous waste management units undergoing closure that have had a past release to soil should include a sampling and analysis section in the closure plan. Additionally, closure of units where there is a potential for leaks or spills, or a potential for hazardous waste or hazardous constituent (as defined in the Appendix to OAC Rule 3745-51-11) migration, should include soil sampling as part of the closure investigation. Such evidence can include but is not limited to:

- Containers, tanks, waste piles or any other unit (such as ancillary pipes) in contact with soil;
- Storage units with underlying pavement or concrete that is cracked or broken;
- Areas receiving runoff or discharge from the unit, such as a ditch, a swale, or the discharge point downgradient from a pipe;
- Visual or olfactory evidence of contamination;
- Knowledge, such as by employees, inspectors, or others, that releases have or may have occurred;
- Length of time the unit has been in existence; and
- Other situations which may lead to soil contamination.

The objectives of soil sampling should be defined in relation to the closure project as succinctly as possible. One objective that should be addressed in the closure plan is the need to define the vertical and horizontal extent of soil contamination and determine the maximum concentrations of contaminants. Therefore each closure plan should explicitly state the intent to define the full nature and extent of soil contamination. However, there may be certain types of closure activities, such as waste in place closures or deep injection well sites where the nature and extent of contamination has been previously defined. The owner/operator of such a site is still responsible for defining the nature and extent of contamination where contamination is suspected or evident outside of the hazardous waste management unit boundary. Other sampling objectives in a closure plan may include, but are not limited to:

- An estimation of the level and variability of a pollutant in a geographic area,
- A determination if the pollution measured is above the applicable or relevant and appropriate requirements (ARARs) or is higher than the ambient levels found in the control area,
- A determination if an area has been cleaned to a generic or site-specific cleanup standard identified by an administrative order,
- A determination of whether listed wastes are present or not, and
- A definition of geotechnical parameters for future remediation activities.

In addition, the closure plan should include a clear statement indicating that additional sampling will occur if results from any initial sampling efforts indicate the full extent of contamination has not been defined. In general, it can be demonstrated that sampling has adequately defined the

nature and extent of soil contamination if the following requirements (as applicable to a site-specific scenario) have been met:

- When sampling soils for organic constituents, sampling should continue until 2 to 4 consecutive analytical results, depending on the sampling interval, in the vertical direction and 2 consecutive analytical results in the horizontal direction show that the concentrations of constituents are below their respective method detection limits.
- When sampling soils for metals, sampling should continue until 2 consecutive analytical results in the horizontal direction are below the method detection limit, the site-specific background remediation standard (BRS) or the Alternate Metal Standard (AMS), which are described in [Section 4.1, Remediation Standards for Soils and Ground Water](#).
- When sampling soils for metals in the vertical direction, sampling should continue until 2 consecutive analytical results in the vertical direction are below the method detection limit, BRS or AMS - whichever is applicable.
- If a saturated zone is encountered during soil sampling, a ground water monitoring program may have to be implemented. For more information, consult [Section 3.12, Ground Water Sampling and Analysis](#) part of this document.

Risk-based standards cannot be used for defining the extent of soil contamination. In order to conduct a risk assessment or use risk-based standards, the exposure point concentration should be calculated for each constituent. Because it is necessary to use the full extent of contamination (*i.e.*, all samples that indicate the presence of contamination) in calculating an exposure point concentration, the extent of contamination should be determined prior to conducting a risk assessment or using risk-based standards.

An adequate soil sampling and analysis plan should include the following information and rationale for each selection:

Data Quality Objectives (DQOs)

Statements concerning the objectives, scope of sampling, and how the data will be used to accomplish the stated objectives should be clearly defined in the closure plan. DQOs should include the need to define the nature and extent of contamination. In addition, the closure plan should, if possible, include a clear statement of the remediation standard for the soil. For example, if a risk-based closure is desired, then this should be stated as a data quality objective. This objective would then serve as a basis for determining quality assurance/quality control (QA/QC) procedures, such as assuring that the detection limits for the analyses are below generic risk-based remediation standards and that the laboratory criteria for valid data is sufficient enough to support that quality analytical results will be obtained. Other DQOs commonly found in closure plans include:

- Estimate the variability of a pollutant in a geographic area.
- Define the areal extent and depth of the pollution and map the pattern of the distribution.
- Determine if an area has been cleaned to a generic or site-specific cleanup standard identified by an administrative order.

U.S. EPA has numerous data quality documents that can be referred to for guidance on developing data quality objectives for a site. These documents can be found at <http://www.epa.gov/quality/qatools.html>.

Closure Confirmation Sampling

A facility that chooses to close by removal or decontamination of contaminated materials is required to demonstrate that any residual contamination remaining in the unit is below regulatory or health based standards. The facility can fulfill this obligation by taking confirmation samples. Confirmation sampling, like any investigatory sampling, should be carefully planned with attention paid to defining DQOs, sample locations, number of samples, quality control samples and analytical considerations. Note that confirmation sampling may not be necessary if the nature and extent of contamination is well defined and excavation meets the remediation standards at the site.

The DQOs for confirmation sampling will be similar to those used and defined during the investigation phase of the closure. In this case, the primary objective is to determine whether the soil or environmental media contains contamination at or above the remediation standard for the unit. The plan should state the DQOs; field and laboratory QA/QC sampling frequency and acceptance criteria; and the required laboratory detection and reporting limits. The plan should also define what actions may result if sample(s) are found above the remediation goal. Note that remediation standards are not necessarily appropriate for the determination of nature and extent of contamination. The plan should include actions that will be taken in the event of failure to demonstrate decontamination through confirmation sampling. Often, this requires amending the closure plan.

While these concepts are developed throughout [Section 3.11, Soil Sampling and Analysis](#) of the CPRG, the DHWM does pose one restriction on confirmation sampling that is not imposed on investigatory sampling. For confirmation sampling, samples should be grab samples not composite samples. This is because spatial information is lost with composite samples so the location of areas of higher concentration cannot be identified. Furthermore, a composite sampling approach may suffer from dilution effects making it difficult to determine whether unacceptable areas of contaminated media are still present. Closure confirmation sampling is to ensure that all areas of a unit have been successfully cleaned and that no contamination above the action level still exists. Therefore, the result of each individual grab sample, not composite or an average of grab sample results, should be compared to the regulatory standard or risk level.

Other considerations that should be discussed in the sampling plan include the number and location of grab samples that will be taken for confirmation. Many plans state that a sample will be acquired from the side-walls and bottom of an excavation for a total of five samples. However, the actual number of samples and locations must be carefully considered and should not follow a pre-determined number of samples. Some factors that will affect the number and location of confirmation samples are the shape and size of an excavation and the location of high areas of contamination. Many guidances, such as Wyoming's Department of Environmental Quality's *Fact Sheet #10 Soil Confirmation Sampling Guidelines* (<http://deq.state.wy.us/volremedi/index.asp>), suggest that the number of samples should increase as the area or length of an excavation increases. In addition, if the excavation is irregular or sinuous in shape, potentially more confirmation samples should be taken to provide adequate coverage. Therefore, five samples should be viewed as the minimum number of samples necessary for confirmation of clean closure in an excavation. DHWM also recommends that the samples be taken in the initial areas of highest contamination.

Sample Acquisition Methods

The sampling section of the closure plan should include a discussion on the general plan or strategy for acquiring samples. There are numerous sampling strategies outlined in environmental literature, but the most common are simple random sampling, stratified random sampling, systematic random sampling and authoritative sampling. Most of these strategies rely on the concept of random sampling to represent waste or contaminated media and to provide justification for the use of certain statistical procedures. The nuances of these strategies are too detailed to discuss in this text, but can be found in U.S. EPA guidance including the *RCRA Waste Sampling Draft Technical Guidance* (EPA530-D-02-002, August 2002).

The plan should discuss the overall sampling strategy and provide any information that relates to the sampling locations and number of samples that will be acquired. For example, if systematic random sampling (*i.e.*, grid sampling) is employed, the grid interval, the method used to derive the grid interval and the method used to select sampling locations at random should be summarized in the sampling plan. For guidelines on how to conduct grid sampling, refer to [Appendix D, Grid Spacing Determination](#).

The method(s) of acquiring samples should be discussed in detail in the sampling and analysis plan or in a Standard Operating Procedure (SOP). These SOPs should be submitted with the closure plan either in the text of the document or in an appendix. The procedures or methods that are selected should be consistent with the DQOs of the closure plan. For example, if volatile organic compounds are constituents of concern, then U.S. EPA's *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Update III*, (SW-846) Method 5035 should be used for sample acquisition instead of a method that would disturb the soil and cause excessive volatilization. For more information regarding sampling soils for volatile organic compounds (VOC), refer to DHWM's (1998) memorandum titled "New Methods for Preservation of Volatile Organic Compounds in Soil."

The type of sample that will be used in characterizing a hazardous waste unit must be carefully considered. The two most common types of samples that are taken at hazardous waste sites are grab samples and composite samples.

Grab samples are recommended when the goal is to determine the extent of contamination at a unit or to determine if remediation standards have been met. A grab sample is defined as a single sample or measurement taken at a specific place and time that represents the material only at that place and time. This definition implies that in order to represent all of heterogeneous media more than one grab sample must be taken. Results from grab samples are usually processed statistically to determine the characteristics of the contaminants in a media. Grab samples do not have the dilution concerns associated with composite samples. Consequently, the average properties of the media, as represented by the upper 95 percent confidence level of the mean, can be statistically determined from grab sample data. Grab samples also have an advantage over composite samples because this acquisition method gives information on the spatial orientation of the contamination.

Composite samples are often used to determine the average chemical properties in an area or in a discrete volume of material. It is also a useful strategy to define whether an area of concern contains a chemical of concern and to suggest the presence of a "hot spot" of higher contamination. Unlike grab

samples, composite samples are composed of more than one grab sample that are physically mixed together. The analytical result theoretically gives an average of the contaminant concentrations from each of the grab samples. The closure plan should supply information on the volume of the individual grab samples that will be composited, the number of grab samples that will be used to make up the composite sample, the method of homogenization, and the method of sub-sampling.

Disadvantages of Composite Sampling

There are several disadvantages associated with composite sampling that must be overcome with careful planning and preparation.

1. **Homogenization of the sample.** In theory, mixing seems trivial, but in practice the physical mixing of soil samples is very difficult to do adequately. Several techniques have been used with variable results depending on the type of soil at a site.

Cone-and-quarter method. The cone and quarter method involves mixing grab samples together then placing the soil into a pile where it is then flattened. The soil is then divided into quarters where two of the quarters are discarded. The remaining two quarters are mixed and the process is repeated until only enough sample remains to fill a sampling jar.

Alternate scooping. The alternate scooping method involves mixing grab samples; then using a spoon or scoop, two piles of soil are formed from the original pile. One of the two piles is then discarded and the process is repeated until only enough soil remains to fill a sample jar.

These techniques and others are described in U.S. EPA's *RCRA Waste Sampling Draft Technical Guidance* (August 2002) and in ASTM Standards D6051-96 and D6323-98 and updates.

One important aspect of composite sampling that should be apparent is that composite samples should not be contemplated when volatile organic compounds are constituents of concern. The physical mixing of grab samples would result in a negative bias that would prevent a representative sample from being formed. However, SW-846 Method 5035 does offer a provision for forming a composite of extracts taken from individual samples. More details on this technique can be found at U.S. EPA's website at the following address:

<http://www.epa.gov/epaoswer/hazwaste/test/main.htm>.

2. **Effect of dilution.** Since a composite is composed of individual grab samples, the analysis will result in an empirical average of the concentrations of contaminants in each of the grab samples. This is theoretically true only if the samples are adequately mixed and subsampled. However, If some of the grab samples are taken outside of the area of contamination and others within the source area, the analytical result may be significantly diluted and not representative of the average contaminant concentration levels in the source area. Dilution may be so severe that the concentration of contaminants are driven below the

analytical detection limit and it may be falsely assumed that a contaminant is not present or is below a regulatory standard. Therefore, care must be exercised in limiting the sampling over the approximate area of contamination. In many cases it is not possible to make this judgement without prior knowledge of the nature of the contamination. U.S. EPA guidance (August 2002) provides guidelines to follow when using composite sampling techniques where the area of contamination is not precisely known. First, the closure unit should be divided into sections and a limited number of grab samples from each section should be homogenized to form a composite. The next step is to define a decision rule based upon the analytical result of the composite sample and the number of grab samples that formed the composite. According to U.S. EPA (August 2002) the decision rule is formed by multiplying the analytical result by the number of grab samples (N) and then comparing this result to the Action Threshold. Mathematically this is expressed in the following equation:

Equation 3-1: Decision Rule for Composite Sampling
<p>All grab samples <i>below</i> threshold: Composite Result x N < Action Threshold</p> <p>One or more grab samples <i>above</i> threshold: Composite Result x N > Action Threshold</p> <p>N = Number of grab samples</p>

If the composite result multiplied by the number of grab samples is below the action threshold, then it can be assumed that the concentration of a contaminant in each grab sample is below the threshold. Conversely, if the composite value multiplied by the number of grab samples is greater than the threshold, then it can be assumed that one or more of the grab samples had results greater than the threshold. This could indicate the presence of a hot spot(s) or higher areas of contamination that should be investigated further. If the composite sample result is below the limit of detection of the analytical instrument, the result may indicate that the chemical of concern is not present or that severe dilution has resulted. If necessary, confirmation that the constituents of concern are not present can be performed by acquiring grab samples from the unit.

3. **Adequate quality control.** Field quality control normally includes collection of duplicate samples. However, duplicate samples are meaningless when using compositing techniques. Quality control for composite sampling should include forming a replicate composite sample. The goal of a replicate composite sample is to determine if there is inherent bias or imprecision in the compositing process. A replicate sample should be composed of the same number of grab samples which are taken from approximately the same locations as the samples used to form the initial composite. The replicate should be prepared and analyzed in the same manner as the initial composite sample. The replicate sample result will then be compared to the original composite value using a predetermined level of precision. Usually for composite

replicates this criteria is set at 25 relative percent difference. Relative percent difference can be calculated using equation 3-2 below. Other factors should be accounted for when compositing samples, including acquiring samples from the same soil horizon and depth, and acquiring grab samples of consistent weight or volume.

Equation 3-2: Relative Percent Difference
$RPD = \frac{X_1 - X_2}{X_{Avg}} \times 100$ <p> X_1 = first concentration observed X_2 = second concentration observed X_{Avg} = average concentration of X_1 and X_2 </p>

Further Information on Sample Acquisition Methods

There are several references concerning sampling strategies, collection of grab or composite samples, sampling devices, and proper sampling methods. The American Society for Testing and Materials (ASTM) lists documents on sampling procedures and other methods, which are available for a fee, at <http://www.astm.org/>. Additionally, U.S. EPA has several references concerning sampling that are available for free at <http://www.epa.gov/>. One commonly used guidance document is U.S. EPA's *SW-846*, or its most current revision. *SW-846*, Chapter 9, or its most current revision, contains a detailed discussion on sampling strategies, types of samples, and sampling devices.

Additional U.S. EPA guidance documents that may be consulted when preparing the sampling and analysis plan include, but are not limited to:

- U.S. EPA. (1990) *A Rationale for the Assessment of Errors in the Sampling of Soils*.
- U.S. EPA. (1991) *Site Characterization for Subsurface Remediation*.
- U.S. EPA. (1992) *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies*.

Number of Samples and Locations

The number and location of potential surface sampling points and potential depths of samples should be discussed in the closure plan. The text should state that authoritative samples will be taken in areas of visual contamination and which field screening techniques that will be used. For example, if a Photoionization Detector (PID) will be used to screen samples for possible volatile organic compounds, then the text should outline the procedures that will be followed in the field or refer to a SOP for field screening procedures which may be included with the closure plan. If possible, the potential soil sampling locations and depths should be shown on a scaled site map.

When sampling soils at various depths (in order to determine the full vertical extent of contamination, or to confirm successful remediation), the selection of a vertical sampling interval depends on several factors, including:

- Soil type and permeability;
- Suspected magnitude of surface contamination;
- Physical state of the waste and its mobility;
- Height of liquid head at the ground surface;
- Length of time that waste was present at the site; and
- Relative toxicity of the waste.

Other factors may be considered on a site-specific basis. The depth intervals typically vary from 4-6 inches to 3 feet. However, through the first 3-4 feet of soil below the surface, the sampling interval should not exceed one foot.

Clean (remediated) soil is obviously the end goal of a closure. The sampling plan should be structured so that it clearly determines when the remediation standard is achieved.

Field Quality Control Samples and Decontamination Procedures

The plan should provide a discussion on the number and type of field quality control samples that will be taken as part of the field investigation. These quality control samples may include trip blanks, field blanks, equipment blanks, rinsate samples, replicate samples and duplicate samples. The type and number of field quality control samples should be selected based upon the data quality objectives of the closure and the type of contaminants that may be present at the site. The closure plan should discuss the number of samples or the frequency at which field quality control samples will be collected. In addition, the closure plan should discuss how the data will be used and the consequences of the sampling results. For example, if duplicate sample results are greater than 20% relative percent difference, the precision of the field sampling program may be questionable. The consequence may be to acquire more field quality control samples or to change the method of sampling. Field quality control samples are discussed in U.S. EPA's *SW-846*, Chapter 9 or its most current revision. Also refer to Ohio EPA's (2006) *Tier I Data Validation Manual*.

Decontamination of sampling equipment is necessary for some sampling investigations. If non-disposable sampling equipment is to be used, field decontamination procedures should be discussed in the sampling plan. Decontamination procedures for heavy equipment and transportation vehicles should also be considered and discussed in the plan. The closure plan should state that quality control data from rinsate samples will be provided to show that the decontamination procedures were adequate. The closure plan should also discuss the evaluation and management of investigative derived waste materials such as soil cuttings, purge water, and soiled personal protective equipment (PPE).

Constituents of Concern

Parameters to be analyzed for in soil may include any element or compound that is a hazardous waste or hazardous constituent, as specified in OAC Chapter 3745-51.⁵ These parameters should not only be based on knowledge of the wastes managed at

⁵

For a detailed discussion about hazardous constituents, refer back to [Section 1.1, Rules Associated with Closure and Post-Closure Plans](#).

the unit, but they may also include other potential elements or compounds used at the facility which may be commingled with the waste. For example, soil underlying an F006 surface impoundment might also be analyzed for 1,1,1-trichloroethane, a solvent likely to be used at a plating facility and carried over into the wastewater treatment sludge. Additional parameters for analysis (e.g., waste decomposition products) may be needed if there is a reasonable possibility that significant waste decomposition has occurred. An example would be vinyl chloride as a possible degradation product of some chlorinated solvents.

U.S. EPA's (1989) *RCRA Facility Investigation (RFI) Guidance, Volume I, Appendix B* can be a useful reference for discussing constituents that should be included in a closure investigation.

Analytical Methods

Analytical methods should be stated for either the specific parameter to be analyzed or the general type of analysis that will be needed for the investigation. For example, the closure plan may state "mercury in soil will be analyzed by SW-846 Method 7471A and all other metal constituents of concern by SW-846 Method 6010B". While most methods come from U.S. EPA's SW-846, Ohio EPA may accept analytical methods from sources other than U.S. EPA. For example, methods from ASTM and American Public Health, American Water Works Association, and Water Environmental Federation's (1999) *Standard Methods for the Examination of Water and Wastewater. Standard Methods* may be acceptable.

It is important to note that Combustible Gas Indicators (CGI), Colorimetric Indicator Tubes, and Photoionization Detectors commonly used as field instruments are not acceptable substitutes for laboratory methods. They may be used to suggest the presence, but not the absence, of hazardous constituents. If portable field instruments are used, they should be confirmed by SW-846 methods. A mobile laboratory may be used if it follows SW-846 methods and has proper QA/QC procedures as described in [Appendix F, Mobile Laboratory Guidance](#).

Any method modifications should be listed in a data narrative that accompanies a data report submitted to Ohio EPA. Any method modifications by a laboratory should be justified with method development and method performance data that assures that the modification is commensurate with the reference method. Furthermore, methods other than those listed in SW-846 should include the quality control and quality assurance procedures so the validity of the analytical results can be assessed. It should be noted that some SW-846 methods, such as SW-846 Method 1311, Toxicity Characteristic Leaching Procedure, are listed by reference in the regulations (Appendix to OAC Rule 3745-51-24) and cannot be modified or substituted with another method.

The lowest possible analytical [Method Detection Limit \(MDL\)](#)⁶ should be achieved for the analytical method that is used. All concentration data should be reported, even if it is estimated, for compounds or elements that have been positively identified in the sample. Sometimes target analytes are present at concentrations which are above the level that can be reliably detected but below the level that they can be reliably quantified. These data are referred to as "qualified" and will be reported as a number which has been "flagged" by the laboratory. Although less reliable than data which are reported above

⁶

Refer to the [Glossary](#) for the definition of Method Detection Limit (MDL) and Estimated Quantitation Limit (EQL).

the [Estimate Quantitation Limit \(EQL\)](#), these qualified data must nevertheless be evaluated carefully by the DHWM reviewer.

Quality assurance and quality control procedures need to be followed. Upon request, evidence of a quality assurance/quality control (QA/QC) plan from the laboratory providing analyses results should be provided. QA/QC elements that may be requested are similar to that contained in U.S. EPA's SW-846, Chapter One. Submittal of a full QA/QC plan is not required, but evidence (a brief program outline or technical summary) of such a program should be presented to show that the laboratory has a complete QA/QC program for SW-846 methods. The full QA/QC plan as well as bench data sheets and chain of custody forms may need to be submitted if the closure plan reviewer desires to further validate the data. For more information on data validation, refer to Ohio EPA's (2006) *Tier I Data Validation Manual*.

Sampling methods and equipment, as well as laboratory analytical methods, should follow guidance in U.S. EPA's SW-846, "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Third Edition" (see 40 CFR 260.11 and OAC 3745-50-11). "Volume II, Field Manual" of SW-846 provides guidance on many areas of environmental and waste sampling. Field sampling methods, including soil sampling, not covered by SW-846 must be acceptable to DHWM before they are used in the closure. This includes methods for drilling, boring, ground water sampling, and other issues. Whenever available, standard approved procedures and methods, as defined by U.S. EPA or Ohio EPA, should be followed.

The results of the soil investigation should be assessed in accordance with the DQOs and performance standards for the closure unit. Based upon these results, additional sampling may be necessary to meet the objectives of the closure project.

3.12 Ground Water Sampling and Analysis

OAC Rules 3745-55-12(B)(5) and 3745-66-12(B)(5) require that a closure plan include:

"A detailed description of other activities necessary during the closure period to ensure that all partial closures and final closure satisfy the closure performance standards, including but not limited to, ground water monitoring, leachate collection, and run-on and run-off control;"

As a general rule, the DDAGW staff should be contacted at the beginning of the closure process in order to help determine if ground water is going to be an issue at the unit and discuss DDAGW involvement in the review of the closure plan.

Owners/operators may have two independent obligations to sample ground water as part of closure. First, if an owner/operator has previously been performing ground water monitoring of the uppermost aquifer complying with the requirements of OAC Rules 3745-54-90 through 3745-54-100 or OAC Rules 3745-65-90 through 3745-65-94 for a land-based unit or is monitoring as part of a permit requirement due to a unit's sensitive hydrogeologic location or the need for an early-warning system to protect a nearby municipal water supply, then the owner/operator's obligation continues throughout the closure period until final certification and, as necessary, during any post-closure period. If an owner/operator is under this obligation for ground water monitoring, it should be discussed in the closure plan. Refer to [Section 5.1, Components for Waste in Place Closure Plans](#), for more information on ground water monitoring for waste in place closures.

A second type of ground water sampling may be necessary to meet the closure performance standard in OAC Rule 3745-55-11 or 3745-66-11. In order to determine the full nature and extent of contamination it will often be necessary to evaluate the impact of unit activities on all saturated zones for site-specific parameters. Owner/operators of land based units may be required to implement both uppermost aquifer monitoring based upon OAC Rules 3745-54-90 through 3745-54-100 or OAC Rules 3745-65-90 through 3745-65-94 and sampling of other saturated zones based upon the closure performance standard in order to complete closure. When either evaluation is needed, the closure plan should include a ground water sampling plan. When both obligations are required, the closure plan may combine the ground water sampling requirements from each.

Determining the Need for Closure Performance-Based Ground Water Sampling

Ground water sampling to meet the closure performance standard should be included in the closure plan for all units if any of the following apply:

- Any underlying ground water is known to be contaminated by the regulated unit in question.
- Soil contamination is known to extend to the uppermost saturated zone, the top of a coarse-grained layer such as sand and gravel, or the top of bedrock.
- Soil contamination is known to extend to within five feet or less of the uppermost saturated zone. Five feet or less is considered to be close enough to the saturated zone that it cannot be precluded that water table fluctuation upwards or further downward migration will not result in future ground water contamination.

Additionally, if a unit is not described by any of the above, but soil contamination is present AND secondary pathways to the ground water (piping, fractures, etc.) are present OR constituents of concern are very soluble and do not adhere to the soil, such that activities at the unit may have impacted the ground water, then the possibility that soil contamination has reached or will reach the water table should be considered.

The following three tests are examples of tools that may be used as indicators to show it is very unlikely soil contamination will reach ground water. A number of different demonstrations would be necessary for Ohio EPA to release an owner/operator from **closure performance-based** ground water sampling as part of closure and/or to demonstrate that leaching to ground water as part of a risk-based closure will not be requested. If, however, the tests indicate that soil contamination will leach to the ground water, no matter how long it takes or what the concentration, then ground water sampling will typically be required to collect information for closure.

- (1) Vadose zone modeling can be applied. [Vadose zone modeling](#) is mentioned later in this document, but a detailed discussion can be found in Ohio EPA's (2005) *Vadose Zone Modeling in RCRA Closure*.
- (2) Leaching tests may be applied to the contaminated soils. A non-detect result would indicate that the contaminant would never leach to ground water. The inherent limitations of these tests should be recognized since they were designed to test the leachability and classification of waste materials rather than be used as "soil leachability tests." These [leaching tests](#) are discussed later in this document. TCLP and SPLP are also discussed in Ohio EPA's (2005) *Vadose Zone Modeling in RCRA Closure*.

- (3) [Appendix E, Ground Water Scoring Matrix](#), contains a scoring system developed by Ohio EPA. The scoring system takes into account the characteristics of the land surface, the vadose zone, the saturated zone(s), and the chemical contaminants. A score of 30 or higher indicates a potential impact and the need for ground water investigation. However, a score below 30 may not mean that an owner/operator is completely exempt from ground water sampling.

If the results from the tests above indicate that ground water sampling is necessary to determine the impact or potential impact of unit activities on ground water, then ground water sampling should be addressed in the closure plan. If ground water sampling is determined not to be necessary at the time of the closure plan approval, a contingent clause should be added to the closure plan approval requiring ground water sampling should the results of the soil sampling and analysis provide new information suggesting likely ground water contamination.

Objectives of Ground Water Sampling

The objectives of ground water sampling should be defined in relation to the closure project as succinctly as possible. In addition to determining the full nature and extent of ground water contamination and its maximum concentration, the ground water sampling plan must provide sufficient data upon which to base an evaluation of compliance with the closure performance standard. If closure by removal is being pursued, the objective would be to show that operation of the hazardous waste management unit has not affected ground water quality to the extent that would adversely affect human health and the environment. Ground water data collection to support closure by removal is addressed in [Section 4.1, Remediation Standards for Soils and Ground Water](#). If the unit will undergo waste in place closure and post-closure care, the objective is to comply with the ground water monitoring requirements contained in OAC Rules 3745-54-90 through 3745-54-100.

Each closure plan, for which ground water sampling is necessary, should explicitly state the intent to define the full rate, nature and extent of ground water contamination and its maximum concentration, along with the full extent of any hazardous immiscible layer. There may be certain types of closure activities where the nature and extent of contamination has been previously defined. In such a case, the closure plan should include a clear statement indicating that additional sampling will occur if results from any initial sampling efforts indicate the full extent of ground water contamination has not been defined.

The extent of ground water contamination may be determined by obtaining ground water samples from a sufficient number of monitoring wells to characterize the limits of the contaminant plume(s). A complete delineation is based on samples collected from the edge of the unit boundary, within the plume itself, the leading edge, and just beyond the leading edge of the plume. Additionally, it needs to be determined if ground water contamination exists upgradient and unrelated to activities at the unit. Knowledge of upgradient water quality may help clarify if ground water contamination downgradient of the unit is truly emanating from the unit and is therefore the owner/operator's responsibility. The delineation should consider all saturated zones with the potential to be contaminated. The common approach is to "step-out" and "step-down" until the delineation(s) is complete.

Additional wells should be installed, as necessary, in a laterally downgradient direction within the same zone and vertically, in the next lower position within the same or lower zone(s). In many instances, vertical placement coincides with vertical variation in geologic materials. Special care should be taken during drilling to prevent cross-contamination of deeper ground water zones. Light Non-Aqueous Phase Liquid (LNAPL) and Dense Non-Aqueous Phase Liquid (DNAPL) extent may entail additional wells (*i.e.*, to track the flow relative to any confining layer).

Data for wells downgradient of the source are compared to background data by visual inspection of the results and/or statistical analysis. All downgradient locations at which significant differences are noted are considered to be within the contaminated area. The concentrations in the plume should be determined using technically acceptable sampling and analytical techniques.

To demonstrate that sampling has adequately defined the nature and extent of ground water contamination, the following should be met:

Horizontally, when analytical results in the horizontal direction show:

- non-naturally occurring hazardous constituents (*i.e.*, organic compounds) below the method detection limit using the method (*e.g.*, SW-846, ASTM, or analytical methods approved by U.S. EPA, etc.) with the lowest detection limit.
- naturally occurring hazardous constituents (*i.e.*, inorganic compounds) below the method detection limit, or the site-specific background which is described in [Section 3.16, Background and Ground Water](#).

Vertically, at a minimum, identify the deepest ground water zone that has non-naturally occurring hazardous constituents (*i.e.*, organic compounds) exceeding the method detection limit using the method (*e.g.*, SW-846, ASTM, or analytical methods approved by U.S. EPA, etc.) with the lowest detection limit or naturally occurring hazardous constituents above method detection limits or site-specific background. This identification can be made by sampling a deeper ground water zone or by demonstrating that vertical migration to a deeper zone is very unlikely. Such a demonstration should be based on the hydrogeology in the vicinity of the unit and the chemical and physical properties of the hazardous constituents.

The above criteria for determining the nature and extent of ground water contamination should not be interpreted as a prescription that applies to every possible unit scenario. They are only guidelines that will generally allow the extent of contamination to be adequately defined in most situations. The actual criteria may vary in accordance with the characteristics of constituents (*i.e.*, their fate and transport capabilities) and the hydrogeologic conditions.

It is important to note that risk-based standards cannot be used for defining the extent of ground water contamination. To conduct a risk assessment or use risk-based standards, the exposure point concentration should be calculated for each constituent. Because it is necessary to use the full extent of contamination (*i.e.*, all samples that indicate the presence of contamination) in calculating an exposure point concentration, the extent of contamination should be determined prior to conducting a risk assessment or using risk-based standards.

Guidance for Ground Water Sampling

Determination of a unit's impact or potential impact on ground water involves a wide array of office, field, and laboratory activities. It is recommended that Ohio EPA's *Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring* as well as other documents identified in Chapter 8 of that guidance be consulted for more information.

Owner/operators who are required by OAC Rules 3745-54-90 through 3745-54-100 or OAC Rules 3745-65-90 through 3745-65-94 to monitor the ground water for the potential impact of their unit on ground water quality may need to verify compliance with the closure performance standard with additional sampling of the ground water. In all cases, Ohio EPA bases closure determinations on site-specific chemical parameters. Consequently, some owner/operators may need to augment their indicator parameter analyses with site-specific parameters and others may need to adjust their sampling frequency. Finally, it may be necessary to sample ground water from non-uppermost aquifer zones to demonstrate compliance with the closure performance standard. Under closure, all saturated zones that are potentially contaminated should be considered.

Parameters to be analyzed for in ground water may include any element or compound that is a hazardous constituent, as specified in OAC Chapter 3745-51.⁷ These parameters should not only be based on knowledge of the wastes managed at the unit, but may also include other potential elements or compounds used at the facility that may be commingled with the waste. Additional parameters for analysis (e.g., waste decomposition products) may be needed if there is a reasonable possibility that significant waste decomposition has occurred. An example would be vinyl chloride as a possible degradation product of some chlorinated solvents.

It should be noted that field instruments are not acceptable substitutes for laboratory methods. They may be used to suggest the presence, but not the absence, of hazardous constituents in ground water. If portable field instruments are used, they should be confirmed by SW-846 methods. A mobile laboratory may be used if it follows SW-846 methods and has proper QA/QC procedures as described in [Appendix F, Mobile Lab Guidance](#).

Whatever method for analysis of ground water samples is chosen, the method should be capable of achieving the lowest analytical detection limit that can be reliably achieved within specified limits of precision and accuracy during routine operating conditions that are available to the facility. All concentration data, even if it is estimated, should be reported for compounds or elements that have been positively identified in the sample. Sometimes target analytes are present at concentrations that are above the level that can be reliably detected but below the level that they can be reliably quantified. These data are referred to as "qualified" and will be reported as a number which has been "flagged" by the laboratory. Although less reliable than data which are reported above the Estimated Quantitation Limit (EQL), these qualified data must nevertheless be evaluated carefully by the DHWM reviewer. For more information on data validation, refer to Ohio EPA's (2006) *Tier I Data Validation Manual*.

Ground Water Sampling Plan Content

A ground water sampling plan that is part of a closure plan should include, but not be limited to:

⁷

For a detailed discussion about hazardous constituents, refer back to [Section 1.1, Rules Associated with Closure and Post-Closure Plans](#).

- **Data Quality Objectives (DQO).** As with soil sampling, statements concerning the objectives of the ground water sampling, the scope of sampling, and how the data will be used to accomplish the stated objectives should be clearly defined in the closure plan. Having information pertaining to the engineering, size, and location of the hazardous waste management unit is critical to an adequate ground water investigation. DQOs should include the need to define the nature and extent of contamination. In addition, the closure plan should, if possible, provide a clear statement of the remediation standard for the ground water. For example, if a risk-based closure is desired, then this should be stated as a data quality objective. This objective would then serve as a basis for determining the QA/QC procedures, such as assuring that the detection limits for the analyses are below the remediation standard.

U.S. EPA has numerous data quality documents that can be referred to for guidance on developing data quality objectives. These documents can be found at <http://www.epa.gov/quality/qatools.html>. The procedures or methods that are selected should be consistent with the data quality objectives of the closure plan.

- **Geology and Hydrogeology.** The closure plan should include a discussion of facility geology and hydrogeology, to the extent that it is known. This generally includes a review of available regional and site-specific information; investigation of site geology, including the types of materials present, the lateral and vertical extent of discernible geologic units, and any geological influences on ground water flow, such as fracturing; investigation of ground water occurrence, including zones that restrict or enhance flow, flow direction, temporal and seasonal fluctuation, flow rate, interconnection to surface water, and human-induced influences. The discussion should be supported by maps and cross-sections that indicate hydrogeologic conditions and ground water flow direction. The locations of any public or domestic supply wells should also be noted, along with any surface water bodies.
- **Historical Ground Water Monitoring.** The closure plan should summarize any ground water monitoring program that has been implemented to date, including its analytical results. All detected hazardous constituents should be noted, including the dates of detection, the concentration of each constituent (minimum, mean, maximum), the analytical method, and the detection limit. The results should also be interpreted (e.g., trend analysis).
- **Proposed Ground Water Sampling.** The closure plan should also discuss the proposed ground water sampling program in detail and provide information that relates to sampling locations, depths, frequency, and the minimum number of samples that will be acquired. The closure plan should clearly describe the sampling that will be done and the criteria that will be used to certify closure. Information on the monitoring well network should be provided, including maps and cross-sections indicating well placement, design details, and a schedule for inspection and maintenance. For each saturated zone, provisions should be made for sampling ground water that is hydraulically upgradient and hydraulically downgradient of the unit. To ensure an adequate assessment of ground water impact, monitoring wells should be appropriate with respect to their drilling, design, placement, and maintenance. Monitoring wells should be capable of yielding samples that

are representative of ground water quality. While direct push sampling and indirect methods (e.g., soil gas analysis, geophysical, and computer modeling) can be used, their results should be used primarily to supplement or guide monitoring well placement, not to make final conclusions. A statement indicating that monitoring wells will be properly abandoned following the Agency's acceptance of the closure certification should be included, if applicable. The closure plan should provide abandonment procedures and a projected date to meet the requirements of OAC Rule 3745-9-10. Refer to Ohio EPA's *Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring*, Chapter 9 and the State Coordinating Committee on Ground Water's (1996) *State of Ohio Technical Guidance for Sealing Unused Wells* for technical standards on abandoning wells.

The method(s) of acquiring samples should be discussed in detail. Important considerations include the type of equipment for removing ground water samples from monitoring wells, the procedures for use of the equipment, decontamination of sampling equipment as necessary, methods for detection and sampling of immiscibles, field QA/QC, sampling frequency and laboratory analysis, including the selected parameters and laboratory QA/QC. These procedures should be submitted with the closure plan either in the text of the document or in an appendix. The procedures or methods that are selected should be consistent with the data quality objectives of the closure plan. Plan content for ground water sampling and analysis is covered in Chapter 10 of Ohio EPA's *Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring*.

The closure plan should provide a discussion on the number and type of field quality control samples that will be taken as part of the ground water investigation. These quality control samples may include trip blanks, field blanks, equipment blanks, rinsate samples, replicate samples and duplicate samples. The closure plan should discuss the number of samples or the frequency at which field quality control samples will be collected. In addition, the closure plan should discuss how the data will be used and the consequences of the sampling results. For example, if duplicate sample results are greater than 20% relative percent difference, the precision of the field sampling program may be questionable. For more information, refer to Ohio EPA's (2006) *Tier I Data Validation Manual*.

If non-disposable ground water sampling equipment is to be used, field decontamination procedures should be discussed in the sampling plan. The closure plan should state that quality control data from equipment blanks will be provided to show that the decontamination procedures were adequate. The closure plan should also discuss the evaluation and management of purge water.

Analytical methods for ground water samples should be stated for either the specific parameter to be analyzed or the general type of analysis that will be needed for the investigation.

Any ground water sampling method modifications should be listed in a data narrative that accompanies a data report submitted to Ohio EPA. Any method modifications by a laboratory should be justified with method

development and method performance data that assures that the modification is commensurate with the reference method. Furthermore, methods other than those listed in SW-846 should include the quality control and quality assurance procedures so the validity of the analytical results can be assessed. It is important to note that if a sampling method is modified, then the sampling and analysis plan contained in the closure plan will also need to be amended. For more information on closure plan amendments, refer back to [Section 1.8, Closure and/or Post-Closure Plan Amendments and Extension of Closure Time Period](#).

As stated previously in the soil sampling section, evidence of a QA/QC plan from the laboratory should be provided upon request. This plan should also address ground water sampling.

Lastly, the closure plan should also explain the procedures that will be used to interpret the ground water quality data, including a detailed discussion of statistical and modeling procedures if applicable. Statistical comparisons of ground water quality should be consistent with the performance standards listed in OAC Rule 3745-54-97 (H) & (I) and the most recent U.S. EPA guidance on statistical analysis of ground water monitoring data at RCRA facilities.

3.13 Surface Water Sampling and Analysis

For all surface water bodies that meet the regulatory definition for surface waters of the state (OAC Rule 3745-1-02-DDD), surface water standards are directly applicable and attainment of these standards must be assessed through the site characterization process. The closure plan should include a characterization of receiving waters, wetland areas, etc. in order to determine if direct or indirect discharges to surface waters have caused impacts. Surface water standards may include chemical and biological water quality standards, anti-degradation criteria, permit limits, or risk-based goals (per ecological and human health risk-based guidance). For more information on water quality standards, contact the Division of Surface Water. Input from Division of Surface Water experts may be required for an adequate review of a surface water sampling and analysis plan.

3.14 Sediment Sampling and Analysis

If there is reason to believe sediments have been affected by the hazardous waste management unit, both chemical and bioassay testing of sediments may be necessary, as well as the evaluation of stressors and biotic communities. Refer to ecological and human health risk assessment guidance for further information.

Sediment sampling is a function of site-specific factors including habitat type, flow regimes, sampling methodologies and required analyses.⁸ Preferential flow paths in moving bodies of water that may result in discontinuous deposition of contaminants in sediments should be evaluated. Sampling and analysis plans should be capable of delineating contamination under these conditions and document that sampling strategies have evaluated these areas, including depositional zones and quiescent areas or inside channel bends where fine grained sediments would most likely settle.

⁸ See Ohio EPA (2001) *Sediment Sampling Guide and Methodologies*.

The sediment characterization depth is a function of site-specific objectives. A primary objective is to characterize the biologically active zone. However, data may also need to be collected to evaluate the potential for scour or release events, affecting other sensitive environments. An example is when evaluating major rivers in the Lake Erie Basin, although the biologically active zone may only be a few centimeters deep, sediment contamination to the scour depth may need to be characterized to ascertain potential impacts on Lake Erie. Alternatively, in a flood plain environment, sediment may need to be characterized to evaluate impact beyond the stream bed.

Standard SW-846 methodologies are, in general, appropriate for sediment chemical analyses. However, special analyses may be required to achieve lower analytical detection limit or address certain contaminants of concern. In addition to collecting samples for chemical analysis, it may be important to collect samples for grain size, specific gravity, water or solids content, total organic carbon content, and cation exchange capacity. These values are often helpful in making operational decisions as well as identifying factors that may affect bioavailability or survival in toxicity testing organisms (that is, some toxicity test organisms are affected by grain size). For information on sediment biological analysis, refer to Ohio EPA's (2003) *Guidance for Conducting RCRA Ecological Risk Assessments*.

3.15 Background and Soil

Background is defined as the concentration of naturally occurring substances that are unaffected by any current or past activities involving the management, handling, treatment, storage or disposal of hazardous wastes or hazardous constituents. Background levels include only naturally occurring substances sampled from unaffected portions of the closure site (that is, samples outside of the unit) and areas surrounding the closure unit. Naturally occurring substances are substances present in their unaltered form or altered solely through naturally occurring processes or phenomena, in a location where they are naturally found.

Background data may be used to develop a remediation standard for closure by removal, define the nature and extent of contamination and/or screen out constituents of concern from a risk assessment. However background data is not required to be determined at every site. Site-specific considerations and the regulatory and remedial strategies will determine the necessity for performing background sampling.

A minimum of twelve background sampling points should be selected to represent an area not directly affected by the RCRA unit or any other concentrated waste management or product handling activities, unless it can be shown that the area undergoing closure was equally affected by these activities.⁹ In some cases, when the soils in the background area and the closure unit have both been similarly affected by a source unrelated to the RCRA hazardous waste management unit (e.g., air emissions, wastewater sludge operations, etc.), concentrations found in the background soils may still be acceptable. Background samples should be analyzed using total constituent analysis.

When collecting background samples, the area in which to sample should be considered, in addition to other things. It is important that background soil samples be of the same type of soil horizon material as any comparison (on-site) soil samples. To confirm this, DHWM recommends the soil texture (percent silt, sand, clay), soil pH and cation exchange capacity be determined. Background sampling locations should be in areas representative of the matrix of interest. For example, background samples should, if possible, be taken within the same

⁹ Refer to [Appendix C, Statistical Evaluation of Hazardous Constituent Levels in Soils](#) for an explanation of the minimum sample size.

aquifer unit, soil type and stratigraphic unit as any comparison samples. Data should be examined for any evidence that may suggest that the measured concentrations are not representative of the background soil.¹⁰

In general, background samples should be eliminated and replaced with a like number of samples from uncontaminated areas if: (1) the background samples were taken in areas known or suspected to be contaminated by a source which did not similarly affect the closure area, or (2) the background samples have possibly been affected by RCRA activities conducted in the area undergoing closure. Areas to avoid for background sampling include, but are not limited to:

- past waste management areas where solid and/or hazardous wastes or wastewater may have been placed on the ground, areas of concentrated air pollutant deposition (from a definable localized source), or areas affected by the runoff;
- roads, roadsides, parking lots, areas surrounding parking lots or other paved areas, railroad tracks or railway areas or other areas affected by the runoff;
- storm drains or ditches presently or historically receiving industrial or urban runoff;
- spill areas, material handling areas, such as truck or rail car loading areas, or near pipelines, fill areas and other areas as determined by Ohio EPA.

Please note: In order to obtain appropriate background samples, it may be necessary to collect samples from a nearby, off-site location. All potential background sampling locations should be included in the closure plan, which will be evaluated and approved by Ohio EPA.

Background data should be checked for sampling and laboratory errors, field evidence of waste materials at the sampling locations, and other problems that indicate the data do not represent true background conditions. Where sufficient evidence indicates that a background sample is not truly representing a background concentration, the datum should be discarded and a substitute sample should be obtained. If no specific error can be documented, then the sample may be retained if an acceptable justification can be provided. For detailed information on outliers, refer to [Appendix C, Statistical Evaluation of Hazardous Constituent Levels in Soils](#).

In some cases, re-mobilization to obtain additional background samples may be difficult and costly. To avoid re-mobilization, the facility should be encouraged to take additional samples beyond the minimum prescribed. These samples may be held by the laboratory pending analysis of the minimum number, and analyzed as “back-ups” if there are data or analysis problems with any of the original sample set.

If any hazardous constituent identified in the waste and included in the list of constituents submitted by the owner/operator and approved by Ohio EPA, is not detected at a rate greater than 90% in the background soil, then the MDL for the individual constituent should be used as the remediation standard. Refer to [Section 4.1, Remediation Standards for Soils and Ground Water](#), for additional discussion on remediation standards and method detection limits.

¹⁰ There may be situations where wide-spread anthropogenic contamination may have to be considered when performing a background study. Elevated levels of constituent concentrations would then be included as background, even if the constituent was not naturally present at these levels or even naturally occurring. This approach should be used cautiously, you must first consult your supervisor.

For more information on background sampling, refer to U.S. EPA's (1995) *Determination of Background Concentrations of Inorganics in Soils and Sediments at Hazardous Waste Sites*.

Lastly, on a case-by-case basis, existing regional soil data may be used (e.g., Alternate Metal Standards).¹¹ These data should be used to establish ranges and as a tool to enhance confidence in site-specific data. Due to limitations in the validity of comparing regional data, such as variations in soil type, laboratory methodology, and sampling context, the use of these data should be discussed with your supervisor.

3.16 Background and Ground Water

Individual measurements or representative concentrations of hazardous constituents in ground water can be compared to background. Background means the concentrations of naturally occurring hazardous constituents at a closure unit and areas surrounding a closure unit that have not been affected by any past or present activities at the closure unit. Naturally occurring hazardous constituents are constituents that are present in their unaltered form or altered solely through naturally occurring processes or phenomena, in an undisturbed location. Since closure is unit-specific, background levels may include naturally and non-naturally occurring constituents in the ground water from anthropogenic sources from an upgradient source. If no suitable methods exist to determine background, then background cannot be the applicable standard.

Procedures for Background Sample Collection

The following items are applicable for collection of representative background:

1. Background data should be collected from a sufficient number of wells, installed at appropriate locations and depths, to yield ground water samples representative of the quality of the background ground water that has not been affected by any past or present activities at the closure unit.
2. Each of the wells should be designed, installed, and developed in a manner that allows the collection of representative ground water samples.
3. Background ground water quality should be established from wells that are hydraulically upgradient of the closure unit. Wells should not be within the hydraulic influence of mounding under the regulated unit, and upgradient ground water quality should not be affected by gas migration from the regulated unit. The background monitoring well system may include wells that are not hydraulically upgradient of the closure unit where:
 - Upgradient wells can not be determined based on hydrogeologic conditions.
 - Sampling of other wells will provide an indication of background ground water quality that is as representative or more representative than that provided by upgradient wells.

¹¹ Flexibility is needed for sites where naturally occurring compounds affect the site media and it can be shown that the compounds were not historically used at the site. Spatial variations of naturally occurring compounds will hinder even best intentions of a statistical comparison causing false positives and unnecessary analysis when compounds are not source related. In such situations, comparison to regional and literature data may also be appropriate, as part of a weight-of-evidence approach. U.S. EPA's (2002) *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* should be consulted.

DHWM recommends more than one upgradient or background well be installed to control or correct for seasonal and spatial variability as well as temporal correlation in the data.

If it is not possible to find an appropriate location to determine background levels of hazardous constituents for ground water on or underlying the property, it may be possible, if deemed appropriate by DHWM, to use ground water quality data from other nearby sites in determining the background concentrations. All ground water quality data should be representative of conditions at the closure unit with sample collection from the proper ground water zone and proper QA/QC followed for sample collection and analysis. If commingled plumes are present, an integrated approach may be possible. Your supervisor should be consulted for guidance on the background assessment in these situations.

Generation of Statistical Background

1. The number of samples collected to establish background should be sufficient for the method selected for comparison, ensuring with reasonable confidence that a release to ground water will be detected. Most statistical methods have a minimum background sample size that is needed for valid results.
2. Sufficient background data should be collected to allow statistical tests to be conducted separately for each hazardous constituent.
3. All data points must be generated independently of one another (OAC Rule 3745-54-97). Enough time should pass between sampling events to ensure that the previously sampled ground water has left the vicinity of the monitoring well.
4. Any statistical method used to establish a background value must be appropriate for the distribution of the data (OAC Rule 3745-54-97). If the distribution is shown to be inappropriate for a normal theory test, then the data should be transformed or a distribution-free theory (non-parametric) test should be used. If distributions for the individual hazardous constituents differ, more than one statistical method may be needed.
5. When a background value is developed, account should be taken of the variance in the data. Variance is the range or spread of data values for one hazardous constituent in a well. When the background value is later statistically compared to other values, the power of that statistical test may be reduced if the variance between the two groups of data is not the same. One of the basic assumptions of statistical testing is homogeneity of variance.
6. Any statistical methods used to determine the background concentrations should account for data below the limit of detection with one or more statistical procedures that are protective of human health and the environment. Any Practical Quantitation Limit (PQL) used in the statistical method should be the lowest concentration level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions using the methods outlined in the most recent version of *SW-846*. The PQL should be below the potable ground water standard.
7. Background data collection should be appropriate to indicate any seasonal and spatial variability as well as any temporal correlation of data.

8. The background data set needs to truly represent the quality of the water moving from the upgradient to downgradient wells. In order to achieve this, the following procedures should be followed:

- a) U.S. EPA, ASTM, and other guidance recommends that outliers are not appropriate for characterizing background data and should not be included. An outlier, greater than five (5) standard deviations above the mean, that has not been eliminated from the data pool because of a bias identified by quality control data, should still not be included in background data. It could be possible that the outlier is a true rare event but it is also possible that the outlier slipped through quality control. Cameron, K.'s (1999) *Draft Statistical Analysis of Ground Water Monitoring Data at RCRA Facilities - Unified Guidance* supports the procedure of excluding outlier data from data pools used to characterize background. In section 8.1 of the draft guidance it states "If either Dixon's or Rosner's test designate an observation as a statistical outlier, the sample should generally not be treated as such until a specific physical reason for the abnormal measurement can be determined....One exception to this rule would be when screening for high outliers in background data...the effect of removing outliers from the background will usually be to improve the odds of detecting upward changes in the concentration levels of downgradient wells, thus furthering protection of human health and the environment..." Considering that the choice is between leaving the data point out which, if incorrect, will wrongly increase false positive demonstrations or leaving it in which, if incorrect, will wrongly increase false negatives, it is better to be on the conservative side of safety and leave the outlier out of the background pool.¹²
- b) Data analysis results that have quality control qualifiers attached to them, indicating a bias, should not be included in background.
- c) Statistical comparisons should not be initiated with a background data set of less than 8 points. The background data set may be increased in sets of 4 data points checking for trends each time, until a data set of at least 16 values has been reached. In general, a statistical test will gain substantially in power (ability to detect contamination if it is present) by allowing it to increase from 8 to 16 data points. Only a minimal increase in power is obtained from further increases of background size.¹³
- d) This data set of 16 background points should continue to be used unless a statistically significant change is identified using ASTM, U.S. EPA, or other statistically approved methods.
- e) Anytime a statistical change in background is identified, using the above mentioned methods, background should not be updated until it is justified that it is not due to past or present activities at the unit. The change

¹² This procedure is supported by ASTM D 6312-98 and Gibbons, R. (1999) "Use of Combined Shewhart-CUSUM Control Charts for Ground-Water Monitoring Applications."

¹³ Davis, C.B. (1998) *Ground-Water Statistics & Regulations - Principles, Progress and Problems*.

needs to be evaluated as to whether it is due to a cyclical change, off-site influence, or just the fact that the initial background data set did not capture the full variability of natural background. If the latter is the case, then continuing to add values to the data pool in sets of at least four will most truly represent the actual background water quality. If the change is due to a gradual, natural quality change or continuing off-site influence, then a “moving window” would be recommended.¹⁴ Gibbons states “...if you update background after four samples, you can expect a release of 3 standard deviation units to be detected in 3.4 monitoring events, but in 13% of the cases, a release of 3 standard deviations units will go undetected....Perhaps most serious, is that frequent updating of background (e.g., after every 4 samples with small initial background sample size (e.g., $n = 8$ background measurements) can lead to a relatively high percentage of cases in which a 3 standard deviation units increase can go undetected.” Thus, Gibbons recommends, as in the ASTM D 6312-98 guidance, that every time background is updated, the new background data group be checked for increasing trends. If after updating background, a new trend is detected, then the background data should not be updated for that well and constituent unless it is demonstrated that the unit is not the cause for the increase in background.

- f) The new background (previous background data plus new background data) should be checked for slowly increasing trends. If a slowly increasing trend is identified then the background should not be updated unless concurrence from DHWM is received that the increasing trend is not the result of a release from the unit. If a trend is identified in the new background data group, then there are three possible actions that can be taken.
 1. Do not update background. If an increasing trend is identified in the background then the option to not update background should be evaluated first. If the landfill, waste unit, or area of concern is suspected of being the cause of the increase, then background should not be updated. If it is apparent that the change in background is due to an alternate source or natural temporal variation, then one of the following two types of background updates should be selected.
 2. Update background by adding data. If the change in background appears to be a cyclic change of short duration, then background should be updated by adding the most recent data points, increasing the background data size to include the full range of natural variation.
 3. Update background to a new time period (moving window). If the change in background appears to be a stair-step type shift (shift of significant duration) or a trend due to an alternate source, then background should be updated by selecting a background time period of adequate size that best represents the current

¹⁴

Gibbons, R. (1999) “Use of Combined Shewhart-CUSUM Control Charts for Ground-Water Monitoring Applications.”

background conditions. The size of the moving window will be dependent upon the rate of change and the best balance between background size and variance.

9. If the background data set was developed and then sampling suspended for a period of time, when sampling is re-established, either a completely new background data set should be developed or as each new background sample is obtained, it should be statistically compared to the old set to see if naturally occurring ground water quality has changed.
10. Any statistical method(s) chosen to establish hazardous constituent background values should be in accordance with the most recently finalized U.S. EPA statistical guidance documents¹⁵. The flow chart for statistical analysis decision making as included in the ASTM guidance document number D 6312-98 may be followed where deemed appropriate by DHWM.

3.17 Background and Sediment

Background sediment characterization methodology does not differ significantly from site sediment characterization methodology. For additional detail, refer to Ohio EPA's (2003) *Guidance for Conducting RCRA Ecological Risk Assessments* (which includes sediment reference values, an additional sediment comparison option) and Ohio EPA's (2001) *Sediment Sampling Guide and Methodologies* (which contains information regarding choosing sampling locations, sampling methodologies, etc.).

Given the difficulty of identifying suitable background sediment locations, to facilitate site-specific sediment characterization in lotic water systems, Ohio EPA has evaluated the data in the Agency's sediment database, and generated generic Sediment Reference Values (SRVs)¹⁶ for certain inorganics. The SRVs are eco-region based and should be used appropriately (*i.e.*, the unit-specific sediment data should be compared to the appropriate eco-regional SRV). The SRVs can be used as a substitute for site-specific background data to determine if the potentially impacted area has contaminated sediment.

SRVs are not available for organics, at this point. If upgradient impacts are a concern at a site, DHWM recommends conducting upgradient sampling to facilitate risk management decisions. Upgradient sediment data cannot, however, be used as a substitute for ecological characterization.

3.18 Background and Surface Water

The Division of Surface Water (DSW) has established, through "reference sites", chemical and biological water quality background standards. Also, on occasion, upstream sampling may be used to establish a type of background. However, the applications are complex, and vary widely on a site-by-site and stream-by-stream basis. Consultation with your supervisor and a DSW biologist is mandatory for any consideration of surface water (or sediment) background.

¹⁵ As this guidance goes to press, the most current U.S. EPA documents include the (1989) *Statistical Analysis of Ground Water Monitoring Data at RCRA Facilities. Interim Final Guidance*, the (1992) *Statistical Analysis of Ground Water Monitoring at RCRA Facilities. Addendum to Interim Final Guidance* and Cameron, K.'s (1999) *Draft Statistical Analysis of Ground Water Monitoring Data at RCRA Facilities - Unified Guidance*.

¹⁶ Ohio EPA. (2003) *Guidance for Conducting RCRA Ecological Risk Assessment*.

3.19 Use of Historical Data

Introduction

RCRA regulated facilities, when undergoing unit closure, are expected to investigate any potential release of wastes from a hazardous waste management unit and determine the nature and extent of contamination. This investigation is dependent upon acquiring soil, sediment, water and waste samples that will determine the impact of contamination and which serve as a basis for remedial measures. Many facilities have been in operation for a significant period of time and sampling data may be present that was collected prior to the initiation of unit closure. This data may greatly benefit the closure investigation if the data meets the Data Quality Objectives (DQOs) set forth in the closure plan. In addition, the closure process will be expedited and less costly because fewer samples will be required.

U.S. EPA has recognized the importance of using historical data and has included discussions on its use in several guidance documents, including

- *Guidance for Data Usability in Risk Assessment, Part A* (publication 9285.7-09A; April 1992) and in the U.S. EPA memorandum *Region 5 policy*; and,
- *Guidance Regarding Historical Data Usage in RCRA Facility Investigations* (Niedergang; May 8, 1998).

If a facility desires to use historical data it should provide DHWM notification prior to the approval of the closure plan. This notification, either verbal or written, should involve:

- discussion of the relevance of the data to the DQOs of the closure process
- the type of media that was sampled
- the number of samples
- the parameters that were analyzed
- the type and amount of Quality Control/Quality Assurance (QA/QC) data that is present.

The DQOs for a unit closure must be known before a determination that historical data is acceptable for use or not (See [Section 3.11, Soil Sampling and Analysis](#), for a discussion of DQOs). For many closure sites, the DQOs may change as the closure of the unit progresses. It is appropriate to re-evaluate the acceptability of existing data at any time within the closure process if the DQOs change. For readers who do not know about DQOs or the DQO process, the U.S. EPA maintains an extensive set of guidance and software tools on the subject at the following website <http://www.epa.gov/quality/>.

Historical data will fall in a continuum of:

- universally acceptable data, which can be used to meet all data quality objectives for closure;
- intermediately acceptable data, which can be used to meet some DQOs but not the highest data quality objectives, and
- unacceptable data, which does not have sufficient quality to meet any data quality objectives.

The facility or its representative should work with DHWM personnel to determine whether or not historical data satisfies the closure plan's DQOs. The following sections in this guidance present DHWM's perspective on the evaluation of historical data.

Requirements to Demonstrate the Acceptability for Historical Data

Once a facility has provided written or verbal communication to the Agency that it wishes to use historical data for the closure, the facility, in most cases, should prepare and submit to DHWM a detailed description of historical data that it intends to use in the closure process. This description should include review of the historical data report(s), a description of the original intended purpose for the data and a discussion of potential uses of this data within the closure process.

An initial review of the historical data should be performed by the facility or its representative. A data review should, consist of:

- Identification of the laboratory performing the analysis,
- Identification of the sampling dates, sample locations, and sample depths,
- Sampling method (e.g. Method 5035 for VOC soil analysis),
- Sample preservation,
- Analysis dates and time, extraction dates and time, preparation dates and times,
- Laboratory reporting and detection limits for the analyses,
- Laboratory ID cross referenced with field sample ID,
- QA/QC sample results and laboratory acceptability criteria,
- Laboratory data narrative with an emphasis on QA/QC irregularities, and
- Original analytical report (hardcopy).

This review should be summarized in a concise report that can be reviewed by DHWM and DDAGW personnel. The acceptability of the historical data will be determined through negotiations with DHWM, DDAGW, the facility and its representatives. Ultimately the decision is made by DHWM with input from DDAGW. In general, three decisions may be agreed upon:

1. accept all or some of the data and use it to support the closure of the unit;
2. require confirmatory sampling prior to making a decision about the acceptability of the data, or
3. reject the data and continue acquiring data to support the closure of the unit.

There is no hard and fast rule about whether to accept the historical data, deny the use of this data or require confirmatory analyses. Decisions to use historical data should be made on a case by case basis. In general, historical data is acceptable for unrestricted use if the data meets the DQO requirements for closure. Typically data of this quality has been generated using acceptable methods of sample acquisition; has all available QA/QC information and has acceptable QA/QC data; the method detection limits and reporting limits are acceptable; and sample locations and depths are relevant to the closure unit.

If the historical data is used to determine future sampling locations, data deficient in some QA/QC criteria or sample acquisition methods may be acceptable. Please note that deficient data cannot be used to determine the absence of contamination or to conclude that no further sampling is necessary. Conversely, if historical data is to be used to support a human health or ecological risk assessment, it must be of the highest quality and meet the reporting and QA/QC documentation requirements for the closure unit.

An example of where historical data may not be used for the highest data quality objectives includes a situation where soil samples were taken from a closure unit and analyzed for VOCs using methods other than described in SW-846 Method 5035. Because the standard for sample acquisition has changed since 1999, this data would not be considered usable

for risk assessment purposes or for a determination that a soil clean standard had been met. However, this data would be acceptable to guide future sampling efforts.

Confirmation sampling may be required if the historical data contains most, but not all the information to make a determination of its acceptability. In addition, confirmation sampling may be required if it is believed that conditions at the closure unit have changed and the historical data no longer reflects the current conditions at the site. Historical data should address all of the current COCs at the site. This situation may arise because of releases of waste to the environment after the historical samples were collected or due to contaminant migration.

Confirmation of Historical Soil Data Through Sampling

If it is determined that confirmation sampling is necessary before historical data can be accepted, the facility will develop a sampling plan that will acquire sample data of sufficient quality to make a comparison with the historical data set. The confirmatory sampling plan should include data quality objectives commensurate with those discussed within [Section 7.1, Data Collection/Evaluation](#). The plan should, at a minimum, state and clearly describe the following:

- Location of samples. Confirmatory samples should be taken at the same location as the historical samples. If samples will be acquired from locations other than in historical locations, the rationale for these locations, and the number of samples should be described in the work plan.
- Number of samples. The number of confirmatory samples and the rationale for selecting the number of samples should be discussed in the plan. The number of samples will depend upon the heterogeneity of the waste, the type of contaminants (volatile, soluble or immobile compounds), and the number of historical analyses that will be confirmed.

Analysis of Soil Confirmation Data for Historical Data Use

U.S. EPA (1998) identifies several situations that might arise when comparing confirmation data with historical data. The first situation arises when historical data and confirmatory data correlate acceptably. How the confirmatory data will be used to verify the historical sampling data should be described. For example, the facility may choose to use statistical procedures. If so, the plan should state the type(s) of statistical tests that will be used, the underlying assumptions inherent in these statistical tests and the level of confidence that will be used to evaluate the data. See [Appendix C, Guidance for Statistical Evaluation of Hazardous Waste Constituent Levels in Soils](#), for a detailed discussion of statistical procedures. In this situation, the data either confirms the presence of contamination or confirms the absence of contamination. Furthermore, if the datasets agree, either statistically or by some criteria (e.g. within 20% between samples from the same location), then the historical data can be used in closure decision-making.

A second situation results when the historical dataset identifies significant releases, but the confirmatory data do not. This situation may arise when natural migration and transformation processes have resulted in changes in the soil concentrations of chemicals of concern. The facility can use the confirmation data to support further investigation sampling that would either identify contaminated media or confirm that clean standards have been achieved.

The third situation results when historical data indicates insignificant releases of waste materials, but the confirmation samples identify that significant releases have occurred. This situation would invalidate the historical sampling results. The closure investigation should proceed and a sufficient number of samples should be taken to meet the DQOs for the unit closure.

There is no rule of thumb for the number of confirmation analyses. However, Niedergang (May 8, 1998), states that a reasonable number of samples for confirmation is to sample 25% of the historical sample locations. The facility or its consultant should consider using the U.S. EPA guidance *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies* (EPA /600/R-92/128, July 1992) and *A Rationale for the Assessment of Errors in the Sampling of Soils* (EPA/600/4-90/013, May 1990) to help determine the number of samples necessary for confirmation.

Historical Data Use and Background Ground Water Concentrations

A special note must be made concerning the use of historical data when determining background concentrations of constituents of concern for ground water compliance monitoring. Background levels include both natural occurring substances, and natural occurring substances from anthropogenetic sources. In rare circumstances, organic constituents may be present in background samples due to off-site contaminant sources. The following performance standards are applicable whether data is collected on or off-site or through Ohio EPA's ambient ground water quality monitoring network.

Ground Water Data Collection and Manipulation Performance Standards

Data must have been collected from a sufficient number of wells, installed at appropriate locations and depths, from the proper ground water zone and proper QA/QC followed for sample collection and analysis. This is to ensure that ground water samples are representative of the quality of the ground water affected by any past or present activities at the unit. If use of historical data from three wells within the plume is proposed for risk assessment without confirmation sampling, then the data should cover consecutive monitoring events, ranging over at least a one-year period to include seasonal variations. The most recent data should have been collected within 12 months of the proposed use in a risk assessment. If confirmation sampling is to occur, then samples from at least three wells within the plume should be collected, including the well with the highest historical contamination levels.

The background dataset should be such that it reflects naturally occurring changes in hydrogeology. If the dataset was developed and then sampling suspended for a period of time, when sampling is re-established, either a completely new background dataset should be developed or, as each new background sample is obtained, it should be statistically compared to the old set to see if naturally occurring ground water quality has changed. Most statistical methods have a minimum background sample size (typically 8 to 10) needed for valid results.

3.20 Financial Assurance Requirements

Ohio EPA's financial assurance requirements are contained in OAC Rules 3745-55-42 through 3745-55-48 for permitted facilities and OAC Rules 3745-66-42 through 3745-66-48 for Interim Standard facilities. The owner/operator of a facility must demonstrate that funds will be available to properly close their facility. If the closure is a waste in place closure, then post-closure care must be provided. In addition, the owner/operator must have financial resources to compensate third parties for any injury or accidents that might result from facility operations.

Financial assurance requirements are to ensure that owner/operators cannot default to state or federal funds because they are unable or unwilling to cover significant closure and post-closure costs.

Financial assurance requirements are required for facilities under Interim Standards once they are subject to hazardous waste rules. The facility's financial assurance information should be submitted to DHWM's CO financial assurance staff. However, new facilities are required to submit evidence of financial assurance documentation with the Part B permit application or 60 days prior to the initial receipt of waste, whichever is later. The financial assurance mechanism must be effective prior to the initial receipt of waste. It is important to note that for a permitted facility, any change to financial assurance must be submitted as a permit modification request.

Cost Estimates

Owner/operators must prepare detailed written estimates of the current costs of closing their facilities and, for disposal facilities, the costs of monitoring and maintaining them after closure.¹⁷ *Detailed* means a listing of the specific costs associated with each major phase of closure and/or post-closure activities for each hazardous waste management unit. Closure activities include, but are not limited to: removal, transportation and off-site disposal of hazardous waste and contaminated media; decontamination activities; construction of a landfill cover system; sampling and laboratory analysis; and certification of closure by a professional engineer. Post-closure activities include, but are not limited to: removal of leachate, inspection and repair of vegetative cover, site security, ground water monitoring, deed notation, and certification of post-closure by a professional engineer. Ohio EPA also requires the inclusion of an appropriate contingency cost in the closure cost estimate.

Owner/operators should prepare cost estimates for closure and/or post-closure care based on the following (OAC Rules 3745-55-42, 3745-55-44, 3745-66-42 and 3745-66-44):

- Closure at the point during the active life of the facility where the extent and manner of its operations would make closure most expensive (e.g., the facility operating with all units filled to capacity);
- Closure activities performed by a third party contractor;
- Disallowance of any resale or salvage credits; and
- Projected post-closure costs for 30 years.

Cost estimates for closure and post-closure care are submitted separately from the closure and/or post-closure plan and must be adjusted annually. Two ways owner/operators can adjust their estimate would be to (1) recalculate the estimate or (2) adjust the estimate for inflation by using the most current inflation factor. Owner/operators must adjust cost estimates following any changes to their closure and/or post-closure plan that would raise the cost of closure and/or post-closure care (OAC Rules 3745-55-42 and 3734-66-42).

¹⁷

Refer to OAC Rules 3745-55-42 and 3734-66-42.

More information on closure cost estimates may be found in cost estimating software programs, such as Costpro[®].¹⁸

Closure and/or Post-Closure Financial Assurance Mechanisms

In order to demonstrate the financial resources to operate a hazardous waste facility, an owner/operator must use one or more of the financial assurance mechanisms specified in OAC Rule 3745-55-51. An owner/operator may demonstrate financial assurance for closure and post-closure care by choosing from the following financial assurance mechanisms: Trust Fund, Surety Bonds, Letter of Credit, Insurance, Financial Test and Corporate Guarantee.

Within sixty days after an acceptable certification of final closure and/or post-closure is received, the Ohio EPA director will notify the owner/operator that financial assurance for final closure and/or post-closure is no longer required.

Third Party Liability Requirements

An owner/operator is required to maintain sudden and/or nonsudden accidental liability coverage until certification of final closure. This coverage ensures that, should an accident resulting in a release of hazardous constituents occur, money will be available to compensate third parties suffering bodily injury or property damage resulting from the accident. A sudden accidental occurrence is an event that is not continuous or repeated, such as a fire or explosion. All TSDF's that are subject to financial assurance requirements must have coverage for sudden accidental occurrences. A nonsudden accidental occurrence is an event that takes place over time and involves continuous or repeated exposure to hazardous waste. An example of a nonsudden accidental occurrence is a leaking surface impoundment that contaminates a drinking water source over time. The owner/operator of a surface impoundment, landfill, land treatment facility or miscellaneous disposal unit must have financial assurance for nonsudden accidental occurrences (OAC Rules 3745-55-47 and 3745-66-47).

¹⁸

U.S. EPA and Tetra Tech EM Inc. have a joint copyright on the CostPro[®] software. The terms of the copyright allow U.S. EPA to distribute the software freely to all entities within the federal government that act on behalf of U.S. EPA. The software is sold commercially, however, to all entities other than the federal government. U.S. EPA, Region 4 maintains the CostPro[®] software and has updated it annually to incorporate current cost data. The cost data used in the CostPro[®] software is provided primarily by R.S. Means Company, Inc. and is published in the *Means Cost Guides*.

Chapter 4

Components for Closure by Removal Plans

As discussed in [Chapter 1](#), there are two broad approaches towards achievement of the closure performance standard - closure by removal or decontamination and closure with waste in place. This chapter discusses plan components for closure by removal situations. All closure by removal situations require the complete removal of the hazardous wastes that were managed in the unit. Additionally, closure by removal situations must also address every medium (soil, ground water, etc.) contaminated with hazardous waste or hazardous constituents in order to meet the closure performance standard of OAC Rules 3745-66-11 and 3745-55-11. Typically this is demonstrated in one of two ways: 1) cleanup of media to pre-existing conditions (e.g., non-detect levels for non-naturally occurring contaminants or background levels for naturally occurring contaminants), or 2) cleanup of media to residential risk-based remediation standards. With both approaches, closure of the unit(s) is achieved and further regulatory controls are not required to ensure continued protection of human health and the environment. This is commonly referred to as an *unrestricted use* closure scenario.

However, DHWM allows the consideration of reasonably expected future land use during cleanups and, in certain situations, applies non-residential (industrial use) exposure assumptions to the development of cleanup standards. DHWM allows the appropriate use of industrial use exposure assumptions when identifying the amount of decontamination necessary to satisfy the “remove or decontaminate” standard. Using industrial use exposure assumptions to identify the amount of decontamination necessary to satisfy the “remove or decontaminate” standard does not affect any other closure requirement. This means, that all hazardous wastes and liners must still be removed. In addition, a remediation standard based on industrial use exposure assumptions must be achieved throughout the closing unit and any areas affected by releases from the closing unit. The resulting remediation standards must also ensure that environmental receptors are adequately protected and that no unacceptable transfer of contamination from one medium to another (e.g., soil to ground water) will occur. All complete and potentially complete pathways must be addressed (e.g., trespasser exposure pathways, and/or construction/maintenance worker exposure pathways, etc.).

Industrial exposure scenario risk-based cleanup standards need to be commensurate to the designated and future use of the site. Industrial use exposure assumptions should not be used unless there is a reasonable degree of confidence that future land use will conform to those assumptions. To ensure future use of the site is consistent with media cleanup standards, such *restricted use* scenarios will require the imposition of an environmental covenant. For more details on the appropriateness of a restricted use approach and corresponding risk assessment considerations, please refer to [Section 6.2, Human Health Risk Assessments](#), or consult your supervisor.

4.1 Remediation Standards for Soils and Ground Water

One of the most essential issues for closure by removal of hazardous waste management units (units) is the determination of remediation standards. All closure by removal plans should include a remediation standard for soil and ground water impacted by the hazardous waste management unit.

For closure by removal, a remediation standard for each contaminant in soil and ground water is required in the closure plan and, for soil, may be determined by either comparison to existing background conditions or through a risk assessment - whichever is applicable. The remediation standard for contaminated ground water is typically determined by comparison to Maximum

Contaminant Levels (MCLs) or through a risk assessment. Additionally ground water may be compared to existing background conditions, if appropriate. Although an owner/operator is not required to attempt a cleanup to background conditions first, it is usually infeasible to attempt a risk-based closure demonstration without substantial sampling data defining the contaminants and the extent of soil and ground water contamination. Risk-based remediation standards are discussed briefly in this section but more detailed information can be found in Chapters 6 ([Risk Assessment in Closure](#)), 7 ([General Concepts in Human Health Risk Assessments](#)) and 8 ([Special Contaminants](#)).

The following sections discuss soil and ground water remediation standards that have been established to provide consistency for hazardous waste closures in Ohio and provide several avenues for facilities to meet the closure performance standard.

Developing a Background Remediation Standard for Soil

As stated earlier, background soil is defined as the concentration of naturally occurring substances that are unaffected by any current or past activities involving the management, handling, treatment, storage or disposal of hazardous wastes or hazardous constituents. Background levels include only naturally occurring substances sampled from unaffected portions of the closure site (that is, samples outside of the unit). Naturally occurring substances are substances present in their unaltered form or altered solely through naturally occurring processes or phenomena, in a location where they are naturally found. Soil from the closure area can be compared to soil from a background area in order to demonstrate that the closure by removal meets the closure performance standard. For more information on background sampling for soil, refer back to [Section 3.15, Background and Soil](#).

If the hazardous constituents found in the closure area are the same as those found in the background soils, then a site-specific Background Remediation Standard (BRS) may be developed as a remediation standard (Refer back to [Section 1.1, Rules Associated with Closure and Post-Closure Plans](#), for a detailed discussion on hazardous constituents). The BRS is defined, based on a normal distribution of data, as the mean background concentration plus two standard deviations of the background data for a specific constituent of concern.

Equation 4-1: Calculation of the Background Remediation Standard (BRS)

$\text{BRS} = \text{mean value} + 2 \text{ standard deviations}$
--

If the concentration of a hazardous constituent of concern in the closure area “significantly” exceeds the site-specific BRS, then the area is considered contaminated and should be remediated. To determine if the BRS has been “significantly” exceeded, refer to [Appendix C, Guidance for Statistical Evaluation of Hazardous Constituent Levels in Soil](#).

Alternate Metal Standards¹ for Soil

All soils contain some (usually small) amounts of metals. The concentration of a particular metal typically varies with the type of soil, the soil’s geological parent material, the geological period and amount of exposure to that particular metal from a natural

¹ Alternate Metal Standards as used here are equivalent to the Generic Remediation Standards that were presented in earlier versions of the CPRG. The name was changed to prevent confusion between what is now known as the Alternate Metal Standards and the Generic Cleanup Numbers that are described in later chapters and appendices of this document.

and/or anthropogenic source, capability of the soil to retain the metal, depth of the soil horizon below ground surface, climate, and other related factors. The following Alternate Metal Standards (AMS) are an attempt to statistically summarize this variability of concentrations for some metals naturally occurring in Ohio soils. They are based on a collection of background metal concentrations from various facilities which completed a RCRA closure of their hazardous waste management unit(s), or underwent some other type of remediation activity. They were developed as an alternative approach to the site-specific BRS method, where the remediation standards are determined through a background soil sampling and analysis process conducted at the particular site.

When this alternative is chosen, the comparison soil should be considered to be contaminated if any metal concentration (based on total metals analysis of comparison samples) exceeds the AMS for that metal (see Table 4-1 for list of Alternate Metal Standards). In other words, the remediation process (usually soil removal followed by sampling) should continue until all comparison samples render concentrations below the AMS. When using background values as cleanup standards, the AMSs can be used for units whose contaminants include barium, cadmium, chromium, ² lead, mercury, nickel, and/or zinc. A combination of the site-specific BRS and the AMS is also a valid approach for developing remediation standards. However it is important to note that the use of the AMS is only valid for establishing non-risk based cleanup goals. Background values used in a site-specific risk assessment screening step to eliminate constituents of concern from further consideration should be based on site-specific background data and not the AMSs.

For more information, refer to [Appendix B, Development of Alternate Metal Standards](#).

Table 4-1: List of Alternate Metal Standards (AMS)	
Metal	AMS [mg/kg]
Barium	140.00
Cadmium	1.25
Chromium	22.00
Lead	37.00
Mercury	0.13
Nickel	33.00
Zinc	90.00

Remediation Standard for Soil for Characteristic Wastes Only

Soils contaminated with hazardous constituents originating solely from characteristic wastes (as defined in OAC Rules 3745-51-20 through 3745-51-24) should be removed and managed as hazardous waste until sampling results and statistical analyses conducted in accordance with the waste characterization procedures described in U.S. EPA's SW-846, Chapter 9, or its most current revision, indicate that the excavated material does not exhibit a characteristic of hazardous waste. Soils which are

²

The BRS and AMS approaches do not distinguish between hexavalent and trivalent chromium. A risk assessment approach can take this distinction into account, providing that the analyses for hexavalent chromium were conducted in accordance with the alkaline digestion method SW-846 3060A and the appropriate SW-846 analytical method, including 7195, 7196A, 7197, 7198 or 7199.

contaminated, but do not exhibit a characteristic of a hazardous waste, should be removed and managed as a solid waste, unless shown to be decontaminated via the risk assessment procedures outlined in Chapters 6 through 8.

Contamination Originating from Wastes Listed for Heavy Metal Content in Soil

Soils contaminated with listed hazardous wastes for which the basis for listing is heavy metal content (*i.e.*, lead, cadmium, chromium, nickel, mercury, or arsenic) will be considered hazardous waste when the results of an analysis for total metals exceed (in a manner explained in this document) either the Background Remediation Standard (BRS), the Alternate Metal Standard (AMS³) or the risk-based remediation standards developed in accordance with Chapters 6 through 8.

Remediation Standard for Non-Naturally Occurring Compounds

Hazardous waste releases may result in soil and ground water contamination from RCRA regulated compounds or elements not naturally occurring in the area of the hazardous waste management unit (*i.e.*, D, F, K, P or U wastes). Soil and ground water in these areas will be considered to be contaminated if the presence of synthetic compounds or non-naturally occurring elements (*e.g.*, volatile organic compounds, semi-volatile organic compounds) are detected above the Method Detection Limit (MDL). However, if upgradient contamination exists in the ground water, then the need for a response and setting a remediation standard will be based ONLY on any portion of non-naturally occurring compounds that the activities at the unit contributed.

The MDL, a statistically derived number, is defined in 40 CFR Part 136 as the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero. It is determined from replicate analysis of a sample in a given matrix type containing the analyte. Most laboratories do not assume a concentration of zero as indicated in the definition. Instead they adjust for matrix interferences as determined using a method blank.

Although the MDL can be determined individually for each matrix from each site, laboratories generally determine them annually from a generic matrix as part of the overall quality assurance process. For more information on how laboratories estimate the MDL, refer to U.S. EPA's SW-846, Chapter 1.

Even though DHWM would like to see the MDL used as a basis for site assessment where achievable according to the data quality objectives, the Estimated Quantitation Limits (EQLs) that are normally found in standard laboratory reports may be sufficient for purposes such as comparison to background, comparison to generic risk-based standards, or calculation of exposure point concentrations.

By definition, the EQL is the lowest concentration that can be reliably quantified within specified limits of precision and accuracy during routine laboratory operating conditions. The EQL is generally five to ten times the MDL, where the multiplier is based on the best professional judgement of the laboratory manager or the QA/QC officer and is established independently by each laboratory. For many analytes, the EQL is selected as the lowest non-zero standard in the calibration curve.

Because there is no standard practice of determining the EQL, both the MDL and EQL should be reported for comparison. In addition, any analyte(s) that is detected above the

³

AMS for arsenic was not established (as explained in [Appendix B, Development of Alternate Metal Standards](#)).

MDL but below the EQL should be reported and qualified as estimated. Finally, if the EQL is used as the remediation standard, then it should be required that the EQLs are below risk-based levels (refer to [Appendix A, Generic Cleanup Numbers](#)).

Evaluation of Ground Water for Unrestricted Closure by Removal

Owner/operators who are attempting to complete an unrestricted closure by removal of their units (not through a risk assessment) may need to collect site-specific ground water monitoring data for hazardous constituents to demonstrate that the operation of the hazardous waste management unit has not affected ground water quality within the vicinity of the unit. This site-specific demonstration should be performed by any owner/operator who determined a need to include ground water sampling in the closure plan (see [Section 3.12, Ground Water Sampling and Analysis](#)) and should include a minimum of eight (8) events over at least a one year period for site-specific constituents following closure activities. Once the site-specific ground water monitoring program has been conducted, it should be determined whether there has been a release to the ground water. If a release to ground water is documented, then additional ground water monitoring may be required. Under limited circumstances where there is no history of detection of non-naturally occurring constituents, a minimum of four (4) events evenly spaced over a one year period may be sufficient.

Unrestricted closure by removal standards for ground water containing both naturally and non-naturally occurring constituents will be considered on a site-specific basis. In general, if the results of the site-specific downgradient ground water monitoring wells do not exhibit hazardous constituent concentrations above the MDL,⁴ above the background levels for naturally occurring constituents, or above constituent concentrations present in upgradient wells unassociated with activities at the unit, then it will be concluded that the hazardous waste management unit has not affected ground water quality. The results should be from eight (8) consecutive events from all wells in the monitoring system over at least a one year period and should be conducted following any removal activities.

A statistical test consistent with the most recent U.S. EPA *Statistical Analysis of Ground Water Monitoring Data at RCRA Facilities* may be performed on all constituents monitored to determine whether the waste management activities at the unit have affected ground water quality. If it can be documented that constituents are present in the ground water (either naturally occurring or as a result of upgradient contamination) and are not associated with the unit waste management operations, then downgradient concentrations may be adjusted (for the purposes of determining unrestricted closure by removal) to account for the upgradient occurring levels for each hazardous constituent present.

Risk Based Remediation Standards

Federal Registers: May 2, 1986 (51 FR 16422) and March 19, 1987 (52 FR 8704) modified the closure performance standard such that risk assessment, or what constitutes “decontamination” of a site, may be considered by U.S. EPA as a closure option. Ohio EPA adopted the equivalent of U.S. EPA’s March 19, 1987 regulations on December 8, 1988. It is DHWM practice to consider risk assessment as an option in closure by removal situations. Complete, site-specific demonstrations of protection of human health and the environment will be expected in such closure plans. Refer to Chapters 6 through 8 for further details on the requirements for risk-based closures.

⁴

The SW-846 method that achieves the lowest detection limit should be used.

Ground Water Monitoring Requirements for Risk Assessment Demonstrations

Owner/operators who are attempting to complete a risk-based closure of their unit(s) where ground water is a concern should collect site-specific ground water monitoring data for hazardous constituents to demonstrate that the operation of the hazardous waste management unit has not affected ground water quality within the vicinity of the unit. A minimum of twelve (12) samples⁵ should be collected from three monitoring wells over four quarters of sampling at each well. These wells should be located within the center of the contaminant plume since they will most likely contain the highest contaminant concentrations.

These twelve samples are then used to establish the exposure point concentration for ground water, which is described in detail in [Section 7.2, Exposure Assessment](#). However, if less than three wells are contaminated, then the maximum concentration should be used as the exposure point concentration for ground water. Whichever level is chosen appropriately as the exposure point concentration, it is then compared to the generic risk-based numbers as found in [Appendix A, Generic Cleanup Numbers](#), or a site-specific risk assessment is performed.

If the generic risk-based numbers or DHWM's risk goals are exceeded, then a ground water remediation system may need to be installed. After this remediation occurs, the facility will need to monitor the ground water for a minimum of two years (eight quarters of sampling from each well) to verify that the applicable risk-based standard is achieved.

If closure can be adequately demonstrated through a risk-assessment and the owner/operator can certify closure in accordance with OAC Rule 3745-55-15 or 3745-65-15, then ground water monitoring will no longer be required. However, if the site-specific ground water monitoring program indicates a release⁶ to ground water above the risk-based standards that prohibits the owner/operator from demonstrating closure by removal or decontamination, then the closure plan should be amended to describe a waste in place closure and ground water monitoring should be conducted in accordance with OAC Rules 3745-54-90 through 3745-54-100.

4.2 Statistical Evaluation of Soil

When closure by removal of a hazardous waste management unit includes remediation of contaminated soil to site-specific background concentrations, the determination of whether the soil has been successfully remediated usually relies on some kind of statistical inference. The concentrations of a constituent in the soil samples (determined through laboratory analysis) form one "statistical sample" of all background concentrations, also known as the background data set. In addition, to complete and certify a closure, soil samples should be collected from under and/or around the unit (the contaminated area now assumed to be remediated) to prove that the constituent concentrations have been "sufficiently" lowered. These concentrations are

⁵ The ground water sampling events should be conducted after removal of the wastes and subsequent decontamination activities. The owner/operator should conduct the ground water monitoring in accordance with the applicable rules and technical guidance.

⁶ A release to ground water has occurred if the downgradient ground water monitoring wells detect hazardous constituent concentrations above the analytical MDL using the method (e.g., SW-846, ASTM, or analytical methods approved by U.S. EPA, etc.) with the lowest detection limit, or above background levels for naturally occurring constituents or constituents present in upgradient wells unassociated with activities at the unit.

data points which form a confirmation data set, also known as a comparison data set. Unless all confirmation concentrations are below the Background Remediation Standard (BRS), a statistical test is necessary to demonstrate (in an objective manner) if a “sufficient” level of soil remediation has been attained.

To begin the statistical comparison process, a closure plan reviewer should determine if the BRSs were established properly, which includes an evaluation of the data set distributions. Both the background data set and the confirmation data set should be tested for normality and, if necessary, normalized with a transformation common to both data sets. Next, the data sets should be evaluated for outlying data points. Based on these results, and whether the data sets are normally distributed or can be normalized, the confirmation data set can be compared to the background data set using parametric statistical methods. If the data sets are not normally distributed nor can they be transformed, then nonparametric statistical procedures can be used to compare the data sets. In general, this procedure allows for comparison between selected observations in such a way that the result of the comparison can be obtained with a specified (required) level of confidence (significance). More details about determining outliers, testing for normality, transforming data sets, parametric tests and nonparametric tests can be found in [Appendix C, Statistical Evaluation of Hazardous Constituent Levels in Soils](#).

4.3 Statistical Evaluation of Ground Water

When closure by removal of a hazardous waste management unit includes remediation of contaminated ground water to a site-specific background concentration, the determination of whether the ground water has been successfully remediated usually relies on statistical comparisons to background for naturally (and non-naturally when upgradient contamination of that nature occurs in the ground water) occurring compounds.

Chapter 13 in the most current Ohio EPA's *Technical Guidance Manual for Hydrogeologic Investigations for Ground Water Monitoring* should be consulted for an overview of performance standards, basic statistical assumptions and assumptions that vary with methods. U.S. EPA's (1989) *Statistical Analysis of Ground Water Monitoring Data at RCRA Facilities. Interim Final Guidance* and (1992) *Statistical Analysis of Ground Water Monitoring at RCRA Facilities. Addendum to the Interim Final Guidance* should be consulted for explanations of statistical methods.

4.4 Description of Removal Efforts and Treatment Processes

Any project which is attempting to close by removal should fully describe each step in removing waste and contaminated soil from the property. This includes a description of staging and the containerization of waste or reagents, equipment, removal patterns and depth increments, loading areas or any other step critical to removal. The plan should clearly define how soil will be removed, stored, loaded and managed once it leaves the property. Also, please note that temporarily staging waste on the ground, even on a liner, may constitute creation of a waste pile and may be subject to closure and a potential enforcement action. There is a provision in OAC Rule 3745-57-74 that allows for the creation of staging piles used for temporary storage of non-flowing remediation waste, if certain requirements are satisfied. The standards and design criteria must be incorporated into a permit, closure plan or order. For existing documents, this can be done through a modification. See OAC Rule 3745-57-74 for all requirements.

Closure plans for facilities where treatment of waste and/or contaminated soil is proposed should fully describe the procedure and its quality control ensuring that all wastes and contaminated soils are adequately treated. For stabilization processes, the description should include, but not necessarily be limited to, a quality assurance/quality control program, a

contingency plan for controlling fugitive dust and spills of stabilized sludge or reagents, the equipment to be used, subcontractor qualifications, scaled drawings showing process design details, percentage of binder in the reagent, equipment decontamination structures, chemical reactions occurring during treatment (mass balance), bench scale and pilot study results, confirmation sampling, and retesting/retreatment criteria. Refer to U.S. EPA's (1992) *Guidance for Conducting Treatability Studies Under CERCLA* for more information.

Similar information should be included for other treatment methods as well. Because there are many ways that a site could be remediated, Ohio EPA will not prescribe a specific remedial technology that must be used. However, the remedy proposed in the closure plan must be carefully reviewed to ensure that the requirements of the closure performance standard (OAC Rule 3745-55-11 or 3745-66-11) will be met.

There are a number of comprehensive resources available that describe remedial technologies, which include both print and electronic materials. Reviewing these available technologies is strongly encouraged to ensure that the remedy addresses the threats to human health and the environment, meets the requirements of other environmental regulations, addresses sources of contamination, can be implemented, and is economical.

Some of the resources available include:

Information Sources for Innovative Remediation and Site Characterization Technologies CD-ROM (EPA 542-C-98-003). This contains over 70 technical documents, databases, newsletter, etc.

- Clean-Up Information Web site (U.S. EPA). This web site contains a wealth of information on remedial technologies, innovative projects, etc. <http://www.clu-in.org/>
- Clu-in's Remediation technology vendor information – Formerly Remediation and Characterization Innovative Technologies (EPA REACH IT) Web site: <http://clu-in.org/vendor/vendorinfo/>
- Superfund Innovative Technology Evaluation Program: Emerging Technology Program (EPA 540-F-95-502) Web site: <http://www.epa.gov/nrmrl/lrpcd/site/pubsETP.html>
- Federal Remediation Technologies Roundtable Web site: <http://www.frtr.gov/>

In addition, efforts to minimize air emissions during treatment or loading, including volatiles and dust, should be described when applicable. Wastewater management must also be considered. Such issues are subject to the review of the Ohio EPA Division of Air Pollution Control and Division of Surface Water, or any other applicable authority, respectively (refer to the [Air Emissions and Wastewater](#) part of this document).

Natural Attenuation Policy

Ohio EPA recognizes that natural attenuation, under certain specific circumstances, can be an acceptable component of a remedy for sites that have contaminated ground water. However, active remediation, including source control and remediation, should be conducted for hazardous waste management units where ground water remediation is required. Naturally occurring processes, such as biodegradation, dispersion, dilution, and/or adsorption can be taken into account in conjunction with ongoing active remediation processes at hazardous waste sites until the ground water cleanup standards have been achieved. Remediation activities, including monitored natural

attenuation activities should not be concluded until the ground water cleanup standards have been achieved at the appropriate compliance point. Refer to the immediately previous paragraphs for more information on sources for remediation technologies.

DHWM has adopted U.S. EPA's (1999) *Use of Monitored Natural Attenuation at Superfund, RCRA Correction Action, and Underground Storage Tank Sites*. The policy addresses the use of monitored natural attenuation for the remediation of contaminated soil and ground water at sites regulated under all programs administered by U.S. EPA's Office of Solid Waste and Emergency Response (OSWER).

Before proposing natural attenuation as a remedy, it should be noted that this is not a "do nothing" approach. Implementation of natural attenuation as a remedy requires significant sampling and site analysis which goes well beyond the typical "nature and extent" sampling that is required for site characterization during RCRA closure. It should be clearly established that the contamination at a site is indeed amenable to natural attenuation.

Also, there are significant requirements for monitoring to demonstrate that the plume is not increasing in size, that contaminant levels are decreasing, and that remediation is progressing at an acceptable pace. The proposal should also demonstrate that implementation of natural attenuation will not cause threats to human health or the environment and that no cross media contamination will occur. For these reasons, proposals for natural remediation will be reviewed carefully and if implemented, Ohio EPA will monitor the project to ensure that the process is progressing satisfactorily. Lastly, should natural attenuation fail, the facility will be required to initiate active remediation to ensure compliance with OAC Rule 3745-55-11 or 3745-66-11.

4.5 Status of Facility After Closure by Removal

A closure by removal plan should clearly state the status of the hazardous waste management unit or facility after closure is completed. For example, it should state if a storage unit is to be operated as a "less than 90 day storage area" (*i.e.*, as a hazardous waste generator storage unit only), and it should describe whether closure is partial or complete. If it is partial closure, then it should name both the hazardous waste management units covered by the closure plan, as well as those remaining in operation.

Chapter 5

Components for Waste in Place Closure Plans, Post-Closure Plans and Certifications

5.1 Components for Waste in Place Closure Plans

Any hazardous waste management unit or affected area where waste material or contaminated soil (with contaminant concentrations above risk-based standards) is to be left in place, has several additional considerations beyond those that are generally required for closure by removal.¹ The waste in place closure scenario usually includes construction of a final cover system, ground water monitoring and thirty years of (financially) secured post-closure care. These considerations allow waste in place closures to comply with the general closure performance standard in OAC Rules 3745-55-11 and OAC Rule 3745-66-11, as well as the unit specific technical performance requirements in OAC Rules 3745-56-28 and 3745-67-28 (for surface impoundments), OAC Rules 3745-56-58 and 3745-67-58 (for waste piles), OAC Rules 3745-57-10 and 3745-68-10 (for landfills), and any additional permit requirements. The goal of these regulations is to minimize the potential of the hazardous component of the waste placed in the land disposal unit to migrate into the environment. This goal is achieved by creating regulatory requirements directed towards liquids management at the unit and rules establishing a comprehensive ground water monitoring and response program. The ground water protection strategy works by combining efforts to both minimize leachate generation and migration into the subsurface along with a ground water monitoring and response program to ensure that ground water quality remains at protective levels after the full extent and concentration of contamination has been determined.

In addition to the required components for all closure plans, waste in place closure plans should also include the waste management history, topographical and geological features, cover design rationale, detailed information about materials used in construction (e.g., low permeability layers, drainage layers, protective layers, etc.), calculations of the slope stability safety factor(s), cover settlement, and drainage and erosion control. Detailed engineering drawings and a construction quality assurance/construction quality control (CQA/CQC) plan are also required for each unit undergoing closure. ("As built" drawings should be submitted with the closure certification.) The final cover and accompanying structures should meet or exceed technical performance standards and design criteria specified in [Appendix G, Final Covers for Hazardous Waste Surface Impoundments, Waste Piles, and Landfills](#). More information on design, testing and construction of the liners and other cover system elements can also be found in U.S. EPA documents included in [Chapter 10, References](#).

The creation of new waste management units such as waste piles or surface impoundments used for closure (including units where waste has been removed for treatment and returned for final disposal) are subject to the Minimum Technology Requirements (OAC Rules 3745-57-03 and 3745-68-011) and the Land Disposal Restrictions (OAC Chapter 3745-270). Wastes removed from a unit, stabilized and placed back into the same unit are also subject to the Land Disposal Restrictions. However, hazardous waste can be "consolidated or treated in-situ within an area of contamination without triggering land disposal restrictions or minimum technology requirements".² Staging piles can also be created for the temporary storage of non-flowing remediation waste, if certain requirements are satisfied under OAC Rule 3745-57-74. The

¹ It is important that the closure plan reviewer contact their supervisor when a waste in place closure plan is received. Often, these types of plan will require review assistance from staff with appropriate engineering expertise.

² U.S. EPA. (1998) *Management of Remediation Waste Under RCRA*.

standards and design criteria must be incorporated into a permit, closure plan or order, which can be done through a modification.

Note that there are several additional regulatory requirements for closed disposal units in OAC Rules 3745-55-17 through 3745-55-20 and OAC Rules 3745-66-17 through 3745-66-21. These requirements concern post-closure plans, post-closure care, notice to local land authority, and restriction notice in the deed to the property.

Ground Water Monitoring for Waste In Place Closures

Hazardous waste management units in which hazardous wastes will be closed in place (surface impoundment, waste pile, land treatment unit, or landfill), should have a closure plan containing the components listed in [Chapter 3, Required Components of All Closure Plans](#). The closure plan should also include a ground water monitoring plan (GWMP) allowing the determination of the full rate, extent, and concentration of site-specific chemical parameters in ground water and meeting the requirements in OAC Rules 3745-54-90 through 3745-54-100 if the unit is closing under the final standard regulations or OAC Rules 3745-65-90 through 3745-65-94 if the unit is being closed under the interim status regulations. It is important to note, that even if a facility certifies closure under the interim status regulations, the ground water monitoring program during the post-closure care period will be conducted under OAC Rules 3745-54-90 through 3745-54-100.

The GWMP should include a sampling and analysis plan (as was discussed in [Section 3.12, Ground Water Sampling and Analysis](#)) and discussions of the following: a characterization of the site hydrogeology and a monitoring well system that adequately defines the uppermost aquifer; data validation and evaluation, which may include a statistical analysis; recordkeeping and reporting activities; and operations and maintenance activities.

Interim status units may need to have their indicator parameter list augmented with site-specific parameters. Also, it may be necessary to sample ground water from non-uppermost aquifer zones to demonstrate compliance with the closure performance standard. All saturated zones that are potentially contaminated should be considered.

Closure plans for units under the ground water final standards should also include each of the four components (underlined below) of the ground water protection standard (GWPS) outlined in OAC Rule 3745-54-92. The owner/operator is required to ensure that the list of hazardous constituents detected in the ground water from a regulated unit do not exceed their respective concentration limits in the uppermost aquifer underlying the waste management area beyond the point of compliance (POC) during the compliance period. The POC is defined as the vertical surface located at the hydraulically downgradient limit of the hazardous waste management area that extends down into the uppermost aquifer underlying the regulated unit(s). The facility is expected to meet the appropriate GWPS at the POC, between the POC and the downgradient facility property boundary, and beyond the facility boundary where necessary.³ If the GWPS is not met at any one of these points, the closure plan or GWMP should include a description of any required response.

5.2 Components of a Closure Certification

All partial or full closures of hazardous waste management units must be certified by both the owner/operator and an independent registered professional engineer licensed to practice in Ohio. (The closure plan should have included a statement acknowledging this requirement.)

³ Refer to OAC Rules 3745-54-95, 3745-54-91(A)(3), and 3745-54-100(E), respectively.

Per OAC Rules 3745-55-15 and 3745-66-15, certifications must be submitted within 60 days of completion of closure. The certification must attest to the fact that the unit or facility (as applicable) has been closed in accordance with the specifications in the approved closure plan. The owner/operator's and independent registered professional engineer's certification statements must include the exact wording found in OAC Rule 3745-50-42(D).

Typically, the certification document should include the following information (also refer to the [closure certification checklist](#) found on the internet and on the [DHWM's internal web page](#)):

- The approved closure plan or reference to the approved plan and a summary of the minor changes to the plan approved by Ohio EPA as well as significant correspondence regarding closure activities;
- A narrative describing all significant activities (e.g., sampling, decontamination, cover (cap) construction, ground water well construction, etc.) during closure;
- The volume of waste removed or closed in place including the volume of waste generated by closure activities such as decontamination. For waste removed or generated, documentation should be included that details proper characterization of the waste (sampling data) and proper management to off-site facilities (copies of manifests);
- Results of all media sampling and analytical activities including raw laboratory data with applicable quality assurance/quality control information;
- Documentation that cleanup standards defined in the approved closure plan have been achieved and that the closure performance standard has been met. This may include documentation that any applicable institutional controls have been implemented;
- As-built drawings for waste in place closures;
- Boring logs and ground water well construction or abandonment details;
- Any other information needed to document compliance with the approved closure plan and the closure performance standard; and
- The certification statement signed by the owner/operator and an independent registered professional engineer.

The independent registered professional engineer or his/her representative should be present for all critical activities during closure. These critical activities include, but are not necessarily limited to, soil sampling, soil removal, backfilling, final cover placement, structure decontamination, etc. The frequency of inspections by the independent engineer should be sufficient to determine the adequacy of each critical activity. The professional engineer must be independent, meaning that he/she cannot be directly employed by the owner/operator's corporation or any of the corporation's subsidiaries. The professional engineer must be an "outside" consulting engineer licensed to practice in Ohio, and should be qualified, demonstrating education and/or experience in the environmental and waste management areas. Reviewers can verify if a professional engineer is registered in Ohio via the state's Board of Professional Engineers web page at <http://www.peps.ohio.gov/>.

5.3 Components for Post-Closure Plans

After completion of a waste in place closure (where the “date of completion” is based on the calendar day by which all requirements in the closure plan were fulfilled, excluding certification and other notifications) a thirty year post-closure care period begins. During the post-closure time period, it may be determined that the hazardous waste and other contaminants will still pose a threat to human health and the environment after the post-closure period is proposed to end. In these cases, the director can extend the post-closure time period under OAC Rules 3745-55-17(A)(2)(b) and 3745-66-17(A)(2)(b). Likewise, it can be determined that hazardous waste and other contaminants will not pose a threat to human health and the environment before the post-closure period is to end, and the director can shorten the time period under OAC Rule 3745-55-17(A)(2)(a) and 3745-66-17(A)(2)(a). The purpose of post-closure is to ensure that no further actions need to be taken to protect human health and the environment once the post-closure certification is approved.

Post-closure is applicable to land treatment units, surface impoundments, waste piles, landfills, units which closed with waste in place, and other units that were closed as landfills because they could not meet clean closure standards [as explained in OAC Rules 3745-218-02(B) (for containment buildings, new facility standards), 3745-248-02(B) (for containment buildings, interim facility standards), and 3745-55-97(B) (for tanks)]. During this time, the closed unit is monitored and its protective features are maintained, as required by OAC Rules 3745-55-18 and 3745-66-18. When closing a surface impoundment or waste pile without a liner, a facility is required to have a contingent post-closure plan under OAC Rule 3745-55-18(A).

Administrative Processes for Addressing Post-Closure Requirements

According to OAC Rule 3745-50-45(A), facilities subject to post-closure requirements must have post-closure permits unless they demonstrate closure by removal or decontamination, or obtain an enforceable document in lieu of a post-closure permit. The denial of a permit for the active life of a hazardous waste management facility or unit does not affect the requirement to obtain a post-closure permit under Ohio law. The permit must address applicable ground water monitoring, unsaturated zone monitoring, corrective action, and post-closure care requirements. The components of a post-closure Part B application can be found in OAC Rule 3745-50-44 (C)(14).

As recognized by both U.S. EPA and Ohio EPA, some owners or operators may have little incentive to seek a post-closure permit. So, as an alternative, a post-closure plan can be submitted. Under OAC Rule 3745-50-45(G) the director may accept this post-closure plan in lieu of the Part B permit application. However, DHWM may elect to require a Part B application in select instances where facilities refuse to comply with Ohio EPA’s request to submit a post-closure plan that demonstrates compliance with the General Facility Standards Chapter of the OAC. Another option is the issuance of administrative orders under the ORC. Any time the rules referenced in this guidance mentions a “permit,” consider that a post-closure plan may constitute an enforceable document equivalent to a permit.

Administrative Process for Conducting Changes to the Post-Closure Plan

Amendment of the plan is a modification and similar to the amendment of a closure plan, see [Section 1.8, Closure and/or Post-Closure Plan Amendments and Extension of Closure Time Period](#), and OAC Rules 3745-55-18(D) and 3745-66-18(D) for more information. Owner/operators must make efforts to complete post-closure as specified in the approved plan. Unlike the rules for closure, however, every facility’s time period for post-closure activities can be different. The facility may need to extend the post-closure period, which can be done as an amendment as per OAC Rule 3745-55-18(D)(2)(b).

A written notification or request for a modification will be submitted in the same way a permit modification is submitted. It must include a copy of the amended post-closure plan for review. A request for modification may be submitted at any time during the life of the plan, and must be submitted when there are changes to the operating procedures, facility design, if events occur affecting the post-closure plan or if the expected final year of closure changes (if applicable). The facility may also request alternative requirements to regulated units as is stated in OAC Rules 3745-55-18(D)(2)(d) and 3745-66(D)(1)(c).

The amendment request must be submitted 60 days prior to any anticipated change, and within 60 days after any unforeseen event which causes a change in the post-closure plan. If an owner who was intending to clean close a unit determines that it should be closed as a landfill, they have 90 days to submit a modification to the director from the day that they made the determination. All requests will be reviewed and acknowledged, accepted, or denied where necessary. The director has the regulatory authority to, with cause, request an amendment to a post-closure plan in accordance with OAC Rules 3745-55-18(D)(4) and 3745-66-18(D)(4). The facility must submit an amendment request within 60 days of the director's request, or within 90 days if it's a surface impoundment or waste pile not previously required to have a contingent post-closure plan.

For Interim Standards post-closure plans, the reviewer should determine if a proposed change or amendment would constitute a Class 2 or Class 3 type of modification according to the criteria in OAC Rule 3745-50-51. Proposed changes that would constitute a Class 2 or 3 modification are required to be processed following the formal decision-making procedure culminating with a director's action as set forth in OAC Rule 3745-66-18(F). Minor amendments consistent with Class 1 type of modifications may be authorized directly, in writing, by the DO Chief or Assistant Chief. (Refer to the [DHWM's internal web page](#) for the boilerplate letter).

Any permitted facility contemplating actions inconsistent with the approved post-closure plan must submit a request for a permit modification to

Ohio EPA, Director
c/o DHWM, Regulatory and Information Services
P.O. Box 1049
Columbus, Ohio 43216-1049

Changes to post-closure plans for permitted facilities are to be handled in accordance with the permit modification requirements of OAC Rules 3745-50-51 and 3745-55-18(D). The approved modified plan will then become a condition to the Ohio hazardous waste permit. Refer to the [DHWM's internal web page](#) for the most current guidance on permit modifications.

Technical Components of a Post-Closure Plan

OAC Rules 3745-55-17 and 3745-66-17 state that the post-closure care period begins once closure is complete and continues for 30 years. The details of the post-closure plan should allow for this 30 year period, unless the director has reduced the time requirements. This includes monitoring and reporting requirements.

The required post-closure plan components are found in OAC Rules 3745-55-18(B) and 3745-66-18(C). In essence, a post-closure plan should ensure long-term effectiveness of all containment systems, especially of the final cover and bottom liner (if present), and

the functionality of all monitoring equipment. These goals must be achieved through carefully thought-out maintenance and inspection activities, whose details and frequencies will be included in the plan. The name, address, and contact information of the person or office in charge of the unit or facility during post-closure period must also be in the plan and kept current.

OAC Rule 3745-55-10(C) allows the director to replace all or part of the post-closure rules with an alternate requirement as part of the permit or other enforceable document. This may be needed because a unit poses a threat to the environment, or it may not be necessary to apply all the post-closure rules in certain cases. If the director has chosen to use alternative requirements for a regulated unit, the alternative requirements or a reference to the alternative requirements should be included in the plan.

Ground Water Monitoring in the Post-Closure Plan

Although the ground water portion of the post-closure plans is reviewed by the DDAGW staff, the DHWM reviewer should have a good understanding of the approach for ground water monitoring and response at the site and associated regulatory requirements. This understanding is critical for DHWM staff in order to appropriately implement and/or act on DDAGW staff recommendations.

OAC Rule 3745-54-90(E) states that the creation of a ground water protection program is applicable to all facilities in post-closure with waste in place, whether they have a permit or a post-closure plan. The purpose of the ground water protection program is to determine if hazardous constituents are affecting the ground water and to take actions to manage contamination of the ground water. The Ground Water Protection Standard (GWPS) of OAC Rule 3745-54-92 indicates which circumstances trigger the initiation of corrective action and when it may end. It establishes a concentration level for each constituent above which corrective action must be initiated. There are four elements to the GWPS: 1) the list of hazardous constituents to be measured; 2) the concentration limits for those constituents above which corrective action must be initiated; 3) the point of compliance where the concentration limit is measured; and 4) the length of time that the measurements must be made. The GWPS must be established in the facility permit when compliance monitoring is initiated.

OAC Rules 3745-54-93 and 3745-54-94 provide information on the hazardous constituents and their concentration limits, respectively. These are key in knowing when to implement certain phases of the ground water protection program. As OAC Rule 3745-54-93 indicates, a hazardous constituent may not have been specifically contained in the waste, it could also have been derived from the waste as a reaction/degradation product. Three options for setting concentration levels for hazardous constituents are provided in OAC Rule 3745-54-94. These include statistical background levels, MCLs found in the table, in OAC Rule 3745-54-94, and alternate concentration limits based upon potential adverse effects on site-specific ground and surface water.

The permit will also specify the point of compliance (POC) in accordance with OAC Rule 3745-54-95. The POC is “a vertical surface located at the hydraulically downgradient limit of the waste management area that extends down into the uppermost aquifer underlying the regulated units.” The facility is expected to meet the appropriate GWPS at the POC, between the POC and the downgradient facility property boundary, and beyond the facility boundary where necessary.

The compliance period is described in OAC Rule 3745-54-96. It is a length of time equal to the number of years the waste management unit was active (including activity prior to

permitting and the closure period). Both the compliance period and the post-closure period may be lengthened or shortened under OAC Rules 3745-54-96(C), 3745-54-90(F) and 3745-55-17(A)(2) if the director feels there is just cause.

There are three different phases of ground water monitoring. OAC Rule 3745-54-91(A) introduces these programs and indicates when each should be implemented. The three programs are: the detection monitoring program, the compliance monitoring program, and the groundwater corrective action program. There are times when facilities must make provisions for more than one program in case they detect or have an exceedance of a hazardous constituent concentration limit. In general, facilities will move from one program to another in this fashion: detection monitoring until a hazardous constituent is detected, compliance monitoring program until an exceedance of the concentration limit is noted, at which point the facility moves to the ground water corrective action program. OAC Rule 3745-54-97 covers the general requirements for a facility under all three monitoring phases such as well locations, sampling and analysis plans, reporting and recordkeeping.

Detection Monitoring Program

All facilities must implement a detection monitoring program if they closed with waste in place but have not detected hazardous constituents in the ground water or if no testing has taken place. OAC Rule 3745-54-98 contains the specific information needed in the detection monitoring program. While the detection monitoring program does not need to include the specific requirements of the GWPS, it still must include monitoring for site-specific hazardous constituents from wells located at the POC. Because the purpose of this program is to determine whether there has been an impact on the ground water quality beneath the site due to activity at a regulated unit(s), the program requires monitoring for indicator parameters, waste constituents, or reaction products related to activity at the unit. It must provide a reliable indication of the presence of hazardous constituents in the ground water, even if the constituents sampled were not in the waste placed in the unit. The plan should include the list of analytes to be sampled, the location of the wells which will be sampled, how often sampling will occur, and the methods and procedures for sampling, analysis, and evaluation.

As indicated in OAC Rule 3745-54-98(D), sampling must occur at least semi-annually. The plan should include language that states if during detection monitoring, statistically significant evidence of contamination is found, the facility will follow the notification requirements in OAC Rule 3745-54-98(G). Paragraph (G)(6) includes provisions to prove that an apparent detection was due to an error in sampling, a different source or natural variation in ground water. This evidence and level of contamination may cause the facility to follow the requirements of either the compliance monitoring or corrective action programs and, at that time, a modification will be submitted as per OAC Rules 3745-54-98(H), 3745-55-18(D), 3745-66-18(D)(interim status), and 3745-50-51 or an amended post-closure plan will be submitted as per OAC Rule 3745-66-21.

Compliance Monitoring Program

OAC Rule 3745-54-91(A)(1)&(3) indicates that compliance monitoring must be instituted when constituents have been detected either at the POC or between the POC and the downgradient property boundary, having "statistically significant evidence of contamination" but with levels that are not greater than the concentration levels established in the plan. In this program, the components of

the GWPS must be set and followed, and the four GWPS items discussed earlier must be included in the plan. The purpose of the compliance monitoring program is to determine if hazardous constituents in the ground water exceed levels that are protective of human health and the environment. OAC Rule 3745-54-99 defines "exceed" in paragraph (D). The compliance ground water monitoring plan should include information for annually determining the ground water flow rate and direction in the uppermost aquifer. Also, as per OAC Rule 3745-54-99(G), annual samples will be taken for all constituents on the ground water monitoring list in the appendix to OAC Rule 3745-54-98. This is to determine if additional hazardous constituents are in the uppermost aquifer and if action needs to be taken. The plan should specify steps the facility will take in the event of an exceedance or if other constituents are found during the annual sampling of the appendix. It must also include the notification procedures of OAC Rule 3745-54-99(H) and (I). Paragraph (I) includes provisions to prove that an apparent exceedance was due to an error in sampling, a different source, or natural variation in ground water. An exceedance may cause the facility to follow the requirements of the corrective action program and at that time a modification will be submitted as per OAC Rules 3745-54-99(J), 3745-55-18(D), 3745-66-18(D)(interim status), and 3745-50-51 or an amended post-closure plan will be submitted as per OAC Rule 3745-66-21.

Ground Water Corrective Action Program

When an exceedance of a concentration limit established under OAC rule 3745-54-94 for any of the hazardous constituents required under OAC Rule 3745-54-93 is confirmed, the facility must implement a ground water corrective action program. As stated in OAC Rule 3745-54-91(A)(2) and (3) the exceedance may have occurred at the POC or between the POC and the down gradient facility property boundary. The ground water corrective action program requirements are found in OAC Rule 3745-54-100, and also must contain the GWPS. The full rate, extent, and concentration of hazardous constituents in the ground water must be determined by the facility as is supported by OAC Rules 3745-54-91(A)(3), 3745-54-100(E)(1) and (2), and 3745-55-11. The facility must implement a corrective action program within a reasonable time period to prevent hazardous constituents from exceeding their concentration limits. Examples of corrective actions are source control efforts, removal of hazardous constituents, remediation efforts or treatment in place. The plan should clearly outline the procedures and a reasonable time line by which constituents will be controlled, removed, or treated (OAC Rule 3745-54-100(E)(3)).

The corrective action program requirements also contain provisions to ensure effectiveness through a ground water monitoring program with semiannual evaluations and reporting per OAC Rules 3745-54-100(D) and (G). Part of the reason for submitting these reports is to determine if the employed plan satisfies the rules. If at any time it is determined that the plan is not meeting the requirements of the rules, a more effective plan must be proposed and a modification submitted in accordance with OAC Rules 3745-54-100(H), 3745-55-18(D) and 3745-50-51. Corrective action must continue until it is ensured that the GWPS is not exceeded. If corrective action continues past the end of the compliance period, the owner or operator must show that the GWPS has not been exceeded for three consecutive years before the program can be terminated.

OAC Rule 3745-54-97 contains general information which must be included in all ground water monitoring plans,⁴ regardless of which phase is being implemented. The monitoring well system must provide ground water that will: represent the quality of background water that has not been affected by the regulated unit, represent the quality of ground water passing the POC, and allow for the detection of contamination in the uppermost aquifer. All plans should include information on the well designs and placement following the requirements of OAC Rule 3745-54-97 (A), (B), and (C). The ground water monitoring plan should include sampling results to provide information on which phase of monitoring the facility should be employing (i.e. detection, compliance or corrective action). These results may include ground water sampling results, soil contamination within two sampling intervals above the ground water table, or other factors as discussed in [Section 3.12, Ground Water Sampling and Analysis](#). The sampling, analytical, and statistical procedures identified in the plan should be appropriate to the facility and ensure accurate measurement of constituents in the ground water. The appendix to OAC Rule 3745-54-98 contains suggested sampling methods and PQLs for hazardous constituents. OAC Rules 3745-54-97(H) and (I) contain information on the statistical procedures and performance standards for analyzing the data obtained during sampling. All plans should incorporate recordkeeping and reporting schedules. Also any operations, maintenance and inspections of monitoring well equipment should be included in the plans.

Alternate Requirements

One way the “alternate requirements” as allowed under OAC Rule 3745-54-90(F), may be implemented is through development of an Integrated Ground Water Monitoring Program (IGWMP). IGWMPs are useful when a facility wishes to integrate unit-specific monitoring and/or clean-up requirements with site-wide corrective action. The source(s) of contamination generally emanate from both a RCRA unit regulated under OAC Rules 3745-54-90 through 100 and a waste management unit regulated under OAC Rule 3745-54-101. An IGWMP may be the most reasonable and economical way to deal with the contamination when the plumes are co-mingled such that it cannot be determined whether activities at the RCRA-regulated unit contributed to the ground water contamination. Under an integrated program, the well system, sampling scheme (including analytes monitored, appropriate sampling and analytical methods, and frequency of monitoring), evaluation procedures, recordkeeping, reporting, and any necessary corrective action are coordinated across the site under OAC Rule 3745-54-101 to minimize duplication of effort while maximizing resources. Note that although the efforts are coordinated under OAC Rule 3745-54-101, OAC Rules 3745-54-90 through 100 are still applicable and may serve as a basis for some of the requirements for the IGWMP.

Reporting for Post-Closure and the Ground Water Monitoring Program

The permit or plan will specify when data from ground water monitoring is to be submitted as per OAC Rule 3745-54-97(J). Facilities should be aware that they will need to submit other information, where applicable, such as evidence of contamination if in detection monitoring (OAC Rule 3745-54-98), exceedance of concentration limits if in compliance monitoring (OAC Rule 3745-54-99), or the semiannual reports to the

4

See [Appendix E, Ground Water Scoring Matrix](#), and the [Ground Water PRF](#) for more information on what Ohio EPA expects in the ground water monitoring plans. Flowchart B: Land Based Units (found in Appendix E and the Ground Water PRF) helps in the decision to determine what type of ground water monitoring program is needed. Flowchart A: Soil Leaching (found in Appendix E and the Ground Water PRF) includes information on what is necessary if contamination has been detected in the soil.

director on the effectiveness of the facility's corrective action program (OAC Rule 3745-54-100). Also reports for unforeseen events still need to be submitted such as action leakage rate exceedances (Surface impoundments OAC Rule 3745-56-23, waste piles OAC Rule 3745-56-53, landfills OAC Rule 3745-57-06).

Other Technical Requirements of Post-Closure

It is difficult to account for all situations in a 30 year period. However, the post-closure plan should be written with as much site-specific information as possible. System maintenance and inspections should be in accordance with the design. At times, it may be necessary to review the approved closure plan and as-built drawings in conjunction with the post-closure plan to make this determination. In general, a post-closure plan should not include any activity that could disturb in-place waste and/or contaminated media, or compromise the integrity of the components of the containment system. The proposed activity description must show that considerations were made for the type of waste and cover system. (See [Appendix G, Final Covers for Hazardous Waste Surface Impoundments, Waste Piles, and Landfills](#), for guidance on design of waste in place covers and containment systems.)

Inspections and Performance Check Points

Inspections during the post-closure care period are important to ensure the closure performance standard continues to be met. The post-closure plan should clearly outline an inspection process and written schedule, including inspecting ground water monitoring equipment. The plan should note that records of inspections, meeting the requirements of OAC Rule 3745-54-15(D), should be kept on file at the facility. Inspections should be based on the rate of possible deterioration of the equipment and be performed at time intervals that are best for the facility's situation; for example, before vegetation is established the inspections should be more frequent compared to a facility where post-closure has been on going for many years.

It is recommended that inspections occur after the final thaw of the cap soil layers in spring, during the highest precipitation season, after the longest dry weather period, significant precipitation events (such as a ten year, 24 hour rain event), and seismic events greater than magnitude 5.5 to detect any erosion, settlement, slope failure, ponding, cracks on the cover surface, loss of vegetation, and other defects. The post-closure plan should provide clear details on how this will be accomplished. When a detrimental item is noted during the inspection, it must be promptly acted upon to correct the problem, and the whole action must be documented. All plans should include a walking inspection to check systems and appurtenances, but aerial photography may also be considered to supplement the walking inspection. Aerial photography can help identify and document the extent of settlement or vegetative stress. The plan should include inspections on the storm water management system to ensure it is not blocked or damaged, and if drain pipes, collection boxes, ditches, sedimentation ponds, etc. need to be cleaned or cleared of unwanted vegetation, silt, rocks and debris.

Repairs and Preventive Maintenance

A good inspection schedule should help to identify when a repair is needed to prevent a major failure, damage or an environmental threat from occurring. The following text will discuss different components of the waste containment system with suggested preventative maintenance that should be detailed in the plan, and how to tell when a repair is needed.

Leachate Collection System (LCS)

The leachate collection system allows for the capture and drainage of liquids that travel downward through a landfill or other similar unit. It consists of a series of pipes and pumps that collect the liquid and then remove it. These systems are not required to be retrofitted for existing landfills, but it is required for all new landfills per OAC 3745-57-03. The post-closure plan should address what will be monitored (leachate flow rates, constituent concentrations) and what actions will be taken if significant changes in data occur. This will be specific to the LCS and the WMU.

Monitoring of the leachate collection system primarily consists of taking periodic measurements of leachate levels in the sumps before and after pumping, and also analyzing the leachate for its chemical makeup. These measurements provide valuable information about performance of various protective design features built into the closed unit, especially the cover and the liner systems. These two systems could have a failure due to a breach in a system's component (like a hole or tear in a geomembrane), soil or waste settlement, slip dislocation, drainage and/or LCS clogging, etc. The quality and quantity of generated leachate can serve as an indication of the system's performance. Normally, the rate of leachate generated should be steady and decrease with time. Leachate collection systems that show precipitation trends (i.e., increase in leachate level immediately following a rain event) indicate that the cover, or some other component is not keeping water out of the waste in accordance with its design. Often, it may be very difficult to determine where the water is coming from, and an extensive observation program may need to be established. A sudden increase in leachate generation can also be an indication of a cap movement failure (a slip, settlement, cave-in, etc). The concentrations of contaminants are expected to increase with time until equilibrium is reached. A sudden decrease in concentrations, on the other hand, may indicate that the cover has been breached and that surface water has entered the waste. Although not common at hazardous waste facilities, biological growth can also have an impact on the LCS system.

Final Cover (Cap) Integrity

As with other aspects of the post-closure plan, the part on the final cover integrity should be specific to the type of cap chosen. See [Appendix G, Final Covers for Hazardous Waste Surface Impoundments, Waste Piles, and Landfills](#), for more information on cap type and design. All plans will include a maintenance and inspections schedule that will help ensure the cap integrity.

The plan should detail how preventative maintenance will be performed on soil-type cover systems to keep the vegetation in a good state. Typically, plans should include a mowing schedule such as twice per year and weeds and brush should also be suppressed. The plan may include the use of fertilizer and pesticides to promote the desired growth and reduce pest damage, but the chemicals used should not interfere with monitoring systems. Soil reconditioning including aeration may be needed as well. Some maintenance tasks that can be included in the plan may need to be performed only when needed, such as regrading to maintain the integrity of the cover. Another maintenance task is the removal of deep rooted plants and the subsequent repair of the hole. When repairing the hole, the roots need to be removed as they leave the possibility that the plant would regrow or decayed roots can provide a pathway for water or animals to break the barrier to the waste. Also incorporated into the inspections

detailed by the plan, may be surveys for burrowing animals or their holes. Their holes should be filled with rocks and soil. Vegetative stress should also be inspected for, because this can be a sign of subsurface problems such as settlement, leachate, or gas leakage.

Facilities using a soil-type cover system must be aware of erosion, and the plan should have an annual maintenance schedule to address it. Those with a moderate slope (3 to 5 percent) will generally need around 0.5% of the cover's total surface area to be replenished. This requirement will increase with increasing slope. Unattended erosion can cause rills which lead to exposure of waste. The plan may need to be amended for areas needing repeated repair, which could be redesigned, possibly with a geosynthetic erosion control blanket - which also needs to be inspected annually, but has very little repairs associated with it. It is very important that the proper plants are chosen for the covers. If an attempt to establish a good grass cover fails after several years, an investigation into the causes of failure should be conducted.

The plan can specify alternative cover designs to be employed, but they must meet the performance standard goals (see [Appendix G, Final Covers for Hazardous Waste Surface Impoundments, Waste Piles, and Landfills](#), for more information on alternative cover designs). Cap performance varies, depending upon its function and where it is used. All designs should prevent water from reaching the waste and contaminating ground water. The plan should contain information that supports post-closure activities. This includes information on maintenance, inspections and monitoring appropriate to the design of the alternative cover.

The plan may need to include inspections for differential settlement. This can occur due to voids left by reactions, voids in place when waste was initially placed in the landfill and voids caused by changes to the top layer. Settlement can cause depressions and ponding of surface waters, or change the storm water flow patterns. These can most easily be found by walking the cover after a rain storm which will show major puddles and ponding. Aerial methods can also be useful.

Gas Control/Collection System

Most hazardous waste landfills will not produce a significant amount of gas. However, depending on the type of waste, or the process used for waste stabilization, an off-gas collection and control system may be necessary. The plan should contain an inspection schedule that incorporates a survey of the gas levels on the surface which can also give an indication of the integrity of the cap barrier. Tilted vents may indicate a cap (or sub-cap) movement. System maintenance and inspections should be in accordance with its design.

Security

In most cases, public access to the closed unit(s)/facility should be prohibited at all times. The plan should employ various traffic control devices such as fences, traffic barriers and signs. All of these items should be inspected regularly for damage due to vandalism or other reasons, and properly repaired when needed. Also, the plan should include a maintenance schedule for roads, ditches, culverts, bridges, ramps, and any other related structures to allow all year-round access to authorized vehicles.

5.4 Components of a Post-Closure Certification

The contaminants at the facility should pose no threat to human health and the environment once the post-closure and the certification process is completed. Because Ohio EPA may chose to extend the post-closure time period under OAC Rule 3745-55-17(A)(2)(b), DHWM staff should notify the facility that they will be choosing to do this before the facility starts going through the post-closure certification process. The facility may still wish to meet with DHWM staff before beginning the post-closure certification process to ensure that DHWM does not find cause to extend the period.

As with the closure plan, the post-closure plan should acknowledge the requirements of post-closure certification. Once the post-closure period has ended the owner/operator and an independent registered professional engineer must certify that the post-closure activities were performed in accordance with the specifications in the post-closure plan. Per OAC Rules 3745-55-20 and 3745-66-20, certifications must be submitted within 60 days of completion of post-closure. The exact wording found in OAC Rule 3745-50-42(D) must be included in the statements of the owner/operator and the independent registered professional engineer.

Chapter 6

Risk Assessment in Closure

6.1 Introduction

The next two chapters of the CPRG are intended to convey the general guidelines for conducting human health risk assessments for RCRA closures, not to serve as detailed instructional guidance. The technical documents cited within this guidance provide more detailed information for site-specific risk assessments. Ecological risk assessments are also a part of RCRA closures. However DHWM has published a separate guidance document which provides information on how to conduct ecological risk assessments. It is Ohio EPA's (2003) *Guidance for Conducting RCRA Ecological Risk Assessments*, which is briefly described in [Section 6.3, Ecological Risk Assessments](#).

Closure Performance Standard¹

Two federal register documents (Federal Register: May 2, 1986 (51 FR 16422) and Federal Register: March 19, 1987 (52 FR 8704)), modified the closure performance standard such that risk assessment was considered a closure option by U.S. EPA. Ohio rules for closure which parallel the 1986 and 1987 federal regulations became effective on November 13, 1987 and December 8, 1988, respectively.

Thus since 1987,² U.S. EPA has interpreted the regulations governing closure by removal and the phrase “remove or decontaminate” to require complete removal of all hazardous waste and liners and removal or decontamination of leachate and other materials contaminated with hazardous waste or hazardous constituents to the extent necessary to protect human health and the environment. As U.S. EPA explained in the 1987 notice, this interpretation means that, except for hazardous waste and liners, for “clean”³ closure, the regulations do not require one to completely remove all contamination (*i.e.*, to background), at or from a closing unit. Rather, some limited quantity of hazardous constituents might remain in environmental media after closure provided they are at concentrations below levels that may pose a risk to human health and the environment. In the 1987 notice, U.S. EPA took the position that the amount of hazardous constituents that might remain in environmental media after closure should be identified through appropriate application of risk information. In the March 19, 1987 notice, U.S. EPA also interpreted the regulations governing closure by removal and the “remove or decontaminate” standard to require consideration of the possibility of cross-media contamination so that, for example, facility owner/operators would have to show

¹ In accordance with the closure performance standard (OAC Rules 3745-55-11 and 3745-66-11), “The owner or operator must close his facility in a manner that:...(B) Controls, minimizes, or eliminates, to the extent necessary to protect human health and the environment, post-closure escape of hazardous waste, hazardous constituents, leachate, contaminated run-off, or hazardous waste decomposition products to the ground water, or surface waters, or to the atmosphere.”

² Federal Register: March 19, 1987 (52 FR 8704)

³ The premise of “clean” closure is that all hazardous wastes have been removed from a given RCRA regulated unit and any releases at or from the unit have been remediated so that further regulatory control under RCRA Subtitle C is not necessary to protect human health and the environment.

that remaining levels of hazardous constituents in soil would not migrate from the soil to air, surface, or ground water in excess of approved concentrations.⁴

Because a closure by risk assessment is considered decontamination (*i.e.*, all media have been decontaminated to risk-based standards), no subsequent post-closure monitoring or post-closure care is required. However, a risk assessment demonstration using an industrial exposure scenario that includes a permanent land use control (*e.g.*, environmental covenant) is also considered decontamination. Depending on the specifics of an industrial exposure scenario closure, additional monitoring may be required. Risk assessment demonstrations based on engineering controls (*e.g.*, fencing, paving, etc.) do not constitute decontamination.

In any closure, the closure performance standard for environmental media can be determined by either comparison to naturally occurring background (for inorganic elements or compounds), MDLs (for organic compounds), and/or through a risk assessment demonstration. Either option may be conducted first. Therefore, the owner/operator does not have to first attempt to achieve background standards or non-detection limits before preparing a risk assessment. For more information on remediation standards for soils and ground water see [Chapter 4, Components for Closure by Removal Plans](#).

Risk Assessment Application

Risk assessment methodologies can be used as a means to demonstrate that in-situ contaminated media meets the health-based standard. The assumptions used in a risk assessment do not apply to “as generated” hazardous wastes, only to in-situ media contaminated with hazardous waste and/or hazardous constituents, and therefore cannot be used to demonstrate that “as generated” hazardous wastes are below risk-based standards. Likewise, regulatory standards, such as constituent levels for the toxicity characteristic and land disposal restriction standards are not appropriate for demonstrating “decontamination.”

A risk assessment demonstration can be considered as a possible closure option for all types of units (*e.g.*, surface impoundments, land treatment facilities, storage areas, waste piles, and tanks) once the hazardous wastes that were managed in the unit are completely removed.

6.2 Human Health Risk Assessments

Residential Exposure Scenario

The most common exposure scenario for risk assessment is the residential exposure scenario. The residential exposure scenario assumes unrestricted human use of the unit where frequent exposures may occur to children and adults as residents. Both present and potential exposure pathways are considered. A unit that meets risk-based standards generated using the residential exposure criteria, including both child and adult receptors, is considered to be decontaminated to unrestricted use standards. This means that the land occupied by the former unit can be used for any purpose, including residential housing. There are no requirements for either activity or access restrictions.

⁴

Memo from Elizabeth Cotsworth, Acting Director of U.S. EPA's Office of Solid Waste, to RCRA Senior Policy Advisors regarding Risk-Based Clean Closure, March 16, 1998 (refer to http://epa.ohio.gov/portals/32/pdf/Removed_CPRG_Appendices.pdf).

Industrial Exposure Scenario and Environmental Covenants

Ohio EPA may allow the owner/operator to meet the closure performance standard through an industrial exposure risk assessment coupled with controlling the future land use of the closure unit through a legally binding environmental covenant. If the owner/operator adequately controls future land use through an environmental covenant (*i.e.*, prohibits residential development or use, thereby limiting direct contact with the soils), then an industrial exposure scenario may be used for quantifying exposures. The industrial exposure scenario assumes industrial use of the unit, where exposures are based on adult workers. Receptors who may be present in this scenario include the following sub-populations: occupational receptors, trespassers, and construction/utility workers. At a minimum, the following routes of soil exposure should be evaluated: ingestion of soil, inhalation of volatiles and particulates from soil, and dermal contact with soil. It may also be necessary to evaluate other pathways such as inhalation of indoor air from vapor intrusion of volatile constituents of concern into an enclosed structure and construction/utility worker exposure to shallow ground water. Like a residential scenario risk assessment, all complete pathways must be evaluated.

Please note that it is **soil standards** that are calculated assuming reduced exposure. For **ground water standards**, in general the appropriate residential risk-based standard or the Maximum Contaminant Level ([whichever is appropriate, see Appendix A, Generic Cleanup Numbers](#)) is used as the cleanup standard. This is due, in part, to the fact that ground water can move and there is usually not a way to control ground water use on properties other than the one where the facility is undergoing closure. In very limited cases, DHWM has allowed the use of off-site ground water standards that are based on restricted ground water use when there was an acceptable control in place. This exception is a site-specific determination made on case specific facts. In one site-specific example, DHWM accounted for the restricted ground water use due to the facility being located in an Ohio Voluntary Action Program Urban Setting Designation (USD) (<http://www.epa.ohio.gov/derr/volunt/volunt.aspx>). Because the facility was located in a USD, there was a control in place to insure that specific ground water exposure pathways were not complete. The resulting risk-based ground water standards were calculated for all remaining potentially complete ground water pathways. Regardless of the basis for the ground water standard calculations, facilities need to demonstrate that industrial soil standards cannot leach quantities of contaminants in excess of the agreed upon ground water cleanup standards.

There are two fundamental issues that must be considered when contemplating the use of an industrial exposure scenario. The first issue is determining when it is technically and practically appropriate to allow the use of an industrial exposure scenario (*i.e.*, site-specific technical issues as well as current and future land use considerations). The second major issue is how to create, monitor and enforce an environmental covenant. If the environmental covenants are not followed by a subsequent owner/operator of the property, a decision would be made to enforce the environmental covenant. At that time, further cleanup may be required depending on the land use (*e.g.*, residential development).

Industrial sites may be remediated to the residential exposure scenario risk-based standards so that environmental covenants are not needed.

Environmental Covenants and Technical Issues

As indicated above, soil standards based on the industrial exposure scenario are calculated with different exposure parameters than those used for the unrestricted use exposure scenario. Also, the young child receptor is not

considered for the industrial exposure scenario. Therefore, it is imperative to evaluate whether or not the reduced exposure to soils in the industrial exposure scenario is appropriate for the closure unit.

Many factors should be evaluated to determine the appropriateness of an industrial land use scenario. The factors should be evaluated qualitatively. Listed below are some of the factors to be considered in determining if an industrial exposure scenario is appropriate:

Technical Issues:

- (1) Ground water considerations (e.g., depth to ground water from where contamination is being proposed to be left in place, potential to impact drinking water supplies, and potential use as a drinking water supply);
- (2) Type of constituents of concern (COCs) (e.g., organics vs. inorganics, and volatiles vs. semi-volatiles), concentration, and toxicity;
- (3) COC environmental fate (e.g., contaminant mobility, biodegradability, toxicity of breakdown products, and persistence);
- (4) Hydraulic conductivity (i.e., permeability and soil porosity) of the soil; and
- (5) Partitioning ability/leachability of the COC (e.g., partitioning/distribution coefficient, and Toxicity Characteristic Leaching Procedure (TCLP) result from area of highest concentration to be left in place).

Practical Issues:

- (6) Site security (e.g., limited access, temporal institutional controls, fencing, geographic controls);
- (7) Adjacent land use considerations for both current and future use (e.g., industrial, commercial, residential; and city zoning designations);
- (8) Length of time for which the facility has been operating at the site and will likely continue to operate at the site; and
- (9) Ongoing site-wide remediation (e.g., RCRA Corrective Action via a permit or enforcement orders, or other mechanism).

In order to better evaluate the suitability of a site for this scenario, the use of the factors listed above should be viewed together. In other words, the answer to one or two of the issues listed is not enough to make a determination, but instead it is an evaluation of all of the information together. Site-specific conditions will dictate which approach is selected, as some factors may be more critical at one site versus another. As a result of differing site-specific details, sites with similar COCs might not necessarily be addressed in the same fashion.

This list of factors above is from U.S. EPA's (1995) *Land Use in the CERCLA Remedy Selection Process*. More detail on determining the appropriateness of the industrial scenario can be obtained from this guidance document.

There may be other factors in addition to those listed above that are important to consider in determining if an industrial exposure scenario is appropriate. For example, community acceptance of a land use choice may play an important role on a site-specific basis.

Administrative Processing of Environmental Covenants⁵

The use of environmental covenants in environmental cleanup programs is now memorialized in Ohio law with the passage of House Bill 516, which became effective on December 22, 2004. This bill provides a clear statutory basis for Ohio EPA and owners/operators of hazardous waste management units undergoing closure to enter into an environmental covenant that will impose use and/or activity limitations on the property or portion of the property where the unit is located. House bill 516 was codified into Ohio Revised Code §§ 5301.80 through 5301.92.

A team approach is necessary for the effective development and implementation of this tool. The team needs to include a designated DO staff person, an attorney from Ohio EPA's Office of Legal Services (Legal), and the facility representative. The designated DO staff person may be the DO closure coordinator, the designated DO risk contact, or the DO inspector in charge of the facility. The designated DO staff person takes the lead on setting up any necessary meetings between the facility representative and Legal and has other specific responsibilities described below.

Facility representatives are encouraged to discuss the feasibility of choosing the industrial exposure scenario option along with any potentially appropriate activity limitations with the designated DO staff person prior to submitting a closure plan. Based on discussions with the facility representative, the designated DO staff person will make a determination about whether the industrial exposure scenario and any activity limitations are reasonable and feasible. The determination regarding the appropriateness of the industrial exposure scenario and activity limitations should be made in consultation with DO management. The DO may also consult with the CO Risk Assessment Unit if necessary prior to making this decision. It is very important for the designated DO staff person to clearly understand and agree with the facility representative on any and all specific use and/or activity limitations that will apply to the unit to be closed.

Once the appropriateness of the industrial exposure scenario and any potentially appropriate activity limitations are determined, DO management will contact the DHWM Supervising Attorney to request that an Ohio EPA attorney be assigned. Although an Ohio EPA attorney is assigned, the designated DO staff person still serves as the point of contact for both the facility and Legal. It is the attorney's responsibility to negotiate and finalize the legal details of the environmental covenant but it is not the attorney's responsibility to finalize the specific activity and/or use limitations for the unit. As the specific use and/or activity limitation appropriate for the unit is a technical matter, and the designated DO staff person

⁵

Note that this procedure only applies to closure and does not apply to units in post-closure.

knows the facility and unit best and what technically is required for closure, it is the DO person's responsibility to be fully versed in the specific use and/or activity limitations before the attorney can be expected to finalize the legal details of the environmental covenant.

Next, the designated DO staff person, Ohio EPA attorney, and facility representative will meet to discuss the environmental covenant procedural process. At this meeting, the obligations associated with the option to use an industrial exposure scenario and any associated activity limitations will be communicated to the facility representative (although it is acceptable for this communication to occur between the Ohio EPA attorney and the facility's attorney through means other than a meeting). In order to successfully complete a closure through an industrial exposure scenario risk assessment, the facility owner/operator is obliged to do the following:

- clearly provide in the closure plan the specific use and/or activity limitations that will apply to the unit and state in the closure plan the commitment to file an environmental covenant, pursuant to ORC §§5301.80 through 5301.92, that will contain those specific use and/or activity limitations;
- provide to the Ohio EPA attorney a legal description of the portion of the property to be restricted and a list of encumbrances specific to that portion of the property; the owner/operator also may also need to do a title search for the property;
- enter into a written environmental covenant with Ohio EPA, and
- file the environmental covenant and provide evidence to Ohio EPA that the covenant was filed in accordance with the terms of the covenant prior to submitting the closure certification to Ohio EPA.

The Ohio EPA attorney will provide a template for the environmental covenant to the facility representative so they are aware of what to expect in the environmental covenant.

The DO has the responsibility of reviewing the closure plan. The normal regulatory time frame for review and approval of a closure plan will continue to apply if an environmental covenant is a component of the closure. An NOD would include any comments on technical issues with the closure, including the use and/or activity restrictions proposed by the owner/operator. The closure plan approval letter is also created by the designated DO staff person.

The designated DO staff person will provide the background information and a description of the environmental response project, i.e., what the facility is doing to close the unit, to the Ohio EPA attorney for inclusion in the environmental covenant. However, the Ohio EPA attorney, in conjunction with the facility representative, has the responsibility of finalizing the environmental covenant. DHWM prefers that the environmental covenant be signed by the facility owner and any holders (and the director) as early as possible. If possible, the environmental covenant should be signed by the facility owner and any holders as early as the director's approval of the closure plan. However, DHWM recognizes that there may be facts that need to be included in the environmental covenant that may not be determined until later in the closure period. Therefore,

at a minimum the environmental covenant must be signed by both the facility owner and holders and the director and filed prior to the facility's submittal of the closure certification.

Table 6-1: Summary of Responsibilities for Environmental Covenants			
Designated DO staff person	DO management	Ohio EPA attorney	Facility Owner/Operator
Serves as point of contact for both Legal and the facility.	Contacts the DHWM Supervising Attorney to request that an Ohio EPA attorney be assigned.		Includes language in the closure plan regarding his/her commitment to file an environmental covenant and the specific use and/or activity limitations that will apply to the unit.
Determines the appropriateness of the industrial exposure scenario and any activity limitations; any and all use and/or activity limitations must be described clearly.		Provides facility with Ohio EPA's environmental covenant template.	Provides the signed environmental covenant to Ohio EPA for the director's approval.
Sets up meetings as needed.		Finalizes the environmental covenant.	Files the approved environmental covenant with the appropriate county recorder.
Review of closure plan.			Provides an exact legal description of the property to be restricted and the activities to be limited.
Draft NOD or approval, whichever is appropriate.			Provides Ohio EPA with evidence that the environmental covenant was filed.
Draft background information and summary of closure approach section for the Ohio EPA attorney to include in the environmental covenant.			Complies with the environmental covenant.

Soil and Ground Water Standards

Generic Cleanup Numbers

DHWM publishes generic risk-based standards called Generic Cleanup Numbers (GCNs). The list of GCNs and their background can be found in [Appendix A, Generic Cleanup Numbers](#). The GCNs were generated for constituents of concern commonly found in closure units in Ohio. The GCNs were calculated using the residential exposure scenario and defaults currently accepted by DHWM. Ecological risks were not considered. The GCNs were developed using common exposure pathways. The GCNs are protective of human health if the closure unit conditions (exposure pathways, receptors, medium, etc.) match those used to calculate them. The GCNs can be used to screen out chemicals from consideration in a site-specific risk assessment, as cleanup standards, or in determining that no further action is necessary at a unit. More detailed information about the appropriate uses of the GCNs can be found in the technical support documentation in [Appendix A, Generic Cleanup Numbers](#). It is important to note that each GCN was calculated based on a single chemical exposure. If the closure unit contains more than one constituent of concern, then the GCNs need to be adjusted to account for that multiple chemical exposure.

Risk-based standards other than as detailed in [Appendix A](#) (such as those found in U.S. EPA's (1996) *Soil Screening Guidance: Technical Background Document* (hereafter referred to as *Soil Screening Guidance*)) are not acceptable without supporting risk-based calculations.

Site-Specific Risk Based Standards

If the hazardous waste management unit has been adequately characterized and all constituents of concern have been appropriately identified, then a site-specific risk assessment may be proposed which establishes risk-based standards by additively addressing all potential routes of exposure to humans and ecological receptors. Site-specific risk assessment proposals should document that the constituents left in the contaminated media will not adversely impact any human or ecological receptors through any current and/or potential exposure pathways. Refer to the risk assessment information contained in this guidance and the Federal Register: March 19, 1987 found at http://epa.ohio.gov/portals/32/pdf/Removed_CPRG_Appendices.pdf for more information. References included in [Chapter 10](#) may also provide further guidance about risk assessment assumptions.

Maximum Contaminant Levels (MCLs) vs. Risk-Based Standards (RBS)

For compounds that have MCLs, the MCLs may generally be used as the maximum allowable concentration in ground water. When an MCL is not available, a risk based standard should be established that meets the cancer and non-cancer risk criteria as established for the hazardous waste closure criteria. Risk based clean-up levels should be developed to meet the following guidelines:

- (1) For known or suspected carcinogens, facilities should establish groundwater clean-up levels that meet the DHWM excess upper bound lifetime cancer risk of 10^{-5} .
- (2) For toxic substances known to cause adverse effects other than cancer, facilities should develop groundwater clean-up levels that meet the DHWM goal of being equal to or below a hazard index quotient of one.

For facilities with multiple chemicals it will be necessary to adjust the risk based standards to account for exposure to multiple chemicals as described in [Appendix A, Generic Cleanup Numbers](#). Chemicals with MCLs are not to be adjusted as they are not based on a specific risk level.

There are instances where the use of MCLs may not be appropriate as groundwater clean-up levels. In instances where there is a completed drinking water pathway to multiple chemicals, DHWM requires the use of either the MCL or a risk based number, whichever number is more conservative. Your closure coordinator should be contacted when deciding which groundwater levels are most appropriate at a site.

DHWM Risk Goals

Regardless of the type of risk assessment performed (residential scenario, industrial scenario, generic inputs, or site-specific inputs, etc.), decontamination of the hazardous waste management unit has been achieved if the total cancer risk does not exceed the upper-bound risk level of $1E-05$, and the total hazard index does not exceed unity ($HI \leq 1.0$), assuming additive effects between hazardous constituents and cumulative effects across all routes of exposure. In other words, the DHWM risk goals are independent of the type of risk assessment performed.

Outdoor Worker Exposure Scenario

Assessment of the appropriate outdoor worker pathway is necessary for many sites using the industrial land use scenario because for most industrial sites there is a possibility that excavations, construction, landscaping, and/or maintenance will occur. This assessment can occur as a part of a full site specific risk assessment. Assessing the risk to outdoor workers does not preclude or require the use of engineering controls or personal protective equipment. However, if site conditions deem the use of engineering controls or personal protective equipment necessary it should be addressed in the risk assessment and in the environmental covenant or documents referenced in the environmental covenant. For risk assessment purposes we have two types of outdoor workers: a general outdoor worker and a construction worker. A general outdoor worker performs activities such as landscaping, or building maintenance and repair, and will typically be exposed for fewer days per year for more years in comparison to a construction worker. A construction worker performs activities such as excavation, demolition, or new building construction, and will typically be exposed for more days per year for fewer years in comparison to the general outdoor worker. These pathways are important because construction workers and general outdoor workers are the most likely to experience exposure to contaminated media at an industrial site.

The following pathways can be applied to all outdoor workers at an industrial site with some modifications to the exposure assumptions. The pathways for outdoor workers include: dermal contact with surface and subsurface contaminated soils, inhalation of volatiles from surface (fugitive dust) and subsurface contaminated soils, ingestion of surface and subsurface contaminated soils, vapors may also need to be included for trench work, utility vaults, manholes and other confined spaces outside the facility building. If the depth to ground water would make this a complete pathway, the potential for dermal exposure to groundwater due to excavation must also be addressed. Any complete pathway not mentioned above must also be addressed. It should be noted that some construction activities on site may lead to preferential vapor intrusion pathways that should be assessed.

While indoor workers are generally assessed using long exposure times and chronic toxicity data, this is not always appropriate for outdoor workers - particularly construction or landscape workers contracted from other companies. If long term exposures are not likely, toxicity data should fall into the subchronic range. U.S. EPA defines subchronic exposure as exposures lasting between two weeks and seven years. If an outdoor worker is likely to be exposed to the same site for more than seven years then chronic toxicity values should be used. Subchronic values are less complete in toxicity databases (i.e., IRIS) than for other types of toxicity data. Sometimes in toxicity sources such as IRIS, chronic values are estimated from subchronic data and the uncertainty conversion can simply be reversed. If the original data was multiplied by 10, as part of the uncertainty factor, to account for the transformation from a subchronic value to a chronic value, the chronic value can be divided by ten to obtain a value that can be used for subchronic exposure. In the absence of an acceptable subchronic toxicity value, a chronic value should be used as a default.

Site specific factors should be evaluated to best assign exposure assumptions for the risk assessment. These factors include the following: amount of past, current, or possible future construction on the site, age of the facility, amount of open space available for new construction, presence (or possible future installation) of buried utility lines or other underground systems or equipment that may need maintenance, repair, or otherwise necessitate excavation, current practices for burying lines or equipment by local utility companies or the facility, any potential for long term construction such as a highway interchange or other large project, persistence/stability of site contaminants, any other information (e.g., from a local planning committee) that can be used. For example, heavy equipment operators and utility workers may need a higher soil adherence factor than a construction worker so the type of work being done should be assessed. Site specific exposure factors should be based on a reasonable maximum exposure to ensure that the site specific exposure will be a conservative estimate. When possible, exposure factors should also be based on reliable sources such as U.S. EPA's Exposure Factors Handbook, or other scientific sources. If a site specific exposure factor is used, that value should be able to be verified during an inspection. The reviewer should use their best professional judgment to ensure that the actual risks to workers from on-site contamination will not exceed DHWM's risk goal. Depth to ground water and any connections via springs, creeks, etc. should also be assessed. For most parameters, the default adult assumptions still apply (e.g., weight of workers is assumed to be the same). Departure from any given standard assumption must be adequately explained and addressed in the risk assessment and environmental covenant or documents referenced in the environmental covenant. The DHWM accepted defaults can be found in the table below along with the defaults presented in [Appendix A Table A-5](#).

Table 6-2: Default Exposure Parameters for Outdoor Workers					
Exposure Parameter		Outdoor Worker	Source	Construction Worker	Source
Exposure Duration	EDw	Site Specific	NA	Site Specific	NA
Exposure Frequency	EFw	Site Specific	NA	Site Specific	NA
Soil Ingestion Rate	IRSw	100 mg/day	SSL	330 mg/day	SSL
Surface Area	SASw	3300 cm ²	RAGS E	3300 cm ²	RAGS E
Adherence Factor	AF	0.5 mg/cm ²	RAGS E	0.7 mg/cm ²	RAGS E
Inhalation Rate	IRAw	20 m ³ /day	SSL	20 m ³ /day	SSL
Particulate Emission Rate	PEF	1.36E+09	RAGS E	1.36E+09	RAGS E
Fraction Ingested	FI	1	Appendix A	1	Appendix A
Conversion Factor, Soil	CFs	0.000001	-	0.000001	-
Dermal Absorption Factor	ABS	See Appendix A	-	See Appendix A	-
Concentration in Air, from soil	CAs	(CS/(PEF*VF)) mg/m ³	SSG	(CS/(PEF*VF)) mg/m ³	SSG
Concentration in Soil	CS	Exposure Point Concentration mg/kg	Appendix A	Exposure Point Concentration mg/kg	Appendix A
Exposure Time	ETw	NA	NA	Site Specific	NA

It is critical that exposure pathways assessed correspond appropriately with the site's environmental covenant. Generally, a facility can rule out exposure pathways as long as they are willing to (and meet the qualifications to) enter into an environmental covenant. If a company claims to never use ground water within their facility, they must have an environmental covenant that addresses the use (and use restrictions) of the ground water within the property boundary. Otherwise, exposure pathways for all unrestricted uses will need to be evaluated. Remember, meeting the required standard (unrestricted use) at the property boundary must be taken into account even if the facility is not going to use the ground water on the site itself. Below you will find the intake equations for the pathways commonly used in a construction/general outdoor worker scenario.

Equation 6-1: Ingestion of Chemicals in Soils and Dust for Construction/General Outdoor Worker Scenario

$$\text{Intake (mg / kg - d)} = \frac{\text{Noncancer \& Cancer}}{\text{CS} \times \text{EDw} \times \text{IRSw} \times \text{CFs} \times \text{FI} \times \text{EFw}} \text{BWa} \times \text{AT}$$

Equation 6-2: Dermal Contact With Chemicals in Soil for Construction/General Outdoor Worker Scenario

$$\text{Absorbed Dose(mg / kg - d)} = \frac{\text{Noncancer \& Cancer}}{\text{CS} \times \text{CFs} \times \text{SASw} \times \text{AF} \times \text{ABS} \times \text{EFw} \times \text{EDw}} \text{BWa} \times \text{AT}$$

Equation 6-3: Inhalation of Volatiles and Particulates From Contaminated Soil for Construction/General Outdoor Worker Scenario

$$\text{Intake (mg / kg - d)} = \frac{\text{Noncancer \& Cancer}}{\text{CAs} \times \text{IRAw} \times \text{EFw} \times \text{EDw}} \text{BWa} \times \text{AT}$$

For example, Site XYZ needs to assess the exposure to outdoor workers. They determine that an outdoor worker performing routine maintenance and landscaping would likely be exposed for 30 days/year for seven years. They then decide to use the recommended exposure assumptions for an outdoor worker, along with site-specific exposure factors for exposure frequency and exposure duration, that are based on historic information from the facility, in their risk calculations. Next, Site XYZ must assess the exposure to the construction worker. Site XYZ has planned to construct a new office building at this location. They determine that a construction worker would likely be exposed for 250 days for one year. They then decide to use the recommended exposure factors for a construction worker, along with site specific exposure factors for exposure frequency and exposure duration, based on the facilities future plans, in their risk calculations.

6.3 Ecological Risk Assessments

The closure performance standard rules (OAC Rules 3745-55-11 and 3745-66-11) direct the facility owner/operator to close their hazardous waste units in a manner that prevents “threats to human health and the environment...” Therefore, ecological risk assessments are conducted as part of a RCRA closure. This may entail nothing more than documenting that there are no important ecological resources on or near the site and/or that the site does not have the potential for a release. The evaluation and documentation process should utilize the Level I Scoping Ecological Risk Assessment (and Ecological Scoping Checklist) as described in Ohio EPA's (2003) *Guidance for Conducting RCRA Ecological Risk Assessments*. Relatively large closure units and those more proximate to ecological receptors are more likely to require further ecological risk assessment. The above referenced guidance discusses these additional levels of assessment and when they will be required.

Chapter 7

General Concepts in Human Health Risk Assessments

Risk assessment is a process utilized to determine if the hazardous waste constituent(s) present in or potentially present in environmental media pose a threat to human health. The National Research Council's (1983) *Risk Assessment in the Federal Government: Managing the Process Working Papers* has defined risk assessment as "the characterization of potential adverse effects of exposures to hazards." U.S. EPA's (1989) *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Part A (RAGS, Part A)* presents a four-step chemical risk assessment process as follows:

- (1) Data Collection/Evaluation;
- (2) Exposure Assessment;
- (3) Toxicity Assessment; and
- (4) Risk Characterization.

7.1 Data Collection/Evaluation

The first step in reviewing a risk assessment is to review the analytical data. The reviewer can compare the analytical data using the discussions found in Chapters 3 ([Required Components of All Closure Plans](#)) and 4 ([Components for Closure by Removal Plans](#)), which include sampling protocol, adequate characterization of the contaminated area, definition of the extent of soil contamination, and definition of the rate and extent of ground water contamination. These discussions also include guidance on sample parameters, number of samples and locations, sample type, background samples, quality assurance/quality control methods and remediation standards.

Because the closure performance standard in OAC Rules 3745-55-11 and 3745-66-11 includes "hazardous constituents," the risk assessment should include all hazardous wastes (*i.e.*, D, F, K, P, or U wastes) and hazardous constituents listed in the Appendix to OAC Rule 3745-51-11 which are likely to be present above background levels for naturally occurring elements or compounds and above method detection limits (MDLs) for non-naturally occurring compounds.

Soil and ground water are considered contaminated if the presence of non-naturally occurring elements or compounds are detected (although not necessarily quantitated), using an appropriate method from U.S. EPA's *SW-846* or from another recognized government or private source. Soil and ground water are also considered contaminated if the presence of elements or compounds exceed the background remediation standards using the appropriate comparison, as detailed in Chapter 4. A detailed discussion on establishing remediation standards for soils and ground water can also be found in [Section 4.1, Remediation Standards for Soils and Ground Water](#).

For some chemicals (*e.g.*, 3,3-dichlorobenzidine, benzo(a)pyrene, bis(2-chloroethyl)ether, dieldrin, 2,4-dinitrotoluene, hexachlorobenzene, n-nitrosodi-n-propylamine, polychlorinated biphenyls (PCBs), styrene, vinyl chloride, etc.), the Estimated Quantitation Limit (EQL) is likely to exceed the risk-based standard. When the risk-based standard is below the EQL, a demonstration should be made that the constituent is not present at levels greater than the method detection limit and at levels which could be a threat to human health. Site information should be reviewed (*i.e.*, develop preliminary data quality objectives) prior to sampling and special analytical services should be requested to minimize the occurrence of EQLs above the risk-based standard.

Data Quality Objectives (DQOs)

In all closure plans, data quality objectives should be clearly stated prior to conducting sampling to ensure that data of known and documented quality are appropriate for use in a risk assessment and that the data are acceptable for demonstrating closure. The stated DQOs should enumerate the quality assurance and quality control (QA/QC) samples that will be reported and list the data validation acceptance criteria for these samples. Furthermore, the facility should determine, within the DQO process, actions that would result from invalid or incomplete datasets. The DQO process is dynamic and may change throughout the course of a facility investigation and closure activities. For example, the DQOs and data validation requirements for sample data used to screen a site for the presence or absence of contamination may be very different from the data quality standards needed for sample data that will be used in a risk assessment.

Because of the importance of decisions made during a facility closure, DHWM must ensure these decisions are based on valid data. Therefore, DHWM has determined that data validation should be incorporated into and used throughout the closure process. This is consistent with U.S. EPA guidance on the DQO process where data validation ensures that data used for facility closure meet acceptable standards of accuracy and precision. To aid in the review of data, Ohio EPA has created a *Tier I Data Validation Manual* and data validation review checklists, which have been incorporated in the [Closure Plan Review Forms \(PRFs\)](#). In addition, DHWM has trained its employees in data validation procedures and believes that the end result will be data of sufficient quality to justify conclusions used in closure activities. The data validation procedures will determine if there are data deficiencies and determine whether data may be used for its intended purpose. Where quality assurance/quality control (QA/QC) indicates that data is not of sufficient quality, re-analysis or re-sampling may be required. Facilities are encouraged to evaluate their own data prior to submittal. This should reduce delays in completing the closure process.

To assure a complete public record of the closure investigation, data summary tables should be included in the body of the closure plan and all raw analytical data, including all QA/QC information, should be included in the appendices of the closure plan. Summary data should not be accepted without the raw analytical data and QA/QC from the laboratory to support such data.

Constituents of Concern

The closure plan should specify all potential constituents of concern (PCOCs). Knowledge of the processes used to generate the hazardous wastes is imperative in determining PCOCs, as some PCOCs may not be readily apparent solely based on waste codes. Likewise, the permitted or unpermitted methods used to treat, store, or dispose of waste materials may create additional PCOCs. For example, hazardous waste incineration has the potential to generate compounds such as polycyclic aromatic hydrocarbons (PAHs) as well as dioxin-like compounds, which may be of greater human health and environmental concern than the initial hazardous waste, and should be addressed as part of the closure. Initially, all samples should be analyzed for all PCOCs. The following PCOCs, at a minimum, should be included in a quantitative risk evaluation when undergoing a risk-based closure, unless adequate justification is provided for excluding individual contaminants:

- (1) All hazardous constituents associated with the listed or characteristic hazardous wastes, any underlying hazardous constituents associated with the hazardous wastes, and any additional hazardous constituents resulting from the permitted or unpermitted treatment, storage, or disposal

of such wastes. Some constituents should remain on the list of PCOCs if they are likely to be present within the contaminated media, even if they are not detected in samples from a given medium, especially if they present a health risk at levels at or less than the quantification limits. If the detection or quantification limits are raised due to matrix interferences encountered during analysis, then PCOCs may also need to be retained;

- (2) Any constituent that has been positively detected in at least one sample in a given medium, including chemicals with no qualifiers attached and chemicals with qualifiers attached that indicate known identities but unknown/estimated concentrations (e.g., J-qualified data);
- (3) Any constituent detected at a level significantly elevated (*i.e.*, 5 or 10 times the blank concentration) above a level of the same chemical detected in associated blank samples (see the [Blank Contamination Section](#) in this chapter);
- (4) Any constituent detected at a level elevated above the naturally occurring level of the same chemical (see [Appendix C, Guidance for Statistical Evaluation of Hazardous Waste Constituent Levels in Soils](#));
- (5) Any constituent that is only a tentatively identified compound (TIC) but may be associated with the hazardous waste management unit based on the facility waste generation and process information; and
- (6) Any transformation/decomposition products of chemicals demonstrated to be present. As an example of such a contaminant, vinyl chloride should always remain a PCOC when chlorinated ethenes and ethanes are associated with the hazardous wastes, even if preliminary data show that the levels of vinyl chloride are currently at or below detection limits.

Transformation and Degradation Products of Chlorinated Solvents

Any transformation products¹ of hazardous constituents should be included as potential constituents of concern and addressed as part of the risk assessment. There is a practical challenge to quantify transformation products. The transformation products may not have formed at the time characterization occurs. This does not mean that they will not be formed at a later time. One approach is to keep known transformation product as PCOCs and evaluate their presence in soil and ground water samples taken throughout the closure and post-closure periods. A second method to evaluate whether transformation products will potentially be formed in significant concentrations, would be to use a first order degradation model such as U.S. EPA's ground water model BIOPLUME III or BIOCHLOR.² For important input parameters, site-specific inputs should be used. In other words, the model must be tailored to the site conditions. There are also issues regarding regulation of constituents that are only concerns through

¹ Transformation products are compounds formed by the chemical or biological actions on constituents present in soil or ground water. Most commonly they are the result of decomposition processes. Help in identifying possible transformation products can be found in the Universal Waste Treatment Standards (OAC Rule 3745-270-48) and the Appendix to OAC Rule 3745-51-30.

² BIOPLUME III can be found at <http://www.epa.gov/ada/csmos/models/bioplume3.html> and BIOCHLOR can be found at <http://www.epa.gov/ada/csmos/models/biochlor.html>.

speculation. Involve your supervisor early in the project if transformation products are of concern.

Handling Chemical Concentration Data Near the Detection Limit in Risk Assessments

U.S. EPA Region III³ guidance or other appropriate guidance⁴ can be consulted when determining how to handle chemical concentrations at or below the detection limit (DL) or quantitation limit (QL) for risk assessment closures. Undetected or unquantified data is termed censored data when used for statistical purposes. Because data is often analyzed statistically to determine an exposure point concentration, the ability to properly handle censored data is often tantamount to successfully quantifying the risk posed from contamination at a facility. How to handle censored data depends on a variety of factors, such as whether the undetected chemical poses a significant health risk at the DL or QL, whether the undetected chemical might reasonably be present in a sample (*i.e.*, is it potentially part of the waste stream associated with that unit), how the data is reported, whether the treatment of censored data will impact the risk estimates, whether the database is sufficient to support a statistical analysis and the percentage of data that is censored. Federal guidance varies on how to use undetected or unquantified data in risk assessment. Several guidance documents recommend using one half the applicable limit for statistical purposes, but the use of the actual detection or quantitation limit should also be considered.⁵ This decision on how the facility will evaluate censored data should be made as part of the DQO process implemented prior to sampling and analysis. If necessary both the quantitation limit and detection limit should be reported. As a general practice, the method detection limits (MDLs) and not just the estimated quantitation limits (EQLs) should be reported for all constituents in which health threats may appear below the EQLs.

As previously mentioned, one factor that could weigh on the use of a quantitation limit or detection limit to represent censored data is how the data is reported. DHWM recommends, where applicable, the use of the EQL. If the EQL is reported by a laboratory and the EQL is below the applicable risk-based standard set for constituents of concern, then half of the EQL should be used to represent censored (non-detect) data in a baseline risk assessment. This course of action should not be applied blindly. A natural exception to use of half the EQL is when samples in the data set are above the MDL but below the EQL (commonly flagged as J qualified data), then half the MDL may be used for non-detect values. This guidance reflects DHWM's belief that any acceptable detection of constituents of concern should be carried through the risk assessment process. Indeed, for RCRA closures, all data qualifiers should be reported in the exposure assessment (including estimated, "J" or "B" qualified concentrations). It is important to note that J qualified data should be used in the risk assessment as if the flag does not exist (*i.e.*, these data should be incorporated directly into the baseline risk assessment as "normal" data points).

Elevated detection limits, due to sample dilution or other interferences, can mask the detection of constituents that may pose a serious health threat at levels below the

³ U.S. EPA. (1991) *Guidance on Handling Chemical Concentration Data Near the Detection Limit in Risk Assessments. Interim Final.*

⁴ For example, U.S. EPA's (2000) *Guidance for Data Quality Assessment: Practical Methods for Data Analysis QA/G-9* or Appendix C of this guidance document, [Table C-2](#) titled How to Handle Non-Detects in Statistics.

⁵ Refer to U.S. EPA's (2000) *Guidance for Data Quality Assessment: Practical Methods for Data Analysis QA/G-9.*

elevated detection limit (e.g., high concentrations of chlorinated compounds, such as trichloroethylene, can result in the non-detection of vinyl chloride and other degradation products, although the degradation products are likely to be present above risk-based levels). While interferences cannot be avoided, the facility should address this issue with its laboratory prior to submitting samples and discuss the required project DQOs and reporting limits that are needed. The laboratory can provide information to the facility on whether or not the analytical requirements can be met and possible solutions to interference problems. If it is determined that these requirements cannot be met, then the facility should contact Ohio EPA, DHWM, for further assistance prior to conducting sampling activities. If a matrix interference has been found from sample data, then the facility and its laboratory should discuss possible alternative analytical methods to overcome the interference.

Blank Contamination

Blank samples provide a measure of determining when contamination has been introduced into a sample set. Various types of blanks (e.g., trip, field, rinsate, container, and preparation/method) are routinely collected in order to determine where in the sample collection or analytical process contaminants were introduced. Some sources for cross contamination are: 1) ambient conditions that can promote cross contamination of the samples (e.g., industrial activities, equipment, decontamination procedures, etc.) and 2) contamination from the laboratory (e.g., laboratory procedures, laboratory water, dilution, method reagents, etc.).

The different types of blanks can help identify where and when cross contamination was introduced into the sample set. Trip blanks will identify whether cross contaminants were introduced by other samples within the batch. Container blanks will identify whether the sampling containers were the source of cross contamination. Field or ambient blanks can determine if other sources from the field area are contributing to blank contamination. Rinsate blanks are used to determine if the sampling equipment was adequately cleaned between the samples. DHWM is aware that most sites will not incorporate all types of blanks within the field quality control procedures. However additional types of blanks may need to be incorporated into field activities if blank contamination is observed.

If blank contamination is observed, sample results should be qualified and evaluated for bias. Refer to Ohio EPA's (2006) *Tier I Data Validation Manual* for detailed information about validating data when blank contamination is present. Generally, the following procedures can be followed if it is determined that there is a potential for bias from cross contamination:

- a) If blanks and corresponding samples contain detectable levels of common laboratory contaminants, such as acetone, methyl ethyl ketone (2-butanone), methylene chloride, cyclohexane, and phthalate esters, then the sample result should remain unqualified only if the concentration in that sample exceeds the blank concentration by a factor of ten (10x Rule).⁶ If the concentration of a common laboratory contaminant in the sample is less than ten times the blank concentration, then the result should be qualified as undetected.

⁶

U.S. EPA. (1999) *Contract Laboratory Program National Functional Guidelines for Organic Data Review*.

- b) If a blank contains detectable levels of one or more organic or inorganic chemicals that are not considered to be common laboratory contaminants, then the sample result should be considered unqualified if the concentration of that chemical in the sample exceeds the blank concentration by a factor of five (5x Rule).⁷ Samples with concentrations that are less than five times the amount in the blank should be considered undetected. In instances where blank contamination is present, the facility should provide possible explanations for the source of contamination. For uncommon laboratory contaminants present in laboratory calibration or method blanks, the laboratory should be contacted to evaluate the possible sources of contamination prior to elimination.

Filtration of Ground Water Samples

Deciding whether or not to filter ground water samples depends on site-specific circumstances. Decisions should be made on a case-by-case basis. Ohio EPA has developed a general framework for making such decisions. In general, filtration should be avoided, if possible, when using such data in a risk assessment. Unfiltered samples should be used to estimate exposure in a risk assessment when the unfiltered water is of potable quality and filtration is not likely to occur prior to use as a drinking water source. Refer to Ohio EPA's *Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring* for guidance on determining if and when sample filtration is necessary.

Composite versus Discrete Soil Sampling

Compositing soil samples from various locations results in an empirical average of the grab/discrete samples that were used to form the composite. This averaging misrepresents areas of higher contaminant concentrations. In addition, composite sampling techniques do not lend themselves to statistical tests such as those used to determine whether on-site concentrations of elements are above background concentrations. Composite samples can be used to assess the presence or absence of contamination in a specific area and can also be used to represent average concentrations/exposures at a site. The number of composite samples and the number of individual grab samples must be carefully evaluated. Federal guidance⁸ should be consulted in determining whether compositing is appropriate and in developing the number of grab samples and composite samples that are necessary to meet the DQOs.

Due to the heterogeneous nature of soil, an adequate number of discrete samples should be collected to appropriately characterize concentration variability in the contaminated area, including any hot spots that are present. Generally, when conducting a risk assessment, the exposure point concentration is calculated using the 95% Upper Confidence Level (UCL) of the arithmetic mean. In order to appropriately establish the 95% UCL, the variability of the site data should be characterized using grab sampling techniques. Exposure characterization based solely on data from composited samples is not appropriate for calculating an exposure point concentration. If a risk characterization is contemplated by a facility, then discrete samples should be collected

⁷ U.S. EPA. (1999) *Contract Laboratory Program National Functional Guidelines for Organic Data Review*.

⁸ U.S. EPA. (1992) *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies*. and U.S. EPA. (2002) *RCRA Waste Sampling Draft Technical Guidance. Planning, Implementation and Assessment*.

in conjunction with any composited samples so that the variability of soil concentrations found can be adequately represented. Composite sampling, however, can be used to reduce costs associated with characterizing large areas of contamination and can provide a better estimate of the mean concentration for a particular area. Refer back to [Section 3.11, Soil Sampling and Analysis](#) for more information on soil sampling.

Background (Naturally Occurring versus Anthropogenic)

[Chapter 4, Components for Closure by Removal Plans](#) addresses naturally occurring levels of chemicals present in the environment. In general, naturally occurring levels are only applicable to inorganic chemicals. At some sites, anthropogenic levels (*i.e.*, concentrations of chemicals that are present in the environment due to human-made sources) of contaminants may be present. Contaminants such as pesticides, PAHs, lead, etc. can be ubiquitous to certain areas or sites. In some cases, when collecting background samples to identify concentrations of naturally occurring substances, the presence of organic chemicals may indicate that the sample was collected in an area influenced by site contamination and therefore, the sample may not qualify as a true background sample.

Inorganic chemicals that are determined to be present at a site at naturally occurring levels can be eliminated from the risk assessment. However, if inorganic chemicals are present at concentrations (using an appropriate non-point comparison, as specified in the [Guidance for Statistical Evaluation of Hazardous Waste Constituent Levels in Soils in Appendix C](#)) that are greater than naturally occurring levels, then the data from all sample points located within the contaminated area or boundary of contamination for that particular unit should be used to calculate an exposure point concentration. NOTE: Once the exposure point concentration is determined from the area of contamination for soil, the determined background level for soil should NOT be subtracted from the concentration of the contaminant found in the area of contamination. The risk from exposure should be assessed to the actual concentrations present in soil inclusive of any naturally occurring contributions. However when determining the risk from ground water, upgradient contamination may be subtracted out. Refer to [Exposure Point Concentration for Ground Water](#) in Section 7.2 for more information.

Anthropogenic levels are ambient concentrations resulting from human sources and can be caused by point sources, such as a nearby factory, or by non-point sources, such as automobiles or other traffic in the vicinity of the unit. In addition to anthropogenic sources (which are generally considered to be non-site related sources), contamination may be present in the area of the hazardous waste management unit which can be attributable to surrounding sources, areas of concern (AOCs), non-hazardous waste management units, RCRA waste management units (WMUs), etc. In such cases, the facility should first identify which contaminants can be attributed to the hazardous waste management unit undergoing closure. The facility should attempt to identify the approximate areas where the waste material was stored, treated, or disposed of. The physical boundary of the unit is defined as the area of soil contamination. The boundary of the unit is established once non-detection limits, naturally occurring levels or anthropogenic levels, and/or contamination from other units, such as WMUs, AOCs, etc. are encountered.

In cases where the boundary cannot be delineated from an adjacent unit and the same constituents of concern (COCs) are applicable to both units, the facility should consider the boundary of the unit to be the point at which the lowest concentrations are found when sampling outwardly from the hazardous waste management unit and at which concentrations, thereafter, tend to increase or to stay relatively at the same

concentration. It is the responsibility of the facility to provide enough supporting sampling and analytical data to be able to delineate a boundary for the hazardous waste management unit. The facility should provide justification for eliminating areas outside of the physical boundary from the hazardous waste closure unit.

7.2 Exposure Assessment

Exposure assessment is the characterization and estimation of the degree of contact (or dose) a potential receptor might have to a chemical in the environment. Several key issues relevant to exposure assessments are exposure scenarios (including sensitive subpopulations), point of exposure, potential exposure pathways (soil, ground water, air and surface water), and exposure factors (such as exposure duration and ingestion rates).

Exposure Scenario

RAGS, Part A was designed to accommodate a wide range of variability among sites. However, this flexibility does not always encourage consistency in remediation decisions. To assure that a consistent level of decontamination is achieved at all regulated hazardous waste facilities, standard exposure assumptions for residential scenarios and industrial scenarios should be used to establish risk-based standards to fulfill RCRA obligations for closing the unit. Both residential and industrial default exposure assumptions are presented in [Appendix A, Generic Cleanup Numbers](#).

Sensitive Subpopulations

Certain subpopulations may be at increased risk from chemical exposures due to increased individual sensitivity, behavior patterns that may result in higher exposures, and/or current or past exposures from other sources. Subpopulations that may be more sensitive to chemical exposures include infants and children, elderly people, pregnant and nursing women, and people with chronic illnesses. Children are potentially at higher risk due to certain behavior patterns (e.g., children are more likely to incidentally ingest large quantities of soil). African Americans may be at higher risk due to increased baseline levels of contaminants, especially lead.⁹ As part of any risk assessment, subpopulations of potential concern in the site area should be identified, including the locations of schools, day care centers, hospitals, nursing homes, retirement communities, residential and recreational areas with children, important commercial or recreational fisheries near the site, and major industries that could potentially contribute to exposures of the surrounding populations at a site. Refer to U.S. EPA's EnviroMapper (<http://www.epa.gov/enviro/html/em/>) for help in locating subpopulations of potential concern.

Point of Exposure and Point of Compliance

The Federal Register: March 19, 1987 specifies that the potential point of exposure to hazardous waste constituents is assumed to be directly at or within the unit boundary for all routes of exposure (surface water contact, ingestion, inhalation, and direct contact). The unit boundary is the limit of soil contamination that can be attributed to the hazardous wastes managed as part of the unit undergoing closure. Exposures to contaminated soil are considered to randomly occur throughout the hazardous waste management unit.

The risk demonstration should be conservative and should eliminate the uncertainties associated with contaminant fate and transport in ground water to a

⁹

Information on lead: <http://www.epa.gov/superfund/lead/>

downgradient receptor, focusing instead on the waste contaminant levels and contaminant characteristics (e.g., soil leachability). Therefore, demonstrations based on horizontal fate and transport evaluations of ground water to a downgradient receptor should *not* be accepted. In other words, attenuation beyond that predicted by organic carbon partitioning calculations, leaching tests, and vadose zone modeling is assumed not to occur (refer to the Federal Register: March 19, 1987).

For hazardous waste management units in which all hazardous wastes have been removed and contaminated soil has been decontaminated to an appropriate risk-based standard, the point of compliance (POC) for contaminated ground water is considered to be the entire contaminated plume area. In other words, a “throughout the plume/unit boundary POC” is applied to hazardous waste closures. This is consistent with the National Oil and Hazardous Substances Pollution Contingency Plan (40 CFR 300, July 1, 1996) and other cleanup programs. Therefore, the facility should demonstrate that the cleanup standards have been attained at all locations within the underlying aquifer that have been impacted by the hazardous waste management unit. This approach is being pursued at this time because DHWM is confident that it will be protective of human health and the environment.

Modeling

U.S. EPA, Office of Solid Waste, issued a memo, dated March 16, 1998, regarding the use and acceptability of fate and transport modeling for RCRA clean closures. In accordance with the Federal Register: March 19, 1987, U.S. EPA required that demonstration of compliance with the regulations governing closure by removal and the “remove or decontaminate” standard be conservative in the sense that the uncertainties associated with contaminant fate and transport are eliminated. U.S. EPA revised its interpretation of the “remove or decontaminate” standard in a memo from Elliot Laws and Steven Herman to RCRA/CERLA National Policy Managers (September 24, 1996) to allow the use of fate and transport modeling during closure (Go to: http://epa.ohio.gov/portals/32/pdf/Removed_CPRG_Appendices.pdf for a copy of these memos).

Models may be used to support clean closure demonstrations by establishing the potential for residual contamination in one medium to migrate to and contaminate another medium (i.e., cross media transfer of contaminants). Therefore, modeling may be used to demonstrate that residual soil contamination will not migrate to and adversely affect ground water quality. Under this guidance, vapor intrusion models that evaluate the potential for soil or ground water contamination to migrate to and impact indoor air quality are also allowed. The reader is directed to [Ground Water Pathways](#) and [Air Pathways](#) in this section for more information about modeling.

Exposure Pathways

An exposure pathway describes the mechanism by which receptors may come into contact with chemicals of concern. It is the course a chemical takes from a source to an exposed organism. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium is also included. The Federal Register: March 19, 1987 specifies that risk assessment demonstrations include all potential exposure pathways and that direct contact

through dermal exposure, inhalation or ingestion will not result in a threat to human health or the environment.¹⁰

Because a residential scenario assumes unrestricted human use of the unit where frequent exposures may occur to adults and children, the risk assessment should include, at a minimum, the following potential pathways in the closure plan (unless adequate justification is provided for eliminating pathways):

- (1) Ingestion of contaminated soil;
- (2) Dermal contact with contaminated soil;
- (3) Inhalation of fugitive dust/volatiles from contaminated soil;
- (4) Ingestion of contaminated drinking water (ground/surface water);
- (5) Dermal contact with contaminated ground water, while showering/bathing;
- (6) Inhalation of volatiles while showering/bathing with contaminated ground water; and
- (7) Vapor intrusion into structures.

If there is a potential for other complete pathways, they should also be addressed. For example, ingestion of locally-caught fish, ingestion of home-grown produce (e.g., fruits/vegetables), ingestion of local animal products (e.g., beef, milk, poultry, eggs, etc.), dermal contact with surface water while swimming, incidental ingestion of surface water, etc., may need to be addressed. Since air, water, and soil pathways are pertinent to all site categories, they are discussed below in more detail.

Soil Pathways

The risk assessment should show that contaminant levels in soil are less than risk-based standards when considering the ingestion, dermal contact, and inhalation of contaminated soil pathways. Total waste constituent levels in soil (dry weight basis) should be used for this analysis, not the results from Toxicity Characteristic Leaching Procedure (TCLP) or Synthetic Precipitation Leaching Procedure (SPLP) testing.

Exposure control measures, such as fencing or capping, are not acceptable sole remedies for hazardous waste closures since the long-term future effectiveness of such measures cannot be reliably controlled. Such measures (e.g., fencing), however, may be necessary components of industrial closures to further eliminate the possibility of exposure to trespassers. Long term operation and maintenance of such controls can be enforced in the industrial closure context through a properly executed environmental covenant. For more information regarding environmental covenants, refer to [Section 6.2, Human Health Risk Assessments](#).

¹⁰

Federal Register: March 19, 1987 (52 FR 8704)

Ground Water Pathways

The risk assessment should show that contaminant levels currently or potentially in ground water are less than risk-based standards when considering potable uses (inhalation of volatiles from ground water, dermal contact with ground water and ingestion of ground water). It may also be necessary to account for vapor intrusion of volatile constituents of concern from ground water and dermal contact with shallow ground water in addition to other complete exposure pathways. The risk assessment should also demonstrate that contaminant levels in the ground water are protective of surface water. The risk assessment should assume that for unrestricted use, a drinking water well is located within the unit and the unit is used for residential purposes where both adults and children live.

Potable Use Ground Water Pathway Exclusion

The potable use ground water pathway exclusion is the elimination of the potable use pathways from a risk assessment. In general, DHWM expects that a number of demonstrations would be necessary to support exclusion of the potable use ground water pathways. The amount of evidence that is necessary would depend on the situation. It may be acceptable to exclude potable use pathways from the risk assessment, and therefore invoke this exclusion if these pathways are not complete. In general the potable use ground water pathways would be considered complete if both conditions are met:

Condition 1: Ground water contamination currently exists or is likely to occur; and

Condition 2: A potable use pathway from contaminated ground water to a receptor exists or is likely to occur.

If this exclusion is granted, all other complete ground water pathways (e.g., vapor intrusion of volatiles from ground water, dermal contact with shallow ground water) must be assessed in the risk assessment.

For condition 1: The criteria in the [Ground Water Sampling and Analysis](#) part of Section 3.12 can be used to determine whether or not ground water is or may potentially be impacted. Some of the tools mentioned in that section (the ground water scoring matrix, leaching tests and vadose zone modeling) are considered predictive tools meant to provide information about whether ground water is currently or will likely be impacted by contaminants. These predictive tools are not meant to negate valid ground water sampling data. If ground water is known to be contaminated, then the potable use ground water pathways cannot be excluded without assessing the potential for exposure (see condition 2 below).

For condition 2: It can be demonstrated that ground water is not likely to be used for potable purposes based on local hydrogeologic conditions (e.g., site geology, hydrogeology, etc.). Among the factors that may be considered are: 1) the absence of

existing or planned potable ground water use of the contaminated saturated zone at or within 0.5 mile of the facility, and 2) contaminated saturated zone yield that is less than 150 gallons per day (about 0.1 gallon per minute).¹¹ This guidance is meant to be predictive of the likelihood of a complete potable use ground water pathway. If there is knowledge of current wells or future placement of wells, then the predictive criteria described above should not be applied.

For any exclusion, the owner/operator should be able to demonstrate that ground water contamination will not emanate beyond the facility property boundary or migrate to another saturated zone that is a current or potential source of potable use ground water. Also, the owner/operator should be willing to establish an environmental covenant against future potable uses that indicates the presence of the contaminated saturated zone and its approximate extent.

Leaching Tests

In accordance with the Federal Register: March 19, 1987, to make the demonstration with respect to the ground water pathway, enough contaminated soil and saturated subsoils should be removed to demonstrate that potential contaminant levels in ground water do not exceed the target cleanup standards in ground water (*i.e.*, residual contaminant levels remaining in the soil will not contribute to any future contamination of ground water greater than the established chronic health levels). The demonstration should show that residual contaminant levels remaining in the soil will not contribute to any future contamination of ground water above established exposure levels. Levels of constituents in ground water may be estimated based on the known characteristics of the hazardous constituents (*e.g.*, solubility and partitioning coefficients) or the results of actual soil leaching tests (*e.g.*, SW-846 methods - TCLP or SPLP).

The test used for the leaching demonstration must be chosen carefully and decisions on why a particular test was chosen should be explained in closure documentation. For example, the TCLP test may not be the best leaching test for lime-stabilized soils, since neutralization of the extraction fluid may not demonstrate the true leachability of constituents of concern.

The TCLP test uses an organic acid for the leaching solution and is considered a good bench top model for chemical behavior in a municipal solid waste landfill. The TCLP test is the method cited in the rule (OAC Rule 3745-270-07) and must be used for waste characterization and to determine compliance with Land Disposal

¹¹

Whether ground water yield is below 0.1 gpm may be calculated either on maximum or average yield over 12 months. If the owner/operator does not want to wait 12 months to make the determination, he/she should test at the time of the highest yield. Estimates of yield should be representative of facility conditions and appropriately address spatial and temporal variations. For guidance on determining yield, the reviewer should consult with DDAGW.

Restrictions (LDRs). The SPLP test uses inorganic acids, and thus may be used as an alternative method for evaluating the impact of precipitation on contaminated media outside of the municipal landfill setting.

Several factors should be considered when using leaching tests to demonstrate that constituents of concern will not adversely impact ground water resources. The TCLP and SPLP tests both use a 20 to 1 ratio of extraction fluid to solid material. For this reason, a dilution factor of 20 is inherently part of the analytical results. To demonstrate that leaching will not occur, the analytical results should be multiplied by 20 and compared to ground water standards unless the site qualifies for a 20 Dilution Attenuation Factor (DAF) as described in [Appendix A, Generic Cleanup Numbers](#), of this document. Risk management decisions, based upon agreement between Ohio EPA and the regulated party, can then be explored on a site-specific basis. These considerations can be based upon site-specific criteria such as separation distance, chemical properties or other means of demonstrating that leaching will not impact ground water. The maximum leachable concentration of constituents, adjusted for dilution, should be used to make the demonstration.

The detection limits of the analytical procedure should also be considered. For example, the TCLP test is most commonly used to demonstrate a waste characteristic of toxicity. The regulatory limits are often expressed in terms of milligrams per liter (mg/L). For many sites, ground water protection standards may be much lower. The owner/operator is advised to seek information from its contract laboratory to ensure that detection limit criteria can be met.

The soil leaching tests should be conducted on soil samples taken from the identified areas of maximum contamination. If the total concentration of an individual hazardous constituent, divided by 20 (the resulting dilution when a solid material is subjected to the TCLP test), is less than the detection limit for an aqueous matrix, then the TCLP test need not be run for the purpose of demonstrating leachability.

U.S. EPA has deferred thirteen constituents from TCLP analysis due to their ability to hydrolyze during transport or due to inappropriate steady-state conditions. These constituents are acrylonitrile, bis(2-chloroethyl)ether, carbon disulfide, 1,2-dichlorobenzene, isobutanol, methylene chloride, phenol, 1,1,1,2-tetrachloroethane, 1,1,2,2-tetrachloroethane, 2,3,4,6-tetrachlorophenol, toluene, 1,1,1-trichloroethane, and 1,1,2-trichloroethane. Due to these reasons, the potential of these contaminants to leach into the ground water should be demonstrated by using partitioning coefficients, vadose zone modeling, or where appropriate, actual ground water sampling data.

Vadose Zone Modeling

Some analytical or numerical based models may be used to determine whether soil contamination can pose an unacceptable risk to ground water resources. In addition, for risk assessment purposes, modeling may be performed to determine whether a ground water pathway to a potential receptor is viable. Modeling for these purposes should take into account the potential for harm to humans and the environment. There are restrictions on the use and scope of modeling. The memo from Elliot Laws and Steven Herman to RCRA/CERLA National Policy Managers (dated September 24, 1996 and found at http://epa.ohio.gov/portals/32/pdf/Removed_CPRG_Appendices.pdf) clearly identifies that fate and transport models should not be used to model contaminated ground water directly underlying the unit to a downgradient receptor for the purpose of establishing a closure cleanup standard in ground water at the boundary of the facility or at a downgradient receptor.

For more information about vadose zone modeling demonstrations, refer to Ohio EPA's (2005) *Vadose Zone Modeling in RCRA Closure*. This manual illustrates a three tier process that allows the user to progress from simple, equation driven models to complex site specific models. The guidance also contains what DHWM believes to be acceptable model assumptions and default soil and hydrological parameters that can be applied to a host of commercial and public domain models.

Ohio EPA recognizes the effort and data requirements for detailed unsaturated zone modeling and will accept models that use limited site data and default values as long as the conservative assumptions and representative default values are used. In addition, the model selected for this level of modeling should be appropriate for site conditions and types of contaminants that are present. For example, it would be inappropriate to use a model designed for leaching of organic chemicals for a site that wishes to model inorganic chemicals. Other situations may also preclude the use of certain models, including large differences in permeability of soil strata and preferential pathways that may promote the migration of contaminants. There are numerous models that can be applied to RCRA closures. Analytical models, such as presented in *Soil Screening Guidance*, can be used for screening purposes as long as default values from Ohio EPA's (2005) *Vadose Zone Modeling in RCRA Closure* are used. Numerical vadose zone models such as SESOIL, VLEACH, and CHEMFLO-2000,¹² among others, can also be used under the appropriate site circumstances.

It is important to note that all of the assumptions, their appropriateness and the input values should be discussed in a detailed modeling report. As discussed in the Ohio EPA's (2005)

¹²

SESOIL can be found at <http://www.seview.com/aboutsesoil.htm> and VLEACH and CHEMFLO-2000 can be found at www.epa.gov/ada/csmos/models.html.

Vadose Zone Modeling in RCRA Closure manual, model applicability will be determined on a site-specific basis. Your supervisor should be consulted prior to using an unsaturated zone model.

Air Pathway

The risk assessment demonstration should include the inhalation of volatile chemicals from the contaminated water and the contaminated soil pathways when evaluating the air pathway. For the inhalation of volatile contaminants from the contaminated soil and water pathway, only constituents with a Henry's Law constant of $1\text{E-}05 \text{ atm-m}^3/\text{mol}$ or greater and with a molecular weight of less than 200 g/mol need to be addressed.¹³ If the constituent meets neither of these criteria, then the inhalation of volatiles pathway does not need to be addressed. The risk assessment demonstration should also address the inhalation of particulates from the contaminated soil pathway and the inhalation of volatiles from the contaminated ground water while showering pathway for those constituents with a Henry's Law constant of $1\text{E-}05 \text{ atm-m}^3/\text{mol}$ or greater and with a molecular weight of less than 200 g/mol .¹⁴

Demonstration for the air pathway should include emission calculations, available monitoring data, and safe inhalation levels based on established exposure levels. The risk assessment demonstration should provide all detailed information, such as the volatilization factor and the particulate emission factor calculations, Henry's Law constants, molecular weights, etc. for all constituents of concern. The closure plan should include all input variables (*i.e.*, chemical-specific, site-specific, and default variables) used to calculate air emissions. Additional information on emissions calculations can be obtained from U.S. EPA's (1988) *Superfund Exposure Assessment Manual (SEAM)*, U.S. EPA's (1985) *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites*, the *Soil Screening Guidance*, and *RAGS, Part B*. More specific information for calculating air concentrations is provided below:

(1) Inhalation of Fugitive Dust (Particulates)

For the inhalation of fugitive dust, the risk assessment should estimate the potential exposure to inorganic compounds or elements. Although semivolatile organic compounds (SVOCs) and volatile organic compounds (VOCs) can adhere to particulates, hazard quotients and cancer risks for SVOCs and VOCs are generally several orders of magnitude less than the impact from other exposure pathways and have little or no impact on the quantitative risk assessment under normal site conditions. Certain site conditions may exacerbate the generation of fugitive dust emissions, such as excess vehicular traffic on unpaved roads. Such conditions may require the use of an alternative particulate emission model and inclusion of SVOCs and VOCs in

¹³ U.S. EPA. (1991) *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)*, (RAGS, Part B).

¹⁴ U.S. EPA. (1991) *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)*, (RAGS, Part B).

addition to inorganics. However, under normal site conditions, only inorganics will generally impact the risk assessment when considering the inhalation of fugitive dust pathway. Potential fugitive dust emissions should be estimated based on the concentrations of contaminants in surface soil samples (typically 0-6 inches) since exposure is most likely to occur from surface soils instead of subsurface concentrations.

In order to calculate particulate emissions, a particulate emission factor (PEF) should first be calculated. The PEF can be calculated using Equation 10, found in *Soil Screening Guidance* and as presented in [Appendix A, Generic Cleanup Numbers](#). Both the emissions portion and the dispersion portion of the PEF equation have been updated since the publication of *RAGS, Part B* in 1991. Site-specific values or the default values given in Appendix A can be used. Values specific to the geographical location may also be substituted where appropriate.

(2) Inhalation of VOCs

To estimate air concentrations from VOCs in soil, a volatilization factor (VF) should first be calculated. The VF can be calculated using Equation 6 found in *Soil Screening Guidance* and as detailed in [Appendix A, Generic Cleanup Numbers](#). The VF found in *Soil Screening Guidance* replaces the Hwang and Falco (1986) model used as the basis for the *RAGS, Part B*, VF equation with the simplified equation developed by Jury et al. Surface and subsurface concentrations from soil in the vadose zone can be used to calculate air concentrations.

Also, the soil saturation concentration (Equation 9 in *Soil Screening Guidance*, also presented in [Appendix A, Generic Cleanup Numbers](#)) should always be calculated to ensure that the calculated VF is applicable to site conditions. At concentrations greater than the soil saturation concentration, the contaminant may be present in free phase and the input parameters for the VF equation are not applicable. If the calculated cleanup standard for soil exceeds the soil saturation concentration, then the soil saturation concentration should be used as the cleanup standard in soil. Default soil saturation concentrations are provided in Appendix A. Site-specific soil saturation concentrations can be calculated using adequately supported site-specific information. The volatilization factor equation contains an input that is related to time called the “exposure interval.” It is therefore important that this input variable is in agreement with the exposure time period that is appropriate for the receptor that is being evaluated. For example, the exposure period for a receptor under the industrial exposure scenario is different than for the residential exposure scenario.

(3) Inhalation of VOCs While Showering

To estimate air concentrations from contaminated ground water while showering, the concentration in air (C_a) should first be calculated based on the concentrations found in ground water.

The C_a can be calculated using the results of the Volatilization Factor for the Water equation presented in [Appendix A, Generic Cleanup Numbers](#). Once C_a has been calculated, C_a can then be substituted into the equation presented in the appropriate intake equation (Appendix A). The default values presented in Appendix A for the water concentration, fraction volatilization, water flow rate, bathroom size, and time spent showering should be used.

(4) Vapor Intrusion

Volatile chemicals in contaminated soils and/or ground water can emit vapors that may migrate into indoor air spaces of overlying buildings. This vapor intrusion pathway may be complete regardless of whether the buildings have basements or not. Accumulated vapors from this complete pathway may range in levels from those that pose near-term safety hazards and acute health effects to low levels that may pose a risk of chronic health effects due to long-term exposure to those low levels. The inhalation exposure pathway from vapor intrusion can be more complex than other pathways because it typically involves the use of indirect measurements and modeling. The vapor intrusion pathway should be assessed to determine whether the pathway is complete and if so, quantify the resulting risk as part of the cumulative risk associated with the unit.

U.S. EPA's most current and comprehensive *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils* is still subject to change and DHWM is in the process of developing guidance on evaluating this pathway. However, for previously completed closures in which the vapor intrusion pathway was evaluated, one of two approaches was used. The JOHNSON and ETtinger (U.S. EPA:1991 and 2002) *Model for Subsurface Vapor Intrusion Into Buildings* (J & E Model) was used with either the current published generic defaults or with measured site-specific soil gas concentrations.

It is important to note that DHWM discourages indoor air sampling. Indoor air sampling results can be misleading because it is difficult to account for contributions from background sources (*i.e.*, sources other than those emanating from the closure unit/contaminant plume). In addition, indoor air sampling conditions that are difficult to control (*i.e.*, HVAC configurations, doors, windows, ingress/egress traffic, temperature, etc.) may potentially confound the results.

Surface Water Pathway

The analysis of potential surface water exposure should compare U.S. EPA and Ohio EPA established water quality standards (OAC Chapter 3745-1) with the levels of constituents that may have the potential to discharge from contaminated ground water to a surface water body or that may have the potential to contaminate a surface water body via surface water runoff from contaminated soil. Models can be used to predict potential surface water impacts and/or when sampling may be required to measure surface water and sediment concentrations. The

surface water exposure analysis should also consider existing surface water contaminant concentrations.

Standards associated with surface water should consider the use of the surface water as drinking water (if appropriate), ecological impacts, impacts to the food chain, and risks associated with its use (e.g., swimming and fishing). Surface water runoff to nearby streams and surface and ground water contamination of surface water bodies can contribute to significant environmental and health risks, especially to those eating contaminated fish.

Exposure Parameters

RAGS, *Part A* describes the human health evaluation process conducted as part of a risk assessment at Superfund sites. It includes standard assumptions for various exposure pathways that have been used to calculate exposures from potential or residual concentrations of contaminants. Exposure equations and parameters listed in [Appendix A, Generic Cleanup Numers](#) are cited from RAGS, *Part A* and U.S. EPA's (1991) *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Supplemental Guidance "Standard Default Exposure Factors"*, found at:

http://epa.ohio.gov/portals/32/pdf/Removed_CPRG_Appendices.pdf, unless otherwise stated. U.S. EPA's (1997) *Exposure Factors Handbook* should be used as the primary source of exposure data. Most exposure pathway equations require only one site-specific value (i.e., contaminant concentrations in the medium (e.g., soil, water, and air) of concern).

Exposure Point Concentration For Soil

The concentration term is one of several parameters needed to estimate a contaminant dose for an individual. Because of the uncertainty associated with estimating the true average concentration at a site, the 95% Upper Confidence Limit (UCL) of the arithmetic mean,¹⁵ rather than the arithmetic mean, should be used for this variable. The choice of the 95% UCL of the arithmetic mean concentration as the appropriate measure for estimating exposure derives from the overriding need to estimate an individual's long-term average exposure. The 95% UCL of the arithmetic mean is based on the assumption that an individual is randomly exposed within the area of soil contamination (defined as the hazardous waste management unit). This value should not be confused with the 95th percentile (which can be approximated for a normal distribution as the mean plus two times the standard deviation).

For each individual constituent of concern, it should be determined whether the data set from the contaminated area approximates a normal or lognormal distribution. In most cases, the data set will more closely approximate a lognormal distribution and will therefore require adjustment as described in U.S. EPA's (1992) *Supplemental Guidance to RAGS: Calculating the Concentration Term*, found at http://epa.ohio.gov/portals/32/pdf/Removed_CPRG_Appendices.pdf. If the calculated 95% UCL of the arithmetic mean exceeds the maximum

¹⁵

The 95% UCL of the mean is defined as a value that, when calculated repeatedly for randomly drawn subsets of site data, equals or exceeds the true mean 95% of the time thus providing a conservative estimate of the mean concentration.

concentration or if the transformed data set does not approximate a normal distribution, then the maximum concentration should be used. The geometric mean should not be used to calculate the concentration term.¹⁶ Refer to the Guidance for Statistical Evaluation of Hazardous Waste Constituent Levels in Soils in [Appendix C, Guidance for Statistical Evaluation of Hazardous waste Constituent Levels in Soil](#), to determine the normality of a data set, and U.S. EPA's (2002) *Calculating the Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* and U.S. EPA's ProUCL¹⁷ for guidance in determining the UCL. DHWM expects that the recommendation from ProUCL will be used when utilizing the program. If a different UCL value is used, the facility should provide the justification for the different value.

Other methods may be used to estimate the exposure point concentrations that take into account the spatial and temporal variability of site data. DHWM does not preclude the use of alternative methods or alternative distributions for estimating the concentration term. Alternate methods can also be used as long as the methods are clearly presented, well documented and supported, and adequately protective of the exposed populations.

Where contamination may be unevenly distributed, resulting in areas of high contaminant concentrations (*i.e.*, hot spots) relative to other areas of the unit, characterization of the hot spots through extensive sampling should be conducted when such hot spots are to be left in place. If hot spots are identified within an area of contamination from the hazardous waste management unit, then the exposure to these areas should be assessed proportionately.

In certain instances where the hot spot area is likely to be encountered more frequently than in other areas of the unit, the hot spot area may require a separate quantitative risk evaluation. The fraction ingested (FI) term should not be adjusted for exposures to hot spot areas when conducting hazardous waste closures (*i.e.*, the FI term should equal 1). The sampling strategy and calculation of the concentration term should take into account hot spot areas. Other factors, such as soil saturation concentrations (*i.e.*, risk assessment assumptions may not apply at levels greater than soil saturation concentrations due to the potential for free-phase contaminants to be present), potential acute exposures, and chemical fate and transport mechanisms should be considered when evaluating a hot spot area. **The soil saturation concentration should be used as a maximum allowable concentration to be left in soil at any point within the hazardous waste management unit.**

Exposure Point Concentration for Ground Water

If the ground water is presently contaminated, then the exposure point concentration for ground water should be established using actual ground water monitoring data (method 4 below). If the ground water is NOT

¹⁶ Refer to U.S. EPA's (1992) *Supplemental Guidance to RAGS: Calculating the Concentration Term* for a discussion on the arithmetic mean versus the geometric mean.

¹⁷ ProUCL can be found at www.epa.gov/nerlesd1/tsc/software.htm.

contaminated but soil contamination may leach into the ground water, then methods (1), (2) and (3) below may be used.

- (1) Using a linear equilibrium soil/water partition equation such as Equation M-7 and M-8 as detailed in [Appendix A, Generic Cleanup Numbers](#). Default parameters are found in Appendix A for generic soils. Site-specific default parameters for specific soil types can be found in Ohio EPA's (2005) *Vadose Zone Modeling in RCRA Closure*;
- (2) Using a method such as Toxicity Characteristic Leaching Procedure (TCLP) or Synthetic Precipitation Leaching Procedure (SPLP) to demonstrate potential leachability of constituents from soil;

Soil samples should be collected from the area of maximum contamination for demonstration of leachability via one of these methods.

- (3) Using an appropriate fate and transport simulation model, such as those discussed in the [Vadose Zone Modeling](#) part of this chapter, to demonstrate soil leachability;

All site-specific inputs (*i.e.*, inputs other than conservative default values) into the model should have adequate supporting data.

- (4) Using actual ground water monitoring data. This approach is necessary for any unit where soil contamination extends to the zone of saturation. See [Chapter 4, Components for Closure by Removal Plans](#), for further information on ground water monitoring requirements for risk assessment closures.

To calculate the exposure point concentration, the 95% Upper Confidence Limit (UCL) of the mean¹⁸ (of a normal distribution or a transformed lognormal distribution) is used to account for the uncertainty associated with estimating the true average concentration. The 95% UCL is calculated with data from at least twelve samples from three monitoring wells over four quarters of sampling at each well. These wells should be located within the center of the contaminant plume since they will most likely contain the highest contaminant concentrations. U.S. EPA's (1992) *Supplemental Guidance to RAGS: Calculating the Concentration Term*, should be used to assist in calculating the exposure point concentration.

However if less than three wells are contaminated, then the maximum concentration (taken from the well with the highest concentration of the contaminant) should be used as the exposure point concentration for ground water. This is reasonable and does

¹⁸

The 95% UCL of the mean is defined as a value that, when calculated repeatedly for randomly drawn subsets of site data, equals or exceeds the true mean 95% of the time thus providing a conservative estimate of the mean concentration.

not constitute a worst-case scenario because it is highly unlikely that with so few wells the true highest concentration will be detected during sampling. Also, if the maximum contaminant concentration is lower than the 95% UCL, then the maximum contaminant concentration should be used as the exposure point concentration.

- (5) For ground water only: It is acceptable to subtract out upgradient non-unit- related concentrations of constituents. Poor upgradient ground water quality, resulting from sources other than the regulated unit, may move beneath the unit and be detected in downgradient wells. The owner/operator should not be held responsible for responding to such contamination under the unit-based closure rules. However, other laws may apply to address contamination not related to the closure unit.

The ground water pathways should consider all hazardous constituents identified through the ground water investigation (minus naturally occurring constituents and upgradient contamination) and all residual constituents remaining in the soils that could potentially leach to ground water. The exposure point concentration should be adjusted for multiple constituents and then compared to the generic risk-based numbers as found in [Appendix A, Generic Cleanup Numbers](#), or a used as part of site-specific risk assessment calculation.

7.3 Toxicity Assessment

Toxicity assessment is the evaluation of the potential health effects associated with hazardous constituents. It provides a process for determining if exposure to an agent can cause adverse effects in the exposed individual(s), and it also provides an estimate of the relationship between the extent of exposure to a contaminant and the incidence of adverse health effects in the exposed individual(s).

Toxicity assessments are generally conducted two different ways depending on whether the chemical has the potential to cause cancer (*i.e.*, carcinogenic effects) and/or whether the chemical has the potential to cause health effects other than cancer (*i.e.*, noncarcinogenic effects). This step involves gathering toxicity information and determining toxicity values (RfDs, RfCs, and SFs) for noncarcinogenic and carcinogenic effects.

Toxicity Information/Values

DHWM recognizes that at any one time there may be conflicting toxicity values for a specific hazardous constituent. For this reason, the following hierarchy of sources should be used when determining the most recent SFs, RfDs, and RfCs that are published and periodically revised by U.S. EPA. When using values from Agency for Toxic Substances and Disease Registry (ATSDR), Health Effects Assessment Summary Tables (HEAST), U.S. EPA Criteria Documents, or other sources, priority should be given to the source that provides the most current information which has been peer reviewed, is available to the public, and is transparent in the methods and processes used to develop the value.

Integrated Risk Information System (IRIS)

To obtain the latest descriptive and quantitative information on chemical elements and compounds, refer to IRIS, which is prepared and maintained by U.S. EPA. Toxicity data found on IRIS should be used as the primary source of information and should supersede all other sources. Toxicological information developed and submitted after inclusion of a toxicity value for a given chemical in IRIS can be considered as a basis for an alternate toxicity value. However, if this information was considered in the development of the IRIS value, then the toxicity value found on IRIS should be used.

For information on IRIS, contact the following:

IRIS Risk Information Hotline
National Center for Environmental Assessment - Cincinnati Office
Office of Research and Development
U.S. Environmental Protection Agency
26 W. Martin Luther King Drive
Cincinnati, OH 45268
Telephone: (513) 569-7254 Facsimile: (513) 569-7159
Web site address: <http://www.epa.gov/iris/>

For noncarcinogens, both oral and inhalation, key pieces of data included in IRIS are the RfD and RfC. The RfD and RfC are defined by U.S. EPA as "an estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure to the human population, including sensitive subpopulations, that is likely to be without appreciable risk of deleterious effects during a lifetime."

For carcinogens, a value known as the unit risk is provided for exposure to carcinogens by the oral and inhalation routes. The unit risk is the upper-level lifetime risk of contracting cancer when exposed to the chemical at a concentration of 1 ug/L in water (assuming consumption of 2 liters of water per day) or 1 ug/m³ in air (assuming continuous exposure). Drinking Water Health Advisories provide estimates of acceptable drinking water levels for chemical substances for various exposure durations. Citations to source documents used to derive these values are included in IRIS, as are review and verification dates, and telephone numbers of U.S. EPA contacts for further information. U.S. EPA regulatory actions resulting from major environmental legislation are another part of the IRIS data.

National Center for Environmental Assessment (NCEA) Provisional Values

NCEA provides provisional values for some compounds. A copy of NCEA's provisional values can be obtained from the NCEA web site, <http://cfpub.epa.gov/ncea>. Withdrawn values from IRIS and Health Effects Assessment Summary Tables (HEAST) may also be obtained at this web site. Provisional and withdrawn values can be used when IRIS values are not available for a chemical.

Generally, it is appropriate to use toxicity values that may have once been included in IRIS or HEAST, but were later withdrawn if no replacement value exists yet in IRIS or HEAST. However, if the chemical contributes significantly to the risk, the reviewer should consult with their supervisor.

Agency for Toxic Substances and Disease Registry (ATSDR) Toxicological Profiles
ATSDR toxicological profiles are a relatively thorough review of the toxicity information on specific contaminants. However, as with NCEA values, DHWM should be consulted if values derived from toxicological profiles are proposed for use.

U.S. EPA Criteria Documents

Criteria documents such as Drinking Water Criteria documents, Drinking Water Health Advisory summaries, Ambient Water Quality Criteria documents, or Air Quality Criteria documents may be consulted in the event that none of the above sources contain appropriate information. The reviewer should consult with their supervisor if these values are proposed for use in calculating a site-specific risk assessment. U.S. EPA Criteria Documents and ATSDR profiles can be obtained through NCEA or National Technical Information Service (NTIS).

Health Effects Assessment Summary Tables (HEAST)

U.S. EPA is in the process of updating the toxicity profiles of the chemicals found in HEAST. U.S. EPA plans to update about 25 HEAST chemicals per year until all HEAST chemicals are updated. U.S. EPA will notify regional risk assessors as the chemical profiles undergo the peer review process and become finalized. In the mean time, the values found in HEAST are still applicable in cases where the sources listed in the hierarchy above do not contain toxicity values for a constituent. The reviewer should consult with their supervisor to verify the scientific uncertainties and issues that may pertain to old HEAST values.

Chemicals Without Inhalation Toxicity Values

If there is not an inhalation toxicity value for a particular chemical based on DHWM's hierarchy of toxicity data sources, then the next step is to look for evidence of inhalation toxicity by consulting the ATSDR Minimal Risk Level (MRL) tables. If there is an inhalation MRL listed for that chemical, then a route-to-route extrapolation will be performed (*i.e.*, use the oral toxicity value as the inhalation toxicity value). National Institute for Occupational Safety and Health (NIOSH), American Conference of Governmental Industrial Hygienists (ACGIH), and Occupational Safety and Health Administration (OSHA) are not acceptable as sources for evidence of chronic inhalation toxicity. In the event that a chemical has either an intermediate or acute ATSDR MRL, and no chronic MRL, then the oral RfD for that chemical should be directly extrapolated as the inhalation RfD.

Constituents Without Chronic Toxicity Values

For some hazardous constituents, formally recommended exposure limits do not yet exist. If no toxicity value can be obtained for a specific chemical, then the chemical should not be automatically excluded from the risk assessment.

Generally, for chemicals without oral or inhalation slope factors, it is appropriate to exclude these chemicals if no carcinogenic data (qualitative or quantitative) is available. It is likely that there is no evidence to suggest carcinogenicity for that specific chemical and therefore does not require evaluation as a carcinogen. A chemical may also be found to only be a carcinogen via a particular route of exposure (*e.g.*, current evidence suggests that cadmium and chromium are inhalation carcinogens, but there is no evidence to suggest oral carcinogenicity). However, a chemical with a provisional or withdrawn slope factor should continue

to be evaluated as a carcinogen until it is classified in IRIS as a noncarcinogen (Class D or E) for the pathway of concern.

For chemicals without chronic toxicity values, the value of a chemical that is related both chemically and toxicologically (*i.e.*, structure-activity relationship) can be used. For example, specific carcinogenic PAH slope factors are generated based on their relative potency to benzo(a)pyrene. This assessment technique is known as comparison based on toxicological similarity. For further information about this technique refer to [Section 8.5 on Polycyclic Aromatic Hydrocarbons](#).

There may be chemicals for which chronic toxicity values or surrogate values are not available. In such cases, the reviewer should evaluate (using his/her best professional judgment), based on acute toxicity and qualitative data and taking into consideration the potential exposure to the chemical and actual concentrations of the chemical that are present, if a chemical is likely to be a risk to human health. Based on this information, it should be determined whether or not a quantitative evaluation is required. It may be determined that chemicals without toxicity values do not require quantitative evaluation. However, at a minimum, their absence from the quantitative risk assessment should be discussed in the uncertainty section of the closure plan. In circumstances where it is determined that the chemical may present a significant risk, the facility should remove the contaminant to below detection limits for organic chemicals or to a demonstrated background level for inorganic chemicals; however, such circumstances are expected to be rare.

Subchronic Toxicity Values

RAGS, *Part A* indicates that a subchronic exposure period can vary from two weeks to seven years. In some scenarios, adult exposure durations may be relatively short. Two examples are a “construction worker scenario” and a “trespasser scenario.” Subchronic RfDs (where available) can be used for these types of short duration adult exposure scenarios. Although the strict definition of a subchronic value as defined by U.S. EPA suggests that subchronic values may be used to evaluate childhood exposures to noncarcinogens (ages 0-6 years), DHWM does not consider subchronic values to be protective of children. Subchronic toxicity values should not be used unless a short duration scenario (*e.g.*, construction worker scenario) requires evaluation.

Converting RfCs to Inhalation Reference Doses

Doses (*i.e.*, intakes and absorbed doses) are calculated in mg/kg-day. For noncarcinogens, the inhalation reference concentrations found in IRIS and HEAST are generally in units of mg/m³. These units need to be converted to mg/kg-day before substituting the toxicity value into the intake equation. The reference concentration (RfC) can be converted to an inhalation reference dose (RfDi) as follows:

Equation 7-1: Conversion of Inhalation Reference Concentration to Inhalation Reference Doses
$\text{RfDi}(\text{mg} / \text{kg} - \text{d}) = \frac{\text{RfC}(\text{mg} / \text{m}^3) \times 20\text{m}^3 / \text{d}}{70\text{kg}}$

Converting Unit Risks to Inhalation Slope Factors

Doses (*i.e.*, intakes and absorbed doses) are calculated in mg/kg-day. For carcinogens, the air unit risk in (ug/m³)⁻¹ can be found in IRIS and HEAST. These unit risks need to be converted to an inhalation slope factor in (mg/kg-d)⁻¹ before substituting the toxicity value into the intake equation. The conversion is as follows:

Equation 7-2: Conversion of Air Unit Risk to Inhalation Slope Factor

$$SF(\text{mg} / \text{kg} - \text{d})^{-1} = \frac{\text{AirUnitRisk}(\text{ug} / \text{m}^3)^{-1} \times 70\text{kg} \times 1000\text{ug} / \text{mg}}{20\text{m}^3 / \text{d}}$$

Adjustment of Toxicity Values

Toxicity values for both noncarcinogenic and carcinogenic effects are generally expressed as administered doses rather than absorbed doses. An adjustment is necessary to match the exposure estimate with the toxicity value if one is based on an absorbed dose and the other is based on an intake (*i.e.*, administered dose). Be sure that exposure estimates and toxicity values for comparison are both expressed as absorbed doses or both expressed as administered doses/intakes.

Because toxicity values are generally expressed as administered doses, the values have to be converted to absorbed doses when evaluating the dermal pathway. Refer to *RAGS, Part A, Appendix A* as guidance for adjusting administered toxicity values to absorbed values. Oral absorption factors are used to convert from an administered dose toxicity value to an absorbed dose toxicity value. When appropriate, published data are available on oral absorption of a specific chemical, the chemical-specific data should be used to make the administered/absorbed dose adjustment. IRIS and ATSDR Toxicological Profiles are good sources of information regarding oral absorption factors. For some examples of chemical-specific oral absorption factors, refer to [Appendix A, Generic Cleanup Numbers](#). If a chemical-specific oral absorption factor cannot be found in Appendix A or in another acceptable, peer-reviewed source, then the following default oral absorption values¹⁹ should be used:

- (1) 58% for PAHs
- (2) 80% for PCBs
- (3) 50% for Dioxins, Dibenzofurans, SVOCs, VOCs
- (4) 1% for Inorganics

As specified in the following Exhibits 7-1 and 7-2 (*RAGS, Part A, Appendix A*, page A-2 and A-3), assuming 100 percent absorption (*i.e.*, using an oral absorption value of 100%) of an administered dose toxicity value for estimating the dermal/absorbed dose toxicity value would be a NON-CONSERVATIVE approach. Therefore Ohio EPA does not recommend this approach either. When converting toxicity values from unit risks, administered dose values, and

¹⁹

U.S. EPA. (2004) *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)*.

reference concentrations, values should be presented with the same number of significant figures as in their sources, since the number of significant figures reflects some of the uncertainty associated with the toxicity data. For a detailed discussion of adjustments for toxicity values see Appendix A in *RAGS, Part A*.

Exhibit 7-1: Example - Adjustment of an Administered to an Absorbed Dose RfD

An oral RfD, unadjusted for absorption, equals 10 mg/kg-day.

Other information (or an assumption) indicates a 20% oral absorption efficiency in the species on which the RfD is based.

The adjusted RfD that would correspond to the absorbed dose would be:

$$10 \text{ mg/kg-day} \times 0.20 = 2 \text{ mg/kg-day.}$$

The adjusted RfD of 2 mg/kg-day would be compared with the amount estimated to be absorbed dermally each day.

Source: U.S. EPA (1989) *RAGS, Part A*, Appendix A, page A-2.

Exhibit 7-2: Example - Adjustment of an Administered to an Absorbed Dose Slope Factor

An oral slope factor, unadjusted for absorption equals $1.6 \text{ (mg/kg-day)}^{-1}$.

Other information (or an assumption) indicates a 20% absorption efficiency in the species on which the slope factor is based.

The adjusted slope factor that would correspond to the absorbed dose would be:

$$1.6 \text{ (mg/kg-day)}^{-1} / 0.20 = 8 \text{ (mg/kg-day)}^{-1}.$$

The adjusted slope factor of $8 \text{ (mg/kg-day)}^{-1}$ would be used to estimate the cancer risk associated with the estimated absorbed dose for the dermal route of exposure.

Source: U.S. EPA (1989) *RAGS, Part A*, Appendix A, page A-3.

Bioavailability

The bioavailability of environmental chemicals is generally not taken into consideration when developing toxicity values (*i.e.*, administered doses in controlled animal studies). The portion that is actually absorbed by the receptor (and is therefore the bioavailable portion) is not determined in these studies. The actual bioavailability is irrelevant as long as risk conclusions are based on comparisons between calculated human intakes and toxicity values developed from administered doses. Bioavailability questions arise as to the potential differences in uptake levels under study conditions versus environmental exposure conditions. Since there generally is not any or enough information regarding the bioavailability of substances under study conditions as well as under actual exposure conditions, it is generally not appropriate to adjust environmental concentrations based on potential bioavailability. Likewise, the bioavailability can vary significantly between different matrices. Adjustments to the 100% bioavailability default assumption in the exposure equation should not be accepted without extensive supporting data for determining the bioavailability under study conditions and site-specific environmental conditions.

7.4 Risk Characterization

Risk characterization combines the exposure assessment and toxicity assessment to derive an estimate of risk due to activities at the hazardous waste management unit.

Screening Chemicals From Further Analysis in a Risk Assessment

When screening chemicals from further evaluation in a human health risk assessment, a variety of optional screening tools are available. These screens include frequency of detection, common laboratory contamination, elimination of tentatively identified compounds, comparison to background and comparison to published conservative risk-based screening values.

Frequency of Detection

Chemicals that are infrequently detected may be artifacts in the data due to sampling, analytical, or other problems, and therefore may not be related to unit operations or disposal practices. A chemical may be a candidate for elimination from the quantitative risk assessment if: 1) it is detected infrequently in one or perhaps two environmental media, 2) it is not detected at high concentrations in any other sampled media, 3) the maximum detection does not exceed an acceptable standard, and 4) there is no reason to believe that the chemical may be present because the chemical is neither linked to unit operations or disposal practices nor is it a degradation product.

A detection frequency limit of 5%, with a minimum of twenty samples, is standard. If a chemical is detected in 5% or less of the samples and it meets the criteria stated above, it may be screened from further consideration in the risk assessment. The detection frequency limit should be approved by DHWM before this screening method may be used. The full extent of contamination should be defined before chemicals can be screened out based on a low frequency of detection.

Common Laboratory Contamination²⁰

A complete data set should include laboratory method blanks which measure the amount of contamination introduced into the data set from analytical procedures. If such blanks are contaminated, then a potential for false detection exists. Chemicals which are detected in both samples and blanks may be screened out if they meet appropriate criteria.

For common laboratory contaminants, the chemical may be screened out if all detected concentrations in the samples are less than ten times the maximum amount detected in the laboratory method blank. Common laboratory contaminants include acetone, methyl ethyl ketone (2-butanone), methylene chloride, cyclohexane, and phthalate esters. If any sample concentration exceeds ten times the concentration of the blank contaminant, a positive result should be reported.

For those chemicals which are not common laboratory contaminants, the chemical may be screened from further consideration if the maximum sample concentration is less than five times the maximum blank concentration. If any

²⁰

U.S. EPA. (1999) *Contract Laboratory Program National Functional Guidelines for Organic Data Review*.

sample concentration exceeds five times the blank contaminant amount, then that contaminant should be retained for further evaluation.

Ohio EPA retains the right to prohibit the use of this screening tool if there is evidence of high analytical contamination which could result in screening detrimental concentrations of site contamination.

Tentatively Identified Compounds

Tentatively identified compounds (TICs) are chemicals that are neither identified nor quantified with certainty. If a TIC is reported to have a low concentration, defined as less than ten times the instrument detection limit, and the TICs cannot be linked historically to the unit, then it may be eliminated from further assessment. High concentrations, a large number of TICs, and/or possible historical use of the TICs warrants retention and additional investigation. The screening of TICs should not be applied to combustion sites as incomplete combustion processes may yield unanticipated compounds.

Background Comparison

For inorganic contaminants, appropriately sampled and derived site-specific background levels may be used to distinguish unit contamination levels from naturally occurring concentrations. If all samples from the same media are less than the site-specific background, then the contaminant may be screened from further consideration. It is important to note that since closure is unit specific, background levels in ground water may include naturally and non-naturally occurring constituents from anthropogenic and autogenic upgradient sources.

Ohio EPA has developed alternate metal standards (AMSs) for seven naturally occurring metals in soil. These values may only be used in closure by removal and are not valid as screening levels for risk assessments.

Risk-Based Cleanup Numbers With Adjustment Factors

Three categories of risk-based numbers may be applied for risk-based screening. These three categories are the following: soil numbers that are protective of direct contact; soil numbers that are protective of leaching to ground water, as well as direct contact to soil; and ground water numbers that are protective of direct contact. Risk-based screening cannot occur when both soil and ground water are contaminated. When screening, only numbers generated for a residential scenario may be used.

Direct contact soil numbers may only be used for screening when the determination has been made that leaching to ground water will not occur. Published direct contact soil numbers that address the appropriate pathways and use DHWM's default factors include DHWM's Generic Cleanup Numbers (GCNs) for direct contact with soil found in [Appendix A, Generic Cleanup Numbers](#), and U.S. EPA Region IX's Preliminary Remediation Goals (PRGs) for residential soil.

Soil numbers that are protective of leaching should be used when the uppermost ground water table has the potential to be contaminated by leaching from the soil. For screening purposes, use the CPRG's GCNs Protective of Ground Water (1 DAF). Again, risk-based screening cannot occur when both soil and ground water are contaminated.

Published direct contact ground water numbers that address all required pathways and use DHWM's default factors include the DHWM GCNs for direct contact with ground water found in [Appendix A, Generic Cleanup Numbers](#). U.S. EPA Region IX's PRGs for residential tapwater do not address dermal contact with ground water, and therefore should not be used in risk-based screening.

Although DHWM's GCNs and U.S. EPA Region IX's PRGs for soil are the standard values accepted by DHWM, other values may be used when justified. However, a complete description of how these risk-based screening values were established and how they are justified for a specific site/unit must also be submitted.

Chemicals are screened out of a risk assessment by comparing the maximum concentration to **residential** cleanup numbers multiplied by an adjustment factor. The adjustment factor should result in a screening risk goal of 1E-06 for carcinogens or a Hazard Index of 0.1 for non-carcinogens. Thus, all DHWM GCNs should be multiplied by 0.1 to develop screening numbers that have a risk goal of 1E-06 for carcinogens or a Hazard Index of 0.1 for non-carcinogens. Non-carcinogenic U.S. EPA Region IX PRGs should be multiplied by 0.1 to yield a Hazard Index of 0.1. The carcinogenic adjustment factor would be 1 for U.S. EPA Region IX PRGs, since the cancer risk goal is already set at 1E-06.

Screening is performed in a simple three-step process.

- (1) In the first step, any chemicals which are known to be a persistent, bioaccumulative and toxic (PBT) chemical *cannot* be screened out of the risk assessment, regardless of their concentrations. Priority PBTs include: aldrin, dieldrin, benzo(a)pyrene, chlordane, DDT, DDD, DDE, hexachlorobenzene, alkyl-lead, mercury compounds, mirex, octachlorostyrene, PCBs, dioxins, furans and toxaphene.²¹
- (2) In the second step, the chemical's maximum site concentration is compared to its soil saturation concentration (C_{sat}) or ground water Maximum Contaminant Level (MCL), whichever is applicable. If the concentration is above its respective C_{sat} or MCL, then it *cannot* be eliminated.
- (3) In the last step, maximum concentrations are divided by their respective cancer and noncancer adjusted screening numbers. The results are then summed across chemicals for each endpoint. The sum for each endpoint must be less than or equal to one, which would be equivalent to a Hazard Index of 0.1 for the noncancer endpoint or a Cancer Risk of 1E-06 for the cancer endpoint. If a sum of 1.0 is exceeded, then the largest contributing chemical(s) should be retained for a quantitative risk assessment, such that the chemicals that are not retained now sum to less than 1.0 (for both cancer and noncancer pathways). These non-retained chemicals are then screened out of the risk assessment process.

It is important to note that no more than 10 carcinogenic constituents of concern (COCs) and no more than 10 non-carcinogenic COCs should be screened out of a risk assessment when using DHWM's GCNs.

²¹

U.S. EPA. (2001) *Priority PBTs*.

Screening During Risk Assessments

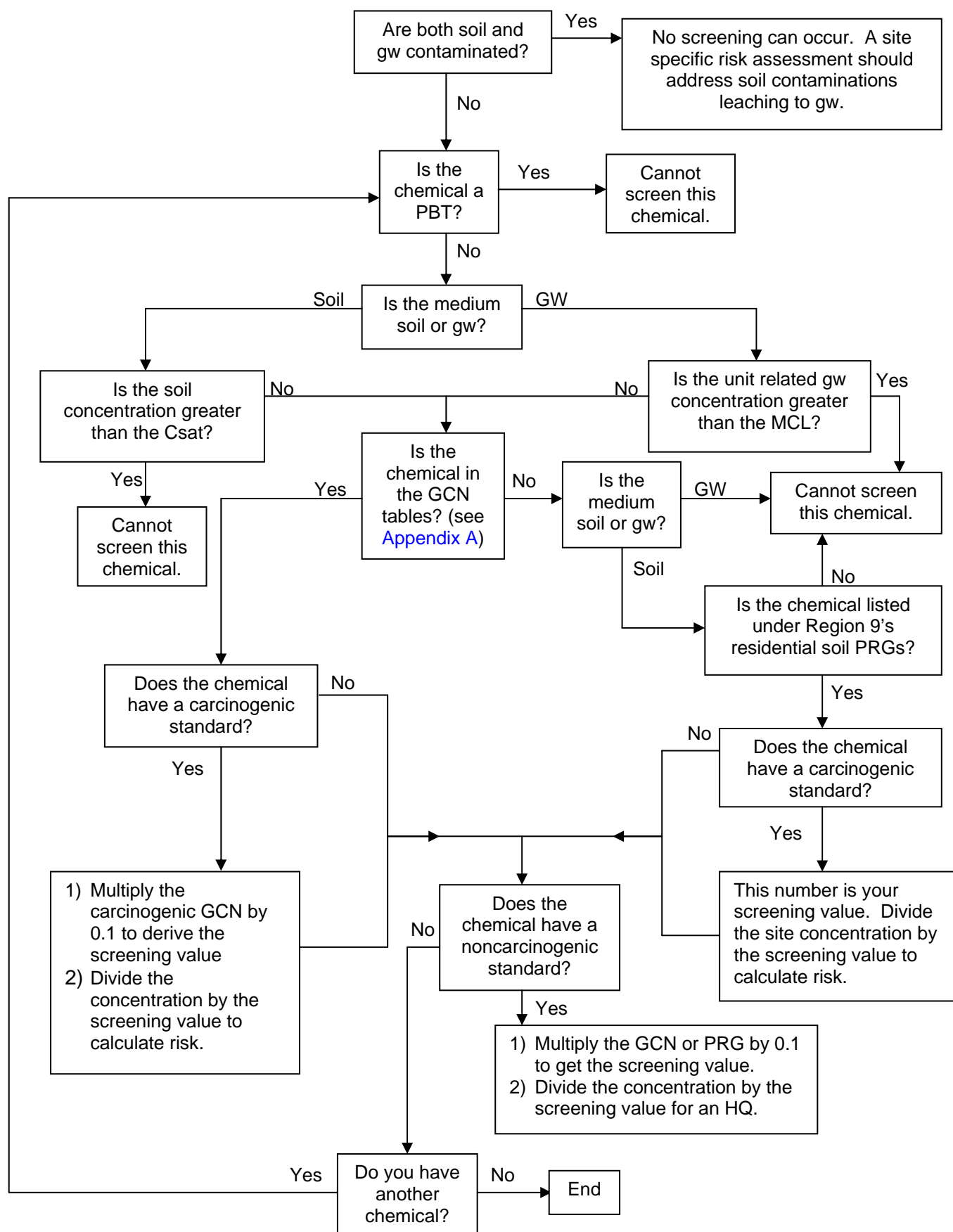


Figure 7-1: Screening Flowchart

Carcinogenic Risk

The carcinogenic risk posed by a hazardous constituent is the average daily intake multiplied by the carcinogenic slope factor (SF). This multiplication product is known as the upper bound individual excess lifetime cancer risk. The risk estimate is upper bound because it is an estimate based on conservative dose-response modeling. The SF is an upper bound probability of cancer risk per unit intake of a chemical over a lifetime (expressed in units of $(\text{mg/kg-d})^{-1}$). SFs are estimated through the use of mathematical extrapolation models for estimating the largest possible linear slope (within the 95% upper confidence limit) at low extrapolated doses that is consistent with the data. The carcinogenic risk estimate (unitless) for each constituent is expressed as:

Equation 7-3: Calculation of Carcinogenic Risk Estimate		
$\text{Risk} = \text{I} \times \text{SF}$		
Risk	=	a unitless probability (e.g., 1E-05) of an individual developing cancer;
I	=	intake averaged over 70 years (mg/kg-d); and
SF	=	slope factor, expressed in $(\text{mg/kg-d})^{-1}$

The equation to determine the dermal slope factor is:

Equation 7-4: Calculation of Dermal Slope Factor		
$\text{SF}_d = \frac{\text{SF}_o}{\text{OABS}}$		
SF_d	=	dermal slope factor $(\text{mg/kg-d})^{-1}$
SF_o	=	oral slope factor $(\text{mg/kg-d})^{-1}$
OABS	=	oral absorption factor (Table A-5, Appendix A)

The cancer risk equation which estimates the incremental individual lifetime cancer risk for simultaneous exposure to several carcinogens is expressed as:

Equation 7-5: Calculation of Total Cancer Risk		
$\text{Risk}_T = \sum_{i=1}^n \text{Risk}_i$		
Risk_T	=	the total cancer risk, expressed as a unitless probability;
Risk_i	=	the risk estimate for i^{th} constituent

To assess the overall potential for carcinogenic risk posed by multiple exposure pathways, it is important to calculate the total exposure cancer risk as follows:

Equation 7-6: Calculation of Total Exposure Cancer Risk
Total Exposure Cancer Risk = Risk (exposure pathway ₁) + Risk (exposure pathway ₂) + ... + Risk (exposure pathway _i)

For carcinogens detected at the unit, the total excess exposure cancer risk must not exceed the upper-bound cancer rate of 1E-05 (*i.e.*, an increased risk of one in one hundred thousand) from the contaminants left in place.

Cancer Guidelines

In the 1986 cancer guidelines,²² U.S. EPA used a system adapted from the International Agency for Research on Cancer to classify hazardous constituents according to a weight-of-evidence scheme based on human studies and animal studies. Hazardous constituents classified as A, B1, and B2 were identified as chemicals that should be included in a carcinogenic risk assessment, while quantitative risk estimates for chemicals listed as class C carcinogens could be performed on a chemical-specific or site-specific basis. An example of a situation that might have required evaluation of a class C carcinogen were situations where a toxicity value was not available to evaluate noncarcinogenic effects; therefore, as a conservative measure, the carcinogenic effects may have been evaluated.

In 2005, U.S. EPA published the *Guidelines for Carcinogen Risk Assessment* in the Federal Register as a revision to the 1986 guidelines. In the revised guidelines, U.S. EPA called for the evaluation of all relevant information and identified that the classification scheme in the 1986 guidelines does not make use of all relevant biological information available. When identifying whether or not to evaluate a chemical as a carcinogen, the reviewer should evaluate the weight of evidence narrative as well as all relevant biological information relating to the carcinogenicity of each chemical, instead of relying only on the 1986 classification scheme. For further information on evaluating carcinogenicity, consult U.S. EPA's (2005) *Guidelines for Carcinogen Risk Assessment*.

Noncarcinogenic Hazard

The noncarcinogenic hazard posed by a hazardous constituent is the average daily intake divided by the RfD or RfC; this ratio is known as the hazard quotient (HQ). The average daily intake is the mass of a hazardous substance contacted per unit body weight per unit time averaged over a portion of a lifetime (*i.e.*, that portion of a lifetime during which exposure actually occurs). Chronic, subchronic, and developmental (to evaluate the potential effects on a developing organism following a single exposure event) RfDs are available for different chemicals. A chronic RfD is an estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure to a member of the human population (including sensitive subpopulations) that will not result in an appreciable risk of deleterious effects during a lifetime. Subchronic RfDs define a daily exposure over shorter time periods (*i.e.*, between two weeks and seven years) that will not result in an appreciable risk of deleterious effects and are generally useful for assessing potential noncarcinogenic effects associated with short-term exposures.

²²

U.S. EPA. (1986) *Guidelines for Carcinogen Risk Assessment*

Developmental RfDs are useful specifically for assessing potential developmental effects resulting from exposure to a compound.

Because Ohio EPA believes it is most appropriate to assume that exposures occur for a minimum of 25 years for industrial scenarios and 30 years for residential scenarios, subchronic values generally are not appropriate for sensitive subpopulations (*i.e.*, children). Therefore, only chronic RfDs should be used unless an alternative scenario requires evaluation (*i.e.*, construction worker).

The HQ (unitless) is expressed as:

Equation 7-7: Calculation of Hazard Quotient	
$HQ = \frac{I_i}{RfD_i}$	
I_i	= intake for i^{th}
RfD_i	= reference dose for the i^{th} toxicant

The equation to determine the dermal reference dose is:

Equation 7-8: Calculation of Dermal Reference Dose	
$RfD_d = RfD_o \times OABS$	
RfD_d	= dermal reference dose (mg/kg-d)
RfD_o	= oral reference dose (mg/kg-d)
OABS	= oral absorption factor (Table A-5, Appendix A)

To assess the overall potential for noncarcinogenic hazards posed by multiple hazardous constituents, it is important to calculate the hazard index (HI). The hazard index is equal to the sum of the hazard quotients and is expressed as:

Equation 7-9: Calculation of Hazard Index	
$\text{HazardIndex} = \frac{I_1}{RfD_1} + \frac{I_2}{RfD_2} + \dots + \frac{I_i}{RfD_i}$	
I_i	= intake for i^{th}
RfD_i	= reference dose for the i^{th} toxicant

The total exposure HI is equal to the sum of the hazard indices and is expressed as:

Equation 7-10: Calculation of Total Exposure Hazard Index
$\text{Total Exposure HI} = \text{HI (exposure pathway}_1\text{)} + \text{HI (exposure pathway}_2\text{)} + \dots + \text{HI (exposure pathway}_i\text{)}$

Be sure to note that both cancer SFs and noncancer RfDs or RfCs are often available for the same hazardous constituent. Carcinogens should be evaluated for noncarcinogenic hazards as well as for carcinogenic risks.

Risk-Based Standard

For both carcinogens and noncarcinogens, decontamination of the hazardous waste management unit has been achieved if the total cancer risk does not exceed the upper-bound risk level of $1\text{E-}05$ and the total hazard index does not exceed unity (*i.e.*, $\text{HI} \leq 1.0$) assuming **additive** effects between hazardous constituents and **additive** effects across all routes of exposure.

The [Risk Assessment Plan Review Form](#) should be used for a general or initial review of a risk assessment. **Do not use the review form alone to evaluate a closure plan.** The reviewer should go beyond the level of detail in the checklist to address the specific details in a plan for an individual site. There are many additional references that the reviewer must be familiar with in order to adequately evaluate a risk assessment. Many of the references can be found in [Chapter 10, References](#).

Segregation Of Chemicals By Effect

Segregation of chemicals results in establishing a health-based standard by effect and mechanism of action. Before segregation can be considered, the risk assessment should identify all adverse effects of the constituent and should not limit health effects to the critical effects which are presented in IRIS and HEAST. The critical effect is based on the lowest level which causes an adverse effect; however, other adverse effects may occur at higher doses. All adverse effects should be identified. As a conservative assumption, all adverse effects can be assumed to occur at the level at which the critical effect occurs. All adverse effects should be evaluated for each chemical. Segregation of chemicals by effect should not rely solely on the studies presented in IRIS or HEAST, but should include a comprehensive review of all the literature available on each constituent and mixtures of constituents of concern. **In lieu of this information, DHWM assumes dose additivity which encompasses additive effects between hazardous constituents and additive effects across all exposure pathways to calculate a total exposure hazard index and a total cancer risk.**

Uncertainty Analysis

An uncertainty analysis should be conducted for all risk-based closures. The degree of uncertainty can be presented using a qualitative, semi-quantitative, or quantitative approach. The decision to conduct a specific type of uncertainty analysis should be made on a site-specific basis. Quantitative statistical uncertainty analysis techniques (*i.e.*, probabilistic risk assessment techniques) generally may not be practical or necessary for hazardous waste closures. However, if a facility chooses to conduct an uncertainty analysis using probabilistic techniques, consult U.S. EPA's (1997) *Guiding Principles for Monte Carlo Analysis* and U.S. EPA's (1997) *Use of Probabilistic Techniques (Including Monte Carlo Analysis) Assessment*. Additional guidance can be

obtained from U.S. EPA's (2001) *Risk Assessment Guidance for Superfund, Volume III: Part A, Process for Conducting Probabilistic Risk Assessment*.

There are several categories of uncertainties associated with risk assessments. The initial selection of substances used to characterize exposures and risk on the basis of the sampling data and available toxicity information are all sources of uncertainty. The toxicity values for each substance that are used to characterize risk are additional sources of uncertainty. There is uncertainty in the chemical monitoring data and in the models used to estimate exposure concentrations. Additional uncertainties are incorporated into the risk assessment when exposures to several substances across multiple pathways are summed. The facility should also evaluate the likelihood of the exposure pathways to occur and the potential for the land use assumptions to occur. Sampling strategies, sample collection techniques, and sample analyses can also account for significant uncertainty at a site. Each facility should attempt to identify the areas where significant uncertainties may exist within the uncertainty section of the closure plan. At a minimum, a qualitative uncertainty analysis should be included as part of a risk assessment.

Chapter 8

Special Contaminants

Contaminants of concern are included in this chapter because their risk assessment deviates from the traditional risk assessment methodology outlined in [Chapter 7, General Concepts in Human Health Risk Assessments](#). In particular, their toxicity assessments are unique due to a variety of reasons listed below.

- Benzene's oral and inhalation slope factors are presented in IRIS as ranges rather than a single toxicity value for each pathway.
- Dioxins and furans are a class of compounds that utilize toxicity equivalency factors as a means of comparing compound toxicities to one standard compound.
- Lead does not have noncarcinogenic reference doses or carcinogenic slope factors available.
- Polychlorinated biphenyls (PCBs) are a class of compounds in which only a few compounds have a reference dose available. The cancer potency of PCB mixtures is presented in IRIS as a tiered system.
- Polycyclic aromatic hydrocarbons (PAHs)'s carcinogenic evaluation uses an assessment technique known as comparison based on toxicological similarity.

This chapter outlines DHWM's recommendations for performing the toxicity assessments for the special contaminants mentioned above.

8.1 Benzene

Background Information

The oral and inhalation slope factors for benzene are currently presented on IRIS as ranges rather than a single point number. The oral slope factor is derived from the inhalation slope factor, with adjustments made for exposure pathways, inhalation absorption and oral absorption. Therefore, this summary will describe the development of the inhalation slope factor risk range.

Benzene is classified as a known human carcinogen by IRIS. Human epidemiological data demonstrate a causal relationship between benzene exposure and various forms of leukemia (most clearly, acute nonlymphocytic leukemia). Animal studies correlate with the human data, as well as suggest additional cancer risks at other organ sites.

The most convincing epidemiological study was performed by Infante et al. (1977) and refined by Rinsky et al. (1981, 1987). These studies followed a cohort of Pliofilm rubber workers who were exposed to airborne benzene concentrations for at least one day from 1940 to 1965. Benzene concentrations were measured, except prior to 1946. Follow-up of the employees occurred through December 31, 1981.¹ This study was chosen by IRIS to develop the benzene slope factor because this cohort had few co-exposures to other chemicals and covered a large range of benzene exposures. The largest problem with the study was the lack of benzene air concentration measurements before 1946.

¹ Rinsky, R.A., A.B. Smith, R. Horning. (1987) "Benzene and Leukemia: an Epidemiologic Risk Assessment".

Also, cancer risk could not be estimated for levels less than 200 ppm-years due to lack of sensitivity of the data.

The largest confounding factor of the Pliofilm study is the development of exposure estimations prior to 1946, when exposure was thought to be the greatest. Two different exposure estimates were used to develop the risk range.² Crump and Allen (1984) assumed a mean dose for the years before exposure was known, and only allowed for decreases in concentrations in later years as air monitoring began and the factory came into compliance with new air regulations. Paustenbach assumed higher concentrations than what was measured in 1946, citing unreliable sampling devices, longer work weeks, and other factors. By assuming higher concentrations, the resulting slope factor is *less conservative* because the slope factor is calculated assuming a higher concentration caused the known set of effects. When a linear dose response model is assumed, Crump and Allen (1984) estimates a risk range of 1.1E-02 to 2.5E-02 for 1ppm, while the Paustenbach et al. (1993) estimates range from 7.1E -03 to 2.5E -02 at 1 ppm. These two estimates form the current IRIS risk range of 7.1E-03 to 2.5E -02 at 1 ppm (7.7 E-03 to 2.7E-02 (mg/kg-day)⁻¹).

Application of Risk Range in Risk Assessment

DHWM recommends using the most conservative end of the benzene risk range (2.7E-02 (mg/kg-day)⁻¹) as the inhalation slope factor for all RCRA risk assessments, including screening, site-specific risk assessments and DHWM's generic applications. This position accounts for the uncertainty in the exposure concentration for the Plioform cohort before 1946. The IRIS risk range is developed by assuming different exposure assumptions prior to 1946. It is the position of DHWM that a three fold uncertainty factor should be applied to the slope factor value to account for uncertainty in this exposure. This three fold uncertainty factor is incorporated by assuming the most conservative end of the range. For the oral slope factor, 5.5E-02 (mg/kg-day)⁻¹ is also based on the most conservative end of the risk range and should be used in calculating risks.

This guidance regarding slope factor risk ranges applies only to benzene. For this particular constituent, the risk range does not reflect slope factor application for sensitive sub-populations or some other science-based distinction. Instead, this risk range merely reflects uncertainty in exposure. The purpose of this policy is to account for the uncertainty reflected in the benzene risk range. If new slope factor risk ranges are presented on IRIS for additional constituents, guidance will be developed on a chemical specific basis.

8.2 Dioxin and Furan

Background Information

Regarding the special class of contaminants, chlorinated dibenzodioxins (CDDs) and chlorinated dibenzofurans (CDFs), and mixtures of these compounds, the most practical risk evaluation methodology available remains based on the use of toxicity equivalency factors, which provide for comparisons of toxicity of the compounds to one standard compound (2,3,7,8 - TCDD). These contaminants share a gross structural similarity with

² Crump, K.S., B.C. Allen. (1984) *Quantitative Estimates of Risk Assessment of Risk of Leukemia From Occupational Exposure to Benzene* and Paustenbach, D., R. Bass, P. Price. (1993) "Benzene Toxicity and Risk Assessment, 1972-1992: Implications for Future Regulation".

PCBs,³ and share many of the same health and environmental concerns. The following information is specific to CDDs, but applies broadly to the similar CDFs as well.

CDDs are a family of 75 different compounds commonly referred to as polychlorinated dioxins. These compounds have varying harmful effects. The CDD family is divided into eight groups of chemicals based on the number of chlorine atoms in the compound. The group with one chlorine atom is called the mono-chlorinated dioxin(s). The groups with two through eight chlorine atoms are called di-chlorinated dioxin (DCDD), tri-chlorinated dioxin (TrCDD), tetra-chlorinated dioxin (TCDD), penta-chlorinated dioxin (PeCDD), hexa-chlorinated dioxin (HxCDD), hepta-chlorinated dioxin (HpCDD), and octa-chlorinated dioxin (OCDD). The chlorine atoms can be attached to the dioxin molecule at any one of eight positions. The name of each CDD indicates both the number and the positions of the chlorine atoms. For example, the CDD with four chlorine atoms at positions 2,3, 7, and 8 on the dioxin molecule is called 2,3,7,8-tetrachlorodibenzo-p-dioxin or 2,3,7,8-TCDD. 2,3,7,8-TCDD is one of the most toxic of the CDDs to mammals and has received the most attention. Thus, 2,3,7,8-TCDD serves as a prototype for the CDDs. CDDs with toxic properties similar to 2,3,7,8-TCDD are called “dioxin-like” compounds.

It is important to note that CDDs are found in the environment together with other structurally related chlorinated chemicals, such as chlorinated dibenzofurans (CDFs) and PCBs. Therefore, people are generally exposed to mixtures of CDDs and other classes of toxicologically and structurally similar compounds. 2,3,7,8-TCDD is one of the most toxic and extensively studied of the CDDs and serves as a prototype for the toxicologically relevant or “dioxin-like” CDDs. Based on results from animal studies, scientists have learned that they can express the toxicity of dioxin-like CDDs as a fraction of the toxicity attributed to 2,3,7,8-TCDD. For example, the toxicity of dioxin-like CDDs can be half or one tenth or any fraction of 2,3,7,8-TCDD. Scientists call that fraction a Toxic Equivalent Factor (TEF).

Exposure to CDDs can also occur through skin contact with chlorinated pesticides and herbicides, contaminated soils, or other materials such as PCP-treated wood and PCB transformer fluids.

More information about CDDs can be obtained from The Toxicological Profile for Chlorinated Dibenzo-p-Dioxins.⁴

Sites Where Dioxins and Furans May Be Found

Sites that should be characterized for the possible presence of CDD and CDF contaminants include:

- Incinerators, furnaces, retorts and other combustion processes
- Areas where open burning took place
- Ash and combustion byproduct disposal units
- Pulp and paper mills
- Wood preservers

³ Please note that no attempt has been made in this discussion to address dioxin-like PCBs, although they have similar toxic properties, and are often evaluated using the methods presented here.

⁴ Agency for Toxic Substances and Disease Registry. (1998) *Toxicological Profile for Chlorinated Dibenzo-p-Dioxins*.

- Manufacturers of chlorinated organic chemicals, especially phenolic compounds and pesticides*
- Manufacturers, handlers, distributors, users and disposers of chlorinated phenols, creosotes, hexachlorobenzene, 2,4-D*, 2,4,5-TP*, Silvex®, Agent Orange, chlorinated herbicides and pesticides*, PCBs, and used oils
- Areas where electrical transformers and capacitors may have leaked fluids, or such fluid was incinerated or disposed
- Sites where insulation was removed from copper components by burning, or electrical equipment was stripped for its copper content

(* Agricultural, horticultural, and roadside herbicidal uses of these materials, when used and applied as intended, should not be included in the target sampling group.) Sampling should focus on ash, soil with high organic content, broadleaf vegetation and animal adipose tissue, although other media may also be contaminated.

Carcinogenic Evaluation Using Toxicity Equivalence Factors

Ideally, risk associated with exposure to these contaminants as mixtures would be determined from long term animal studies, or studies based on chronic exposures. These methods are expensive, and result in unacceptable lag-times for addressing environmental contamination. Short term biological assays represent an improvement in methodology, but remain prohibitively costly.

One could also assume simple additivity of all congeners present. This approach then equates all CDD compounds with their most toxic cousin, 2,3,7,8-TCDD. This approach is overly conservative, and not supported by existing toxicological data.

Based on these factors, and a review of current literature,⁵ the methods described in U.S. EPA's (1986) *Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzo-p-dioxins and -Dibenzofurans (CDDs and CDFs) and 1989 Update* should be used in most risk assessments. This approach is widely supported by the scientific community, and is tentatively being recommended for continued use by U.S. EPA in draft documents currently undergoing peer review.

If a compound or class of compounds noted on Table 8-1 is a constituent of concern, the following method will be applied:

1. The concentration term for all congeners (compounds with similar structures) is determined;
2. The concentrations are multiplied by the Toxicity Equivalence Factor (TEF) which is derived from Table 8-1, to express the concentrations in terms of 2,3,7,8 - TCDD equivalents;
3. These concentrations are then arithmetically summed to determine exposure in terms of 2,3,7,8 - TCDD equivalents (See Equation 8-1); Note that this summing of the scaled doses is consistent with dose addition.

⁵ This review included an assessment of the document U.S. EPA. (2000) *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures*, which was found to be consistent with the guidance presented in this concept paper.

4. This exposure is then evaluated with toxicity information on 2,3,7,8 - TCDD. Carcinogenic effects generally drive the risk assessment. A slope factor of $1.5\text{E}+05$ per mg/kg-day⁶ should be used for both oral and inhalation routes.

Please note, however, "...that the TEF method should be largely reserved for special situations where the components of the mixture are known, where the composition of the mixture is not expected to vary much with time, and where the extrapolations are consistent with existing animal data..."⁷

Equation 8-1: Calculation of Toxicity Equivalent	
$\text{TEQ} = \sum_{i=1}^n C_i \times \text{TEF}_i$	
TEQ	= Toxic Equivalent, in mass/mass units, ⁸ to be applied to the slope factor to calculate carcinogenic risk
C_i	= Concentration in mass/mass units of the i^{th} congener of concern
TEF_i	= Toxic Equivalence Factor of the i^{th} congener of concern, read from Table 8-1
n	= Total number of congeners

Also note that Table 8-1 on the next page is derived from U.S. EPA's (1986) *Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzo-p-dioxins and -Dibenzofurans (CDDs and CDFs) and 1989 Update* and Van den Berg et. al. (1998) "Toxicity Equivalency Factors (TEFs) for PCBs, PCDDs & PCDFs for Humans and Wildlife".

⁶ U.S. EPA. (1997) *Health Effects Assessment Summary Tables: Annual FY 1997 Update*. Note that U.S. EPA's (1984) *Assessment of Emissions of Specific Compounds from a Resource Recovery Municipal Refuse Incinerator* quotes a slope factor of $1.6\text{E}+05$ per mg/kg-day

⁷ U.S. EPA. (1986) *Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzo-p-dioxins and -Dibenzofurans (CDDs and CDFs) and 1989 Update*

⁸ For example, picograms per kilogram or micrograms per kilogram.

Table 8-1: Toxicity Equivalence Factors	
Compound	Toxicity Equivalence Factor
Mono-, Di- and TriCDDs	0
2,3,7,8 - TCDD	1
Other TCDDs	0
1,2,3,7,8 - PeCDDs	1
Other PeCDDs	0
1,2,3,4,7,8 - HxCDDs	0.1
1,2,3,6,7,8 - HxCDDs	0.1
1,2,3,7,8,9 - HxCDDs	0.1
Other HxCDDs	0
1,2,3,4,6,7,8 - HpCDDs	0.01
Other HpCDDs	0
OCDD	0.0001
Mono-, Di-, and TriCDFs	0
2,3,7,8 - TCDFs	0.1
Other TCDFs	0
1,2,3,7,8 - PeCDF	0.05
2,3,4,7,8 - PeCDF	0.5
Other PeCDFs	0
1,2,3,4,7,8 - HxCDFs	0.1
1,2,3,6,7,8 - HxCDFs	0.1
1,2,3,7,8,9 - HxCDFs	0.1
2,3,4,6,7,8 - HxCDFs	0.1
Other HxCDFs	0
1,2,3,4,6,7,8 - HpCDFs	0.01
1,2,3,4,7,8,9 - HpCDFs	0.01
Other HpCDFs	0
OCDF	0.0001
T= Tetra, Pe= Penta, Hx= Hexa, Hp= Hepta, O= Octa	

Analytical Methods

The analytical methodology employed for these compounds should be one of the following taken from the most recent edition of *SW-846*:

Method 8280A: The Analysis of Polychlorinated Dibenzo - *p* - Dioxins and Polychlorinated Dibenzofurans by High Resolution Gas

Method 8290: The Analysis of Polychlorinated Dibenzo - *p* - Dioxins and Polychlorinated Dibenzofurans by High Resolution Gas Chromatography/High Resolution Mass Spectrometry (HRGC/HRMS).

The choice of method will be site-specific, and depend on the interplay among DQOs, constituent concentrations, and matrix interferences. The use of alternate methods may be considered on a case-by-case basis, but is strongly discouraged. All data should be validated, at a minimum, at the Tier One level.

8.3 Lead

[Section 4.1, Remediation Standards for Soils and Ground Water](#), provides information about the various remediation alternatives available for units undergoing closure. Comparison to unit-specific background (BRS), comparison to Alternate Metal Standards (AMS) and comparison to a derived risk-based cleanup standard are all remediation options for lead contaminated closure units. Lead differs from other contaminants and therefore traditional risk assessment methodologies do not apply. DHWM has used a lead specific model to provide a generic risk-based cleanup number as an optional remediation standard. A facility undergoing closure may also utilize adequately supported justified unit-specific information to calculate a risk-based unit-specific remediation standard. Details about the derivation of both the soil and ground water risk-based cleanup numbers are given in the following sections.

Risk-Based Cleanup Number for Lead in Soil

Lead, an inorganic contaminant associated with many closure units, does not lend itself to traditional risk assessment methods since there are not scientifically agreed upon reference doses (RfD), reference concentrations (RfC), or a carcinogenic slope factor (SF). Instead of these standard toxicity values, blood lead (PbB) concentrations are used as an indicator of lead exposure. Developing fetuses and young children are two sensitive subpopulations.

Due to the inability to utilize traditional risk assessment methods, a risk-based cleanup number was derived using a lead specific U.S. EPA model, the Integrated Exposure Uptake Biokinetic (IEUBK) Model. A generic, risk-based soil cleanup number of 245 mg of lead per kg of soil was derived for residential closures using the IEUBK Model. The IEUBK Model is a simulation model. The foundation of the IEUBK model is the construction of a detailed and thorough exposure scenario for children aged 0 to 84 months (0 to 7 years). The model simulates lead uptake, distribution within the body, and elimination of lead from the body. The IEUBK model was selected for the development of a residential risk-based soil cleanup number for Ohio hazardous waste closures primarily because the model has been extensively peer-reviewed by scientists from both government and private sectors. The IEUBK model is biologically plausible, computationally correct, and empirically valid (*i.e.*, a satisfactory correlation between observed PbB levels and soil lead concentrations has been demonstrated).⁹ Ohio EPA has retained the model default input parameters in order to preserve consistency between projected and measured PbB levels.

⁹ U.S. EPA. (1994) *Guidance Manual for the IEUBK Model for Lead in Children*.

The model provides the probability that lead exposed children will have PbB concentrations exceeding a health-based level of concern. A PbB concentration of greater than 10 micrograms per deciliter ($\mu\text{g/dL}$) in children has been determined to be a health-based level of concern by the United States Centers for Disease Control (CDC).¹⁰ When the IEUBK Model is run with input parameter defaults and a soil concentration of 245 mg of lead per kg of soil, the model predicts that approximately 95% or greater of the modeled hypothetical children do not exceed a target PbB concentration of 10 $\mu\text{g/dL}$. A soil concentration of 245 mg/kg was retained as the closure cleanup number. This standard is protective of 95% or greater of each subpopulation within the total modeled population.

Ecological receptors were not considered in setting the generic risk-based soil cleanup number of 245 mg of lead per kg of soil for residential closures. The IEUBK Model does not include ecological receptors. If there are complete pathways for important ecological receptors, the generic risk-based soil cleanup number of 245 mg/kg is neither an appropriate nor a protective cleanup value.

Because of the unique risk assessment modeling approach, lead is evaluated separately in an assessment that involves multiple constituents.

Risk-Based Cleanup Number for Lead in Ground Water

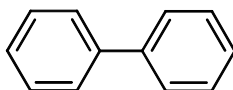
The IEUBK Model was used to generate a risk-based ground water cleanup number based on a blood lead criteria of 10 $\mu\text{g Pb/dL}$ blood. Assuming a soil lead concentration of 245 mg/kg and model generated concentration of lead in dust, the ground water concentration should be 5 $\mu\text{g Pb/L}$ water or less in order for all segments of the hypothetical population to meet the blood lead criteria. Therefore, the generic risk-based cleanup number for lead in ground water is 5 $\mu\text{g Pb/L}$ water for both the closure unit and at the property boundary. The generic risk-based cleanup number should be met at the property boundary because there is no control over soil lead concentrations on neighboring properties. The expectation is that all neighboring properties meet the soil lead standard. If the soil standard (245 mg/kg) is met, then a ground water concentration of 5 $\mu\text{g Pb/L}$ water will not exceed the blood lead criteria.

With prior approval from the DHWM, a unit-specific risk-based lead standard may be generated. If a unit-specific risk-based ground water cleanup number for lead is calculated, it should not exceed the U.S. EPA Safe Water Drinking Act Action Level of 15 $\mu\text{g Pb/L}$ water.

8.4 Polychlorinated Biphenyls

Background Information

Polychlorinated biphenyls (PCBs) are a class of chemical compounds in which 1-10 chlorine atoms are attached to the biphenyl molecule. The general chemical structure of chlorinated biphenyls is as follows:



¹⁰ Centers for Disease Control and Prevention. (1991) *Preventing Lead Poisoning in Young Children*.

There are 209 possible compounds called congeners. In addition, since there can be free rotation between the benzene rings, various configurations are possible. (The most toxic congeners are coplanar). The term “homolog” is used for all of the compounds with the same number of chlorines and the PCBs of a given homolog with different substitution patterns are isomers.¹¹

Sites Where PCBs May Be Found

Throughout the 20th century, PCBs were used for many diverse purposes ranging from dielectric fluids to pesticides. From 1929-1977, the Monsanto Company, the sole manufacturer of PCBs in the United States, produced 700,000 tons of PCBs. Due to their low flammability, PCBs were used extensively for insulating and cooling electrical equipment, particularly in transformers, large capacitors, and fluorescent lamp ballasts. The majority of PCBs were used in the production of dielectric fluids for transformers, capacitors, and other electrical components. The following represents a partial list of products that contain PCBs (many are past uses that are currently not allowed): epoxy paints and protective coatings; hydraulic and heat transfer fluids (due to their high boiling point); carbonless copy paper; paints; adhesives; sealants; pesticides; plasticizers; lubricants; construction materials; cutting oils; fuel tank coatings; inks; oil/lubricants for vacuum pumps, air compressors, and gas transmission turbines; pesticide extenders; plastic electrical cable insulation; plasticizers in rubber; plasticizers in synthetic resins; sound deadening felt; and viscosity testing liquids.¹²

Non-Carcinogenic Evaluation

Of the Aroclors listed in IRIS (Aroclor 1016 (CAS # 12674-11-2), Aroclor 1248 (CAS # 12672-29-6), and Aroclor 1254 (CAS # 11097-69-1)), two have oral RfDs (Aroclor 1016 and Aroclor 1254). An oral RfD of 7E-05 mg/kg-day is listed for Aroclor 1016. The oral RfD for Aroclor 1254 is 2E-05 mg/kg-day.¹³

For the risk assessment calculations based on noncarcinogenic risk of PCB exposure, the RfD for Aroclor 1254 (2E-05 mg/kg-day, IRIS) should be used to represent the noncarcinogenic hazard of total PCBs. Commercial PCBs differ from PCBs found in the environment. Commercial PCBs tested in laboratory animals were Aroclor mixtures, not environmental mixtures that had been bioaccumulated. Bioaccumulated PCBs appear to be more toxic than commercial PCBs¹⁴ and appear to be more persistent in the body.¹⁵ For exposure through the food chain, hazards can be higher. Nonetheless, because of the limited reference dose information available from accepted sources, coupled with constraints of the recognized analytical methodology, the more conservative of the two Aroclor reference doses available should be used for PCB mixtures.

¹¹ Agency for Toxic Substances and Disease Registry. (1998) *Toxicological Profile for Chlorinated Dibenzo-p-dioxins*.

¹² Agency for Toxic Substances and Disease Registry. (1998) *Toxicological Profile for Chlorinated Dibenzo-p-dioxins*.

¹³ U.S. EPA. (2003) *Integrated Risk Information System*.

¹⁴ Aulerich, R.J., R.K. Ringer, and J. Safronoff. (1986) Assessment of primary vs. secondary toxicity of Aroclor 1254 to mink and Hornshaw, T.C., R.J. Aulerich, H.E. Johnson. (1983) Feeding Great Lakes fish to mink: Effects on mink and accumulation and elimination of PCBs by mink.

¹⁵ Hovinga, M.E., M. Sowers, H.E.B. Humphrey. (1992) Historical changes in serum PCB and DDT levels in an environmentally-exposed cohort.

Reference concentrations are not available at this time. Do not perform a route-to-route extrapolation from the RfD. In the unlikely event that inhalation of these low-volatility compounds appears to be a major exposure pathway, see your supervisor.

Carcinogenic Evaluation

In IRIS, the cancer potency of PCB mixtures is determined using a tiered approach. Each tier is accompanied by criteria for use. Each tier has an upper-bound and central-estimate slope factor associated with it.

For the risk assessment calculations based on carcinogenic risk of PCB exposure, carcinogenic risk should be derived using the high risk and persistence upper-bound slope factor of 2.0 per (mg/kg)/day to represent the carcinogenic risk of total PCBs. The high risk and persistence slope factor was selected on the basis of the criteria presented in IRIS. This tier is the most protective and appropriate choice for modeling PCB exposures. The selection criteria for use of the high risk and persistence tier slope factor include food chain exposure; sediment or soil ingestion; dust or aerosol inhalation; dermal exposure if an absorption factor has been applied; presence of dioxin-like, tumor-promoting, or persistent congeners; and early-life exposure, many of which are classic pathways evaluated for risk assessment.¹⁶

Some PCBs persist in the body and retain biological activity after exposure stops.¹⁷ Compared with the current default practice of assuming that less-than-lifetime effects are proportional to exposure duration, rats exposed to a persistent mixture (Aroclor 1260) had more tumors, while rats exposed to a less persistent mixture (Aroclor 1016) had fewer tumors.¹⁸ Thus there may be greater-than-proportional effects from less-than-lifetime exposure, especially for persistent mixtures and for early-life exposures.

Highly exposed populations include some nursing infants, and consumers of game fish, game animals, or products of animals contaminated through the food chain. Highly sensitive populations include people with decreased liver function and infants.¹⁹

Because of the potential magnitude of early-life exposures,²⁰ the possibility of greater perinatal sensitivity,²¹ and the likelihood of interactions among thyroid and hormonal

¹⁶ U.S. EPA. (2003) *Integrated Risk Information System*.

¹⁷ Anderson, L.M., L.E. Beebe, S.D. Fox, et al. (1991) "Promotion of Mouse Lung Tumors by Bioaccumulated Polychlorinated Aromatic Hydrocarbons."

¹⁸ Brunner, M.J., T.M. Sullivan, A.W. Singer et al. (1996) *An Assessment of the Chronic Toxicity and Oncogenicity of Aroclor 1016, Aroclor 1242, Aroclor 1254, and Aroclor 1260 Administered in Diet to Rats*.

¹⁹ Calabrese, E.J. and A.J. Sorenson. (1977) "The Health Effects of PCBs with Particular Emphasis on Human High Risk Groups."

²⁰ Agency for Toxic Substances and Disease Registry. (2000) *Toxicological Profile for Polychlorinated Biphenyls (PCB)*, Dewailly E., J.P. Weber, S. Gingras, et al. (1991) "Coplanar PCBs in Human Milk in the Province of Quebec, Canada: Are they More Toxic Than Dioxin for Breast Fed Infants?", and Dewailly E., J.J. Ryan, C. Laliberte, et al. (1994) "Exposure of Remote Maritime Populations to Coplanar PCBs."

development, it is reasonable to conclude that early-life exposures may be associated with increased risks. Due to this potential for higher sensitivity early in life, the “high risk” tier is used for all early-life exposure.

It is crucial to recognize that commercial PCBs tested in laboratory animals were not subject to prior selective retention of persistent congeners through the food chain (that is, the rats were fed Aroclor mixtures, not environmental mixtures that had been bioaccumulated). Bioaccumulated PCBs appear to be more toxic than commercial PCBs²² and appear to be more persistent in the body.²³ For exposure through the food chain, risks can be higher than those estimated in this assessment. Therefore, for a myriad of reasons, the high risk and persistence upper-bound slope factor is the appropriate choice for modeling carcinogenic risk of PCBs.²⁴

Unit Risk Estimate and Drinking Water Concentrations

For ingestion of water-soluble congeners, the middle-tier slope factor can be converted to a unit risk estimate and drinking water concentrations associated with specified risk levels.

Upper-bound slope factor:	0.4 per (mg/kg)/day
Upper-bound unit risk:	1E-05 per µg/L

These estimates should not be used if drinking water concentrations exceed 1000 µg/L, since above this concentration the dose-response curve in the experimental range may provide better estimates.

Surrogates

This method is, in essence, an application of surrogate substitution, the practice of which is discouraged elsewhere in the guidance. The methods presented are a sound approach to assessing risk from a complex mixture of similar compounds. As more data on these mixtures, particularly weathered mixtures, become available, this guidance will be updated accordingly.

Analytical Methods

Although PCB exposures are often characterized in terms of Aroclors, this can be both imprecise and inappropriate. Total PCBs or congener or isomer analyses are recommended.

The analytical methodology employed for these compounds will be one of the following taken from the most recent edition of *SW-846*:

²¹ Calabrese, E.J. and A.J. Sorenson. (1977) “The Health Effects of PCBs with Particular Emphasis on Human High Risk Groups.” and Rao, C.V., A.S. Banerji. (1988) “Induction of Liver Tumors in Male Wistar Rats by Feeding Polychlorinated Biphenyls (Aroclor 1260).”

²² Aulerich, R.J., R.K. Ringer, and J. Safronoff. (1986) Assessment of primary vs. secondary toxicity of Aroclor 1254 to mink and Hornshaw, T.C., R.J. Aulerich, and H.E. Johnson. (1983) Feeding Great Lakes fish to mink: Effects on mink and accumulation and elimination of PCBs by mink.

²³ Hovinga, M.E., M. Sowers, and H.E.B. Humphrey. (1992) Historical changes in serum PCB and DDT levels in an environmentally-exposed cohort.

²⁴ U.S. EPA. (2003) *Integrated Risk Information System*.

Method 8082: Polychlorinated Biphenyls (PCBs) by Gas Chromatography

Method 8275A: Semivolatile Organic Compounds (PAHs and PCBs) in Soils/Sludges and Solid Wastes Using Thermal Extraction/Gas Chromatography/Mass Spectrometry (TE/GC/MS).

Method 9078: Screening Test Method for Polychlorinated Biphenyls in Soils

Method 9079: Screening Test Method for Polychlorinated Biphenyls in Transformer Oil

The choice of method will be site-specific, and depend on the interplay among data quality objectives, constituent concentrations, and matrix interferences. The use of alternate methods may be considered on a case-by-case basis, but is strongly discouraged. All data should be validated, at a minimum, at the Tier One level. (Note that the screening methods are semi-quantitative, and the data generated may not be used for assessing risk.)

Table 8-2: PCB Toxicity Values Summary		
Toxicity Value	Endpoint	Notes
2E-05 mg/kg-day	Noncancer risk	
2.0 per (mg/kg)/day	Carcinogenic risk	
0.4 per (mg/kg)/day	Carcinogenic risk of water-soluble congeners	Should not be used if drinking water concentrations exceed 1000 µg/L

8.5 Polycyclic Aromatic Hydrocarbons

Background Information

Polycyclic Aromatic Hydrocarbons (PAHs)²⁵ are a group of chemicals that may be formed during the incomplete burning of coal, oil, gas, wood, garbage, or other organic substances. There are more than 100 different PAHs. PAHs generally occur as complex mixtures (e.g., as part of combustion products such as soot), not as single compounds. PAHs occur naturally in coal or crude oil. After distillation, refining or coal gas generating processes, they are present in mixtures of heavier fractions like coal tar and creosote. They also can be manufactured as individual compounds for research purposes or chemical manufacturing; however, not as the mixtures found in combustion products. A few PAHs are used in medicines and to make dyes, plastics, and pesticides. Others are contained in asphalt used in road construction. They can also be found in substances such as crude oil, coal, coal tar pitch, creosote, and roofing tar. They are found throughout the environment in the air, water, and soil. They can occur in the air, either attached to dust particles or as solids in soil or sediment.

²⁵ Also known as polynuclear aromatic hydrocarbons, and PNAs.

The following 16 PAHs are most often encountered in remedial work:		
acenaphthene	benzo(g,h,i)perylene	fluorene
acenaphthylene	benzo(k)fluoranthene	indeno(1,2,3-cd)pyrene
anthracene	chrysene	naphthalene
benz(a)anthracene	dibenz(a,h)anthracene	phenanthrene
benzo(a)pyrene	fluoranthene	pyrene
benzo(b)fluoranthene		

These 16 PAHs are highlighted in this guidance because (1) more information is available on these than on the others; (2) they are suspected to be more harmful than some of the others, and they exhibit harmful effects that are representative of the PAHs; (3) there is a greater chance of exposure to these PAHs than to the others; (4) Standard SW-846 methods for their detection and quantitation are widely available; and (5) of all the PAHs analyzed, these were the PAHs identified at the highest concentrations at NPL hazardous waste sites.

Although PAHs are accumulated in terrestrial and aquatic plants, fish, and invertebrates, many organisms are able to metabolize and eliminate these compounds. Bioconcentration factors (BCFs), which express the concentration in tissues compared to concentration in media, for fish and crustaceans are frequently in the 10-10,000 range. Food chain uptake does not appear to be a major source of exposure to PAHs for aquatic animals.

PAHs are generally not produced commercially in the United States except as research chemicals. However, PAHs are found in coal, coal tar, and in the creosote oils, oil mists, and pitches formed from the distillation of coal tars, and in the heavier fractions of petroleum products. Of the 16 PAHs noted, only four are produced commercially in the United States in quantities greater than research level: acenaphthene, acenaphthylene, anthracene, and naphthalene.²⁶

Sites where PAHs may be found

PAHs are sufficiently ubiquitous that their detection is likely at almost any site. However, some facilities are more likely than others to have *generated* PAHs, and are at greater risk for PAH contamination. Sites that should be characterized for the possible presence of PAH contaminants include:

- Incinerators, furnaces, retorts and other combustion processes
- Areas where open burning took place
- Ash and combustion byproduct disposal units
- Bitumen and asphalt production facilities
- Wood preservation operations based on creosote or coal tar products
- Manufactured gas and coal tar production and handling facilities
- Coal extraction, storage and combustion

²⁶ Narrative for this section to this point adapted from Agency for Toxic Substances and Disease Registry's (1995) *Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs)*, with minor additions and changes for clarity and readability. Two PAHs discussed in this document, were eliminated from this paper due to a lack of available data on their toxicity and carcinogenicity, benzo(e)pyrene and benzo(j)fluoranthene.

- Coke manufacture, storage and combustion
- Smoke houses
- Petroleum extraction, refining, storage and combustion
- Petroleum waste landfarming units and land disposal facilities
- Used oil storage, treatment and combustion sites
- Aluminum production facilities
- Sites where insulation was removed from copper components by burning, or electrical equipment was stripped for its copper content

Non-carcinogenic Evaluation

Non-carcinogenic PAHs should be evaluated using standard risk assessment methods. Table 8-3 lists the PAHs discussed in this section, their weight of evidence for carcinogenicity, and RfDs for the non-carcinogenic compounds. The PAHs listed as having a carcinogenic weight of evidence 'C' or 'D' should be evaluated for possible chronic toxic effects.

Table 8-3: Sixteen Environmentally Common PAHs			
Compound Name	CASRN²⁷	RfD (mg/kg-d)	Carcinogenic Weight of Evidence
acenaphthene	83-32-9	6E-02	No Data
acenaphthylene	208-96-8	No Data	D - Not Classifiable
anthracene	120-12-7	3E-01	D - Not Classifiable
benz(a)anthracene	56-55-3	No Data	B2 - Probable Human Carcinogen
benzo(a)pyrene	50-32-8	No Data	B2 - Probable Human Carcinogen
benzo(b)fluoranthene	205-99-2	No Data	B2 - Probable Human Carcinogen
benzo(g,h,i)perylene	191-24-2	No Data	D - Not Classifiable
benzo(k)fluoranthene	207-08-9	No Data	B2 - Probable Human Carcinogen
chrysene	218-01-9	No Data	B2 - Probable Human Carcinogen
dibenz(a,h)anthracene	53-70-3	No Data	B2 - Probable Human Carcinogen
fluoranthene	206-44-0	4E-02	D - Not Classifiable
fluorene	86-73-7	4E-02	D - Not Classifiable
indeno(1,2,3-cd)pyrene	193-39-5	No Data	B2 - Probable Human Carcinogen
naphthalene ²⁸	91-20-3	2E-02	C - Possible Human Carcinogen
phenanthrene	85-01-8	No Data	D - Not Classifiable
pyrene	129-00-0	3E-02	D - Not Classifiable

²⁷ Chemical Abstracts Service Registry Number

²⁸ Naphthalene has an inhalation toxicity Reference Concentration (RfC) of 3E-03 mg/m³, or 8E-04 mg/kg-d.

No RfCs are available for any of these PAHs, with the exception of naphthalene. If the inhalation pathway is considered to be a significant source of risk, as in cases where inhalation of contaminated particulates is likely, a route-to-route extrapolation of the toxicity value may be required.

Note that the carcinogenic PAHs do not have RfDs. Carcinogenicity is considered to be the driving factor for these compounds, and the non-carcinogenic toxicity analysis does not need to be done.

Carcinogenic Evaluation Using Relative Potency Factors

For the seven carcinogenic PAHs listed, the only carcinogenic toxicity data available is a Relative Potency Factor (RPF) that describes potency relative to that of benzo(a)pyrene.²⁹

This assessment technique is known as a comparison based on toxicological similarity. This section will describe the process used to generate toxicity values for the carcinogenic PAHs. It should be noted that a risk-based standard can be calculated using the standard process with no additional modifications after the appropriate toxicity value has been determined.

Table 8-4: Summary Table of PAHs for Which RPFs Were Used to Derive the Carcinogenic Slope Factor Toxicity Value				
Compound	Oral Carcinogenic Slope Factor	Inhalation Carcinogenic Slope Factor	Dermal Carcinogenic Slope Factor	RPF Value
benz(a)anthracene	7.3E-01	7.3E-01	3.6E-01	0.1
benzo(b)fluoranthene	7.3E-01	7.3E-01	3.6E-01	0.1
benzo(k)fluoranthene	7.3E-02	7.3E-02	3.6E-02	0.01
benzo(a)pyrene ³⁰	7.3E+00	7.3E+00	3.6E-00	1.0
chrysene	7.3E-03	7.3E-03	3.6E-03	0.001
dibenz(ah)anthracene	7.3E+00	7.3E+00	3.6E-00	1.0
indeno(1,2,3-cd)pyrene	7.3E-01	7.3E-01	3.6E-01	0.1

Use of Relative Potency Factors in the Determination of Oral Slope Factors

The following PAH's have individual relative potency factors (RPFs).³¹
benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene,

²⁹ U.S. EPA. (1993) Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons.

³⁰ Note: It is implied that RPF is 1 since this is the carcinogenic PAH those with RPF's are calculated relative to.

³¹ Detailed information on the risk assessment of mixtures, and the use of relative potency factors, may be found in U.S. EPA's (2000) *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures*.

dibenz(ah)anthracene, and indeno(1,2,3-cd)pyrene. The RPF was multiplied by the oral carcinogenic slope factor for benzo(a)pyrene found in IRIS to generate the appropriate oral carcinogenic slope factor for the individual PAH's (see Table 8-4).

Use of RPFs in the Determination of Inhalation Slope Factors

RPFs were also used in the determination of inhalation carcinogenic slope factors. Given the presence of a benzo(a)pyrene inhalation slope factor in an NCEA Issue Paper,³² the RPFs presented in Table 8-4 are also appropriate for application to the benzo(a)pyrene (BaP) inhalation slope factor.

The evaluation of whether the RPFs derived for use with BaP oral slope factors are appropriate for use with the BaP inhalation slope factor requires the consideration of pathway-specific mechanisms of action for oral relative to inhalation exposures to BaP and other PAHs. The tumor sites identified in the NCEA issue paper³³ for the BaP inhalation slope factor include the larynx and pharynx.³⁴ These tumor sites coincide with the site of administration. It is also important to note that some tumors were found in identical locations (e.g., larynx and pharynx) for both inhalation and oral exposures.

Evidence of these point of entry effects with toxicity information categorizing PAHs are "complete" carcinogens in mouse skin (*i.e.*, genotoxic and capable of promotion activities) provides some circumstantial evidence that the same mechanism of action may be present for the pathways assessed. Given that the same mechanism of action is likely present and that point of entry effects are present at identical locations across both inhalation and oral studies, it should be appropriate to assume that the relative potency factors as presented for oral exposures can be directly applied for inhalation exposures.

Use of RPFs in the Determination of Dermal Slope Factors

The PAH-specific dermal toxicity slope factor was derived through extrapolation from the PAH-specific oral slope factors. The oral absorption factor was assumed to be 0.58³⁵ in all cases. If the PAH is listed in Table 8-4, then the PAH-specific oral slope factor incorporated a relative potency factor.

The relative potency factors described by U.S. EPA³⁶ are primarily based on studies with the dermal exposure pathway. The guidance describes the weight of evidence in support of the relative potencies and uses the relative potencies observed for dermal, oral and intrapulmonary injection exposure to PAHs as part

³² U.S. EPA. (1999) *Risk Assessment Issue Paper: Status of Inhalation Cancer Unit Risk for Benzo(a)pyrene* (CAS No. 50-32-8).

³³ U.S. EPA. (1999) *Risk Assessment Issue Paper: Status of Inhalation Cancer Unit Risk for Benzo(a)pyrene* (CAS No. 50-32-8).

³⁴ Thyssen, J. et al. (1981) *Inhalation studies with Benzo(a)pyrene in Syrian Golden Hamsters*.

³⁵ Chang, L.H. (1943) *The Fecal Excretion of Polycyclic Hydrocarbons Following Their Administration to the Rat*.

³⁶ U.S. EPA. (1993) *Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons*.

of the justification for the values of the proposed relative potencies. For further technical justification, also refer to Ohio EPA (1997) *Voluntary Action Program: Development of Generic Numerical Direct Contact Standards. Extrapolation of the Oral Slope Factor for Benzo(a)Pyrene to the Dermal Pathway*.

Modification of the intake calculation by dermal absorption factors (soils) and dermal permeability constants (waters) remains the same as one would treat other compounds.

Additivity of PAH mixtures

When a mixture of PAH compounds is being evaluated, following the determination of toxicity values, the methods described in [Section 7.4, Risk Characterization](#), should be followed. The cumulative risk of a combination of PAHs should be assumed to be additive. The risk analysis and uncertainty analysis should also take into account the possibility that the composition of the PAH mixture (and hence its toxicity) may, through weathering, change with time.

Surrogates

This method is, in essence, an application of surrogate substitution, the practice of which is discouraged elsewhere in the guidance. However, in this case, extensive research into the relative potency of these constituents has been performed, and the U.S. EPA accepts the method as standard.

Analytical Methods

Samples should be preserved and handled the same as samples for semi-volatiles analysis. The analytical methodology employed for these compounds should be one of the following taken from the most recent edition of *SW-846*:

Method 8100: Polynuclear³⁷ Aromatic Hydrocarbons (Gas Chromatography)

Method 8270C: Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS)

Method 8275A: Semivolatile Organic Compounds (PAHs and PCBs) in Soils/Sludges and Solid Wastes Using Thermal Extraction/Gas Chromatography/Mass Spectrometry (TE/GC/MS)

Method 8310: Polynuclear Aromatic Hydrocarbons (High Performance Liquid Chromatography (HPLC) with Ultraviolet and Fluorescence Detection)

The choice of method will be site and medium specific, and depend on the interplay among data quality objectives, constituent concentrations, and matrix interferences. The use of alternate methods may be considered on a case-by-case basis, but is strongly discouraged. All data should be validated, at a minimum, at the Tier One level.

³⁷ The terms 'polycyclic' and 'polynuclear' may be used interchangeably in this context.

Chapter 9

Glossary

Absorbed Dose: The amount of a substance penetrating the exchange boundaries of an organism after contact. Absorbed dose is calculated from the intake and the absorption efficiency. It usually is expressed as mass of a substance absorbed into the body per unit body weight per unit time (mg/kg-d). Dermal contact should be expressed as an absorbed dose.

Additive Risk: The sum of the risks associated with all of the applicable exposures to the constituent(s) of concern across all applicable pathways.

Administered Dose: The mass of substance given to an organism and in contact with an exchange boundary (e.g., gastrointestinal tract) per unit body weight per unit time (mg/kg-d). Ingestion and inhalation are expressed as administered doses. Also, termed normalized exposure rate and is equivalent to intake.

Anthropogenic Background: Ambient chemical concentrations present in the environment as a result of human activities not specifically related to a RCRA unit.

Aquifer: A geologic formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to wells or springs.

Aquifer, confined: An aquifer bounded above and below by impermeable beds or by beds of distinctly lower permeability than that of the aquifer containing confined ground water.

Aquifer, unconfined: An aquifer in which there are no confining beds between the zone of saturation and the ground surface. There will be a water table in an unconfined aquifer.

Area of Concern (AOC): An area which has received, at any time, solid or hazardous waste through deliberate placement of the waste or because of an accidental release or spill.

Assessment Monitoring: An investigative monitoring program under RCRA requirements that is initiated after the presence of a contaminant in ground water has been detected and confirmed. The objectives of this type of program are to determine the concentrations of constituents that have contaminated the ground water and to quantify the rate and full horizontal and vertical extent of migration of contamination.

Attenuation: The reduction or removal of constituents in the ground water by the sum of all physical, chemical and biological factors acting upon the ground water.

Background Monitoring: The first year of ground water sampling under RCRA Interim Standards. All wells in the monitoring system are sampled on at least a quarterly basis to determine the concentration of ground water quality, drinking water, and indicator parameters. For facilities under the Permitted Facility Standards, background is the data set from upgradient or background wells for each constituent used for statistical comparisons with downgradient results.

Bedrock: A term for the consolidated rock that underlies the unconsolidated soils and glacial debris.

Biodegradation: The natural breakdown of chemical constituents through biological processes of naturally occurring organisms.

Borehole: A hole drilled into the earth, usually for exploratory purposes. Casings and screens may be added to create a monitoring well.

Buried Valley: A depression in bedrock covered by unconsolidated glacial drift.

Carcinogen: Any substance or agent that produces cancer in humans or animals.

Casing: A durable pipe placed in a borehole to prevent the walls from caving, and to seal off surface drainage or other undesirable water, gas or other fluids from entering the well.

Closure: The process of decommissioning and decontaminating an area or structure used to manage hazardous waste(s).

Closure Performance Standard: Goals the closure activities must meet in order for a hazardous waste management unit to be certified closed, as detailed in OAC Rules 3745-55-11 and 3745-66-11.

Contamination: The introduction into air, soil or water of any chemical material, organic material, live organism, or radioactive material that will adversely affect the quality of the medium.

Corrective Action: RCRA Corrective Action, as required by the 1984 Hazardous and Solid Waste Amendments, includes a site wide investigation and potential remediation as necessary to protect human health and the environment. This term is discussed further in Section 2.1, RCRA Corrective Action Program. However ground water corrective action, as defined in OAC Rule 3745-54-100, is part of the ground water monitoring requirements where a facility must cleanup the ground water to the ground water protection standard. DHWM generally uses **Corrective Action** for the first definition while **corrective action** is used for the latter.

Critical Effect: The adverse health effect used as the basis for the derivation of the reference dose (RfD). The critical effect is selected from the different adverse health effects (*e.g.*, liver, kidney, or blood defects) produced by a given chemical (*i.e.*, the adverse health effect with the lowest dose level that produced toxicity).

Cumulative Risk: Aggregate risk associated with the synergistic effects of a variety of chemicals.

Detection Limit: The lowest concentration of a chemical that can be reliably reported to be different from zero concentration.

Dose-Response: The process of quantitatively evaluating toxicity information and characterizing the relationship between the dose of a contaminant administered or received and the incidence of adverse health effects in the exposed populations.

Downgradient: In the direction of decreasing hydrostatic head.

Downgradient Well: A well that has been installed hydraulically downgradient of a unit and is capable of detecting the migration of contaminants from a site. RCRA regulations require the installation of three or more downgradient wells depending on the site-specific hydrogeological conditions and potential zones of contaminant migration.

Equipment Blank: Chemically pure solvent (typically distilled water) that is passed through an item of field sampling equipment and returned to the laboratory for analysis, to determine the effectiveness of equipment decontamination procedures.

Estimated Quantitation Limit (EQL): The EQL is the lowest concentration that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions. EQLs are reported in SW-846 for most organic methods. Most organic SW-846 methods give EQLs, based upon matrix, which are often set at some multiple of MDLs established for reagent water.

Exposure: Contact of an organism with a chemical or physical agent.

Exposure Assessment: The determination or estimation of the magnitude, frequency, duration, and route of exposure.

Exposure Pathway: The course of a chemical or physical agent from a source to an exposed organism. Each exposure pathway includes a release from a source, an exposure point, and an exposure route.

Exposure Point: Potential contact of a chemical or physical agent with the outer boundary of an organism. Exposure is quantified by the concentration of the agent contacted in the medium and the frequency and duration of contact, and then by subsequently linking these together to estimate exposure or dose.

Exposure Route: The way a chemical or physical agent enters an organism after contact (e.g., ingestion, inhalation, dermal contact).

Exposure Scenario: A set of facts, assumptions, and inferences about how a potential exposure takes place that aids the assessor in evaluating, estimating, or quantifying exposures.

Field Blank: A laboratory-prepared sample of reagent-grade water or pure solvent that is transported to the sampling site for use in evaluation of field sampling procedures.

Final Closure: The closure of all hazardous waste management units at the facility in accordance with all applicable closure requirements in the hazardous waste rules so that hazardous waste management activities under Chapters 3745-54 to 3745-57, 3745-65 to 3745-69, 3745-205, and 3745-256 of the Administrative Code are no longer conducted at the facility unless subject to the provisions in rule 3745-52-34 of the Administrative Code.

Generator: Any person, by site, whose act or process produces hazardous waste identified or listed in Chapter 3745-51 of the Administrative Code or whose act first causes a hazardous waste to become subject to the hazardous waste rules.

Ground Water: Water below the land surface in a zone of saturation.

Ground Water, Confined: The water contained in a confined aquifer. Pore-water pressure is greater than atmospheric at the top of a confined aquifer.

Ground Water, Perched: The water in an isolated saturated zone located within the vadose zone. It is the result of the presence of a layer of material of low hydraulic conductivity. Perched ground water will have a perched water table.

Ground Water Flow: The movement of water through openings in sediment and rock that occurs in the zone of saturation.

Hazardous Constituent(s): Those constituents listed in the appendix to rule 3745-51-11 of the Administrative Code.

Hazard Index (HI): The sum of more than one hazard quotient for multiple substances and/or multiple exposure pathways.

Hazard Quotient (HQ): The ratio of a single substance exposure level over a specified time period (e.g., chronic) to a reference dose for that substance derived from a similar exposure period.

Hazardous Waste: A hazardous waste as defined in rule 3745-51-03 of the Administrative Code.

Hazardous Waste Facility: a) All contiguous land, and structures, other appurtenances, and improvements on the land, used for treating, storing, or disposing of hazardous waste. A facility may consist of several treatment, storage, or disposal operational units (e.g., one or more landfills, surface impoundments, or combinations of them). b) For the purpose of implementing corrective action under rule 3745-54-101 of the Administrative Code, all contiguous property under the control of the owner or operator seeking a permit under the hazardous waste rules. This definition also applies to facilities implementing corrective action under RCRA Section 3008(h) or section 3734.20 of the Revised Code. c) Notwithstanding subparagraph (b) of this definition, a remediation waste management site is not a facility that is subject to rule 3745-54-101 of the Administrative Code, but is subject to corrective action requirements if the site is located within such a facility.

Hazardous Waste Management Unit (unit): Means a contiguous area of land on or in which hazardous waste is placed, or the largest area in which there is significant likelihood of mixing hazardous waste constituents in the same area. Examples of hazardous waste management units include a surface impoundment, a waste pile, a land treatment area, a landfill cell, an incinerator, a tank and its associated piping and underlying containment system and container storage area.

A container alone does not constitute a unit; the unit includes containers and the land or pad upon which they are placed.

Hydrologic Unit: Geologic strata that can be distinguished in the basis of capacity to yield and transmit fluids. Aquifers and confining units are types of hydrologic units. Boundaries of a hydrologic unit may not necessarily correspond either laterally or vertically to geologic formations.

Hydrostratigraphic Unit: A formation, part of a formation, or a group of formations in which there are similar hydrologic characteristics, allowing for grouping into aquifers or confining layers.

Indicator Parameters (Interim Standards): Chemical parameters specified for analysis under the RCRA requirements as indicators of ground water contamination, including pH, specific conductance, total organic carbon (TOC), and total organic halogens (TOX).

Indicator Parameters (Permitted Facility Standards): Site-specific parameters or chemicals of concern reasonably expected to be in or derived from waste contained in a regulated unit.

Injection Well: A well into which fluids are injected.

Intake: A measure of exposure expressed as the mass of a substance in contact with the exchange boundary per unit body weight per unit time (mg/kg-d). Also, termed normalized exposure rate and is equivalent to administered dose.

Integrated Ground Water Monitoring Program (IGWMP): A single program that combines all unique monitoring elements and resolves conflicting monitoring elements when any two or more monitoring programs are required for a given waste management unit or group of units.

Intrinsic Permeability: A term describing the relative ease with which a porous medium can transmit a liquid under a hydraulic or potential gradient. It is distinguished from hydraulic conductivity in that it is a property of the porous medium alone and it is independent of the nature of the liquid or the potential field.

Leach: To wash or drain by percolation.

Leachate: Any liquid, including any suspended components in the liquid, that has percolated through or drained from hazardous waste.

Less Than Detection Limit (Non-Detect): A phrase which indicates that a chemical constituent was either not identified or not quantified at the lowest level of sensitivity of the analytical method being employed by the laboratory. The chemical constituent is either not present in the sample, or it is present in such a small concentration that it cannot be measured by the analytical procedure.

Low Yielding Monitoring Wells: A relative term referring to a well that cannot recover in sufficient time after well evacuation to permit the immediate collection of water samples.

Maximum Contaminant Level: The highest concentration of a solute permissible in a public water supply, as specified in the National Primary Drinking Water Standards established under the Safe Drinking Water Act (SDWA) by U.S. EPA.

Method Detection Limit (MDL): The MDL is a statistically defined number based upon the standard deviation of seven replicate analyses of a standard that is analyzed over multiple-day time -period. The MDL is the minimum concentration of an analyte that can be determined with 99 percent confidence that the true value is greater than zero.

Monitoring Well: A well that is constructed by one of a variety of techniques for the purpose of extracting ground waste for physical, chemical, or biological testing, or for measuring water levels.

Naturally Occurring Background: Parameters in unaltered form or altered solely through naturally occurring processes or phenomena from a location where it is naturally found.

Nonpoint Source: A source of contamination in which the contaminant enters the receiving water in an intermittent and/or diffuse manner.

Normal Distribution: The character of data that follows the Gaussian distribution (bell) curve.

Ohio Administrative Code (OAC): The document which contains the regulations used to facilitate management of hazardous wastes in the State of Ohio.

Partial Closure: The closure of a hazardous waste management unit in accordance with the applicable closure requirements of Chapters 3745-54 to 3745-57 and 3745-205 or 3745-65 to 3745-69 and 3745-256 of the Administrative Code at a facility that contains other active hazardous waste management units. For example, partial closure may include the closure of a tank (including its associated piping and underlying containment systems), landfill cell, surface impoundment, waste pile, or other hazardous waste management unit, while other units of the same facility continue to operate.

Permitted Facility: A facility that has possession of a current Ohio hazardous waste permit.

Piezometer: An instrument used to measure head at a point in the subsurface; a nonpumping well, generally of small diameter, that is used to measure the elevation of the water table or potentiometric surface.

Piezometric Surface: The surface defined by the levels to which ground water will rise in tightly case wells that tap an aquifer.

Plume: A body of contaminated ground water originating for a specific source and influenced by such factors as the local ground water flow pattern, density of the contaminant, and character of the aquifer.

Post-Closure: Period of time following completion of closure during which a facility must conduct monitoring and maintenance activities to ensure the integrity of liner and leak detection systems and to prevent or control releases to the environment.

Potable Use: Ground water uses which include inhalation of volatiles from ground water, dermal contact with ground water, and ingestion of ground water. Refer to [Potable Use Ground Water Pathway Exclusion](#) in Section 7.2 for more details.

Potentiometric Surface: An imaginary surface representing the static head of ground water. The water table is a particular potentiometric surface. Used synonymously with Piezometric surface.

Practical Quantitation Limit (PQL): The PQL is generally defined in the same way as an EQL. The PQL is the lowest concentration that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions. PQLs are generally five to ten times the MDL.

Qualifier: A code appended to an analytical result that indicates possible qualitative or quantitative uncertainty in the results.

Qualitative: An analysis that identifies an analyte in a sample without numerical certainty.

Quantitative: An analysis that gives a numerical level of certainty to the concentration of an analyte in a sample.

Rate of Migration: The time ground water or a solute in ground water takes to travel from one stationary point to another. Generally expressed in units of time/distance.

Reference Concentration (RfC): An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a No-Observed-Adverse-Effect Level (NOAEL), Lowest-Observed-

Adverse-Effect Level (LOAEL), or benchmark concentration, with uncertainty factors generally applied to reflect limitations of the data used. The preferred toxicity value for evaluating noncarcinogenic effects resulting from exposure. Reference concentrations are converted to inhalation reference doses (RfDi) when used in intake equations.

Reference Dose (RfD): An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a No-Observed-Adverse-Effect Level (NOAEL), Lowest-Observed-Adverse-Effect Level (LOAEL) or benchmark dose, with uncertainty factors generally applied to reflect limitations of the data used. The preferred toxicity value for evaluating noncarcinogenic effects resulting from exposures.

Risk: The probability that a hazardous constituent(s), when released into the environment, will cause adverse effects in exposed humans or other biological receptors.

Risk Assessment: The process used to determine the threats posed by a hazardous constituent(s). Elements include data collection/evaluation of the hazardous constituents present in the environmental media; assessment of exposure and exposure pathways; assessment of the toxicity of the hazardous constituents; and characterization of human health and ecological risk.

Risk Characterization: The description of potential adverse effects (the nature and often the magnitude) of human exposures to hazards.

Runoff: Any rainwater, leachate, or other liquid that drains over land from any part of a facility.

Saturated Zone: That part of the earth's crust in which all voids are filled with water.

Slope Factor (SF): A plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime. The slope factor is used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime exposure to a particular level of a potential carcinogen.

Sole Source Aquifer: Means an aquifer designated as a sole source of drinking water under sections 1424(E) of the Safe Drinking Water Act (1974) at 42 U.S.C.A. 300F, as Amended.

Solubility: The total amount of solute species that will remain indefinitely in a solution maintained at constant temperature and pressure in contact with solid crystals from which the solutes were derived.

Specific Conductance: The ability of a cubic centimeter of water to conduct electricity; varies directly with the amount of ionized minerals in the water. Measured in micromhos per centimeter.

Static Water Level: The elevation of the top of a column of water in a monitoring well or piezometer that is not influenced by pumping or conditions related to well installation, hydrologic testing or nearby pumpage.

Stratigraphy: The study of the age of rock (or unconsolidated) strata and its succession.

Surface Water: The portion of water that appears on the land surface (e.g., oceans, lakes and rivers)

Total Excess Cancer Risk: The upper-bound probability on the estimated excess cancer risk associated with exposure to multiple hazardous constituents and multiple exposure pathways.

Toxicity Assessment: Determination of whether exposure to an agent can cause adverse effects in the exposed individual(s). It is used to provide an estimate of the relationship between the extent of exposure to a contaminant and the incidence of adverse health effects in the exposed individual(s).

Trip Blank: A sample container filled in the laboratory with reagent-grade, distilled, deionized water that is transported to the sampling site, handled the same as other samples, then returned to the laboratory for analysis as a quality control measure to check sample handling procedures.

Turbidity: Cloudiness in water due to suspended and colloidal organic and inorganic material.

Unconsolidated: Naturally occurring geologic materials that have not been lithified.

Unit Risk: Risk per unit concentration of the substance in the medium where human contact occurs.

Unsaturated Zone: The zone between the land surface and the water table. Also called vadose zone and zone of aeration.

Upgradient Well: One or more wells placed hydraulically upgradient of a site, that are capable of yielding ground water samples representative of background conditions (whether affected or not affected by upgradient activities).

95% Upper Confidence Limit (UCL) of the Arithmetic Mean: The upper limit on a normal distribution curve below which the observed mean of a data set will occur 95% of the time.

Uppermost Aquifer: The geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility's property boundary.

Vadose Zone: See unsaturated zone.

Waste Management Unit: Any discernible unit at which solid waste, hazardous waste, infectious waste (as those terms are defined in Chapter 3734. of the Revised Code), construction and demolition debris (as defined in Chapter 3714. of the Revised Code), industrial waste, or other waste (as those terms are defined in Chapter 6111. of the Revised Code), has been placed at any time, irrespective of whether the unit was intended for the management of solid waste, hazardous waste, infectious waste, construction and demolition debris, industrial waste, or other waste. Such units include any area at a facility at which solid waste, hazardous waste, infectious waste, construction and demolition debris, industrial waste, or other waste has been routinely and systematically released.

Water Table: The surface in a ground water body at which the pore water pressure is atmospheric. It can be measured by installing a shallow well extending a few feet into the zone of saturation and then measuring the water level in those wells.

Well: Any shaft or pit dug or bored into the earth, generally of a cylindrical form, and often walled with bricks or tubing to prevent the earth from caving in.

Well Development: The act of repairing damage to the borehole caused by the drilling process and removing fine particles from formation materials so that natural hydraulic conditions are restored and yields are enhanced.

Well Log: A record that includes descriptions of geologic formations and well testing or development techniques used in well construction.

Well Screen: A filtering device that allows ground water to flow freely into a well from the adjacent formation, while minimizing or eliminating the entrance of sediment into the well.

Well Yield: The volume of water discharged from a well; measured in units of gallons per minute or cubic meters per day.

Weight-of-Evidence Classification: From U.S. EPA's (2005) Guidelines for Carcinogenic Risk Assessment, below is the classification system for characterizing the extent to which the available data indicate that an agent is a human carcinogen. An agent may have more than one descriptor.

Carcinogenic to Humans	Strong evidence of human carcinogenicity.
Likely to be Carcinogenic to Humans	The weight of the evidence is adequate to demonstrate carcinogenic potential to humans but does not reach the weight of evidence for the descriptor "carcinogenic to humans."
Suggestive Evidence of Carcinogenic to Potential	The weight of evidence is suggestive of carcinogenicity; a concern for potential carcinogenic effects in humans is raised, but the data are judged not sufficient for a stronger conclusion.
Inadequate Information to Assess Carcinogenic Potential	Data is inadequate for applying one of the other descriptors.
Not Likely to Be Carcinogenic to Humans	The available data are considered robust for deciding that there is no basis for human hazard concern.

Yield: The quantity of water per unit of time that may flow, or be pumped, from a well under specified conditions.

Chapter 10

References

Previous versions of the CPRG contained the following documents in the appendices, but they have been removed. In an effort to reduce paper use, these documents can be found on-line at: http://epa.ohio.gov/portals/32/pdf/Removed_CPRG_Appendices.pdf or by contacting DHWM CO (614-644-2917) and requesting a hard copy.

Appendix Entitled: Clarification Concerning the Arsenic MCL

Lim, Ed. (2003) Memo to Distribution, June 4. "Clarification Concerning the Arsenic MCL"

Appendix Entitled: U.S. EPA Documentation Regarding Risk Based Closure

US EPA (1987) "Interim Standards for Owners of Hazardous Waste Treatment, Storage, and Disposal Facilities; Final Rule". Federal Register: March 19, 1987. 52 FR 8704 pg 3-14

Cotsworth, Elizabeth (1998) Memo to RCRA Senior Policy Advisors, Regions I-X, March 16. "Risk-Based Clean Closure"

Herman, Steven A. (1996) Memo to RCRA/CERCLA National Policy Managers, Regions I-X Agency, September 24. "Coordination between RCRA Corrective Action and Closure and CERCLA Site Activities"

Appendix Entitled: Supplemental Guidance for Calculating the Concentration Term

U.S. EPA (1992) "Supplemental Guidance to RAGS: Calculating the Concentration Term" OSWER Publication 9285.7-081, May

U.S. EPA (2002) "Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites" OSWER Publication 9285.6-10

Appendix Entitled: Supplemental Guidance to RAGS: Standard Default Exposure Assumptions

U.S. EPA (1991) "Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Supplemental Guidance „Standard Default Exposure Factors” OSWER Directive 9285.6-03, March 25

References Cited Within the Document

- Agency for Toxic Substances and Disease Registry. (1995) *Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs)*. Department of Health and Human Services. Atlanta, GA. <http://www.atsdr.cdc.gov/toxprofiles/tp69.html>
- Agency for Toxic Substances and Disease Registry. (1998) *Toxicological Profile for Chlorinated Dibenzo-p-dioxins*. Department of Health and Human Services. Atlanta, GA. <http://www.atsdr.cdc.gov/toxprofiles/tp104.html>
- Agency for Toxic Substances and Disease Registry. (2000) *Toxicological Profile for Polychlorinated Biphenyls (PCB)*. Department of Health and Human Services. Atlanta, GA. <http://www.atsdr.cdc.gov/toxprofiles/tp17.html>
- Agency for Toxic Substances and Disease Registry, U.S. EPA, et al. *Public Health Implications of Exposure to Polychlorinated Biphenyls (PCBs)*. <http://www.atsdr.cdc.gov/DT/pcb007.html>
- American Public Health, American Water Works Association, and Water Environmental Federation. (1999) *Standard Methods for the Examination of Water and Wastewater. Standard Methods*. 20th Edition. Washington, D.C.
- American Society for Testing and Materials. (1990) Standard Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites. ASTM D5088-90.
- American Society for Testing and Materials. (1998) Standard Guide for Developing Appropriate Statistical Approaches for Ground-Water Detection Monitoring Programs. ASTM D 6312-98.
- Andelman, J.B. (1990) "Total Exposure to Volatile Organic Compounds in Potable Water". *Significance and Treatment of Volatile Organic Compounds in Water Supplies*. Ram NM, Christian RF, and Cantor KP, eds. Lewis Publishers. Chelsea, MI.
- Anderson, L.M., L.E. Beebe, S.D. Fox, et al. (1991) "Promotion of Mouse Lung Tumors by Bioaccumulated Polychlorinated Aromatic Hydrocarbons." *Exp Lung Res* 17:455-471.
- Aulerich, R.J., R.K. Ringer, and J. Safronoff. (1986) "Assessment of primary vs. secondary toxicity of Aroclor 1254 to mink." *Arch. Environ. Contam. Toxicol.* 15:393-399.
- Brunner, M.J., T.M. Sullivan, A.W. Singer, et al. (1996) *An Assessment of the Chronic Toxicity and Oncogenicity of Aroclor 1016, Aroclor 1242, Aroclor 1254, and Aroclor 1260 Administered in Diet to Rats*. Battelle Study No. SC920192. Columbus, OH.
- Calabrese, E.J., A.J. Sorenson. (1977) "The Health Effects of PCBs with Particular Emphasis on Human High Risk Groups." *Rev Environ Health* 2:285-304.
- Cameron, K. (1999) *Draft Statistical Analysis of Ground Water Monitoring Data at RCRA Facilities - Unified Guidance*.
- Centers for Disease Control and Prevention. (1991) *Preventing Lead Poisoning in Young Children*. A statement by the Centers for Disease Control and Prevention. Atlanta, GA. <http://wonder.cdc.gov/wonder/prevguid/p0000029/p0000029.asp>

- Chang, L.H. (1943) "The Fecal Excretion of Polycyclic Hydrocarbons Following Their Administration to the Rat". *Journal of Biochemistry* 151: 93-99.
- Code of Federal Registers. (1996) *National Oil and Hazardous Substances Pollution Contingency Plan (NCP)*. 40 CFR 300. Washington, D.C.
- Crump, K.S. and B.C. Allen. (1984) *Quantitative Estimates of Risk Assessment of Risk of Leukemia From Occupational Exposure to Benzene*. Prepared for the Occupational Safety and Health Administration by Science Research Systems, Inc. Ruston, LA. Unpublished.
- Davis, C.B. (1998) *Ground-Water Statistics & Regulations - Principles, Progress and Problems*. 2nd Edition. Environmetrics and Statistics, Ltd. Henderson, NV.
- Dewailly, E., J.P. Weber, S. Gingras, et al. (1991) "Coplanar PCBs in Human Milk in the Province of Quebec, Canada: Are they More Toxic Than Dioxin for Breast Fed Infants?" *Bull Environ Contam Toxicol* 47:491-498.
- Dewailly, E., J.J. Ryan, C. Laliberte, et al. (1994) "Exposure of Remote Maritime Populations to Coplanar PCBs." *Environ Health Perspect Suppl* 102(1):205-209.
- Frink, C. R. (1996) "A Perspective on Metals in Soils." *Journal of Soil Contamination*. 5(4):329-359.
- Giardino, N.J., E. Gumerman, J.B. Andelman, C.R. Wilkes, and M.J. Small. (1990) "Real-Time Measurements of Trichloroethylene in Domestic Bathrooms using Contaminated Water." *Proceedings of the Fifth International Conference on Indoor Air Quality and Climate*. Toronto, Canada, Vol. 2, pp.707-712, July 29, 1990.
- Gibbons, R. (1999) "Use of Combined Shewhart-CUSUM Control Charts for Ground-Water Monitoring Applications." *Ground Water*. Vol. 37, number 5, pp 682-691, October 1999.
- Holmgren, G.G.S., M.W. Meyer, R.L. Cheney, and R.B. Daniels. (1993) "Cadmium, Lead, Zinc, Copper, and Nickel in Agricultural Soils of the United States of America." *J. Environ. Qual.* 22:335-338.
- Hornshaw, T.C., R.J. Aulerich, H.E. Johnson. (1983) "Feeding Great Lakes fish to mink: Effects on mink and accumulation and elimination of PCBs by mink." *J. Toxicol. Environ. Heal.* 11:933-946.
- Hovinga, M.E., M. Sowers, H.E.B. Humphrey. (1992) "Historical changes in serum PCB and DDT levels in an environmentally-exposed cohort." *Arch. Environ. Contam. Toxicol.* 22:362-366.
- Infante, P.F., R.A. Rinsky, J.K. Wagoner, R.C. Young. (1977) "Leukemia in Benzene Workers". *Lancet* 2: 76-8.
- Johnson and Ettinger (U.S. EPA: 1991, 2002) Model for Subsurface Vapor Intrusion Into Buildings. http://www.epa.gov/oswer/riskassessment/airmodel/johnson_ettinger.htm
- Logan, T. J., and R. H. Miller. (1983) *Background Levels of Heavy Metals in Ohio Farm Soils*. Research Circular 275. Ohio Agricultural Research and Development Center. Ohio State University. Wooster, Ohio.

- National Research Council. (1983) *Risk Assessment in the Federal Government: Managing the Process Working Papers*. Committee on the Institutional Means for Assessment of Risks to Public Health.
- Ohio EPA. (1997) *Voluntary Action Program: Development of Generic Numerical Direct Contact Standards. Extrapolation of the Oral Slope Factor for Benzo(a)Pyrene to the Dermal Pathway*. Division of Emergency and Remedial Response. Columbus, OH.
- Ohio EPA. (1998) *New Methods for Preservation of Volatile Organic Compounds in Soil*. Division of Hazardous Waste Management. Columbus, OH.
http://epa.ohio.gov/portals/32/pdf/new_methods.pdf
- Ohio EPA. (2001) *Sediment Sampling Guide and Methodologies*. Division of Surface Water. Columbus, OH. <http://www.epa.ohio.gov/portals/35/guidance/sedman2001.pdf>
- Ohio EPA. (2003) *Guidance for Conducting RCRA Ecological Risk Assessment*. Division of Hazardous Waste Management. Columbus, OH.
<http://www.epa.ohio.gov/portals/32/pdf/March%20ERAG.pdf>
- Ohio EPA. (2003) *Tier I Data Validation Manual*. Division of Hazardous Waste Management. Columbus, OH. <http://epa.ohio.gov/portals/32/pdf/TierIDVManual.pdf>
- Ohio EPA. (2005) *Vadose Zone Modeling in RCRA Closure*. Division of Hazardous Waste Management. Columbus, OH.
<http://epa.ohio.gov/portals/32/pdf/VadoseFinal122904.pdf>
- Ohio EPA. *Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring*. Division of Drinking and Ground Waters. Columbus, OH.
<http://www.epa.ohio.gov/ddagw/tgmweb.aspx>
- Ohio EPA. Plan Review Forms. Division of Hazardous Waste Management. Columbus, OH.
<http://www.epa.ohio.gov/dhwm> - Click on "Forms & Publications", Keyword: Closure
- Paustenbach, D., R. Bass, P. Price. (1993) "Benzene Toxicity and Risk Assessment, 1972-1992: Implications for Future Regulation". *Environmental Health Perspectives* 101 (Supplement 6): 177-200.
- Rao, C.V. and A.S. Banerji. (1988) "Induction of Liver Tumors in Male Wistar Rats by Feeding Polychlorinated Biphenyls (Aroclor 1260)." *Cancer Lett* 39:59-67.
- Rinsky, R.A., R.J. Young, A.B. Smith. (1981) "Leukemia in Benzene Workers". *American Journal of Industrial Medicine* 2: 217-245.
- Rinsky, R.A., A.B. Smith, R. Horning. (1987) "Benzene and Leukemia: an Epidemiologic Risk Assessment". *New England Journal of Medicine* 316: 1044-1050.
- State Coordinating Committee on Ground Water. (1996) *State of Ohio Technical Guidance for Sealing Unused Wells*.
<http://www.epa.ohio.gov/portals/28/documents/gwqcp/wellsealguid.pdf>
- Tetra Tech EM, Inc. under U.S. EPA. *Costpro*® - Cost Estimating Software Program.

- Thyssen, J. et. al. (1981) "Inhalation Studies With Benzo(a)Pyrene in Syrian Golden Hamsters". *Journal of the National Cancer Institute* 66: 575-577.
- U.S. Department of Health and Human Services. (1985) *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities*. Publication Number 85-115. National Institute for Occupational Safety and Health. Washington, D.C.
<http://www.cdc.gov/niosh/85-115.html>
- U.S. EPA. (1984) *Assessment of Emissions of Specific Compounds from a Resource Recovery Municipal Refuse Incinerator*. EPA/560/5-84/002. Washington, D.C.
- U.S. EPA. (1985) *Guide for Decontaminating Buildings, Structures, and Equipment at Superfund Sites*. EPA/600/2-85/028. Office of Research and Development. Cincinnati, OH.
- U.S. EPA. (1986) *Guidelines for Carcinogen Risk Assessment*. EPA/630/R-00/004. Risk Assessment Forum. Washington, D.C.
<http://cfpub.epa.gov/nceal/cfm/recordisplay.cfm?deid=54933>
- U.S. EPA. (1985) *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites*. EPA/600/8-85/002. Office of Health and Environmental Assessment. Washington, D.C. <http://www.epa.gov/natlibra/ols.htm>
- U.S. EPA. (1986) *Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzo-p-dioxins and -Dibenzofurans (CDDs and CDFs) and 1989 Update*. EPA/625/3-89/016. Washington, D.C. <http://www.epa.gov/natlibra/ols.htm>
- U.S. EPA. (1988) *Superfund Exposure Assessment Manual (SEAM)*. EPA/540/1-88/001. Office of Remedial Response. Washington, D.C.
<http://www.hanford.gov/dqo/project/level5/sfndxass.pdf>
- U.S. EPA. (1989) *RCRA Facility Investigation (RFI) Guidance*. EPA/530/SW-89-031. Office of Solid Waste. Washington, D.C.
<http://www.epa.gov/epawaste/hazard/correctiveaction/resources/guidance/sitechar/index.htm>
- U.S. EPA. (1989) *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Part A*. EPA/540/1-89/002. Office of Emergency and Remedial Response. Washington, D.C.
<http://www.epa.gov/oswer/riskassessment/ragsa/index.htm>
- U.S. EPA. (1989) *Statistical Analysis of Ground Water Monitoring Data at RCRA Facilities. Interim Final Guidance*. Office of Solid Waste. Washington, D.C.
- U.S. EPA. (1990) *A Rationale for the Assessment of Errors in the Sampling of Soils*. EPA/600/4-90/013. Environmental Monitoring Systems Laboratory. Office of Research and Development. Las Vegas, NV. <http://www.epa.gov/swrust1/cat/rational.pdf>
- U.S. EPA. (1991) *Guidance on Handling Chemical Concentration Data Near the Detection Limit in Risk Assessments. Interim Final*. Region III. Roy L. Smith, PhD.
<http://www.epa.gov/reg3hwmd/risk/human/info/guide3.htm>

- U.S. EPA. (1991) *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)*. OSWER 9285.7-01B. Office of Emergency and Remedial Response. Washington, D.C. <http://www.epa.gov/oswer/riskassessment/ragsb/index.htm>
- U.S. EPA. (1991) *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Supplemental Guidance "Standard Default Exposure Factors"*. OSWER 9285.6-03. Office of Emergency and Remedial Response. Washington, D.C.
- U.S. EPA. (1991) *Seminar Publications. Design and Construction of RCRA/CERCLA Final Covers*. EPA/625/4-91/025. Office of Research and Development. Washington, D.C.
- U.S. EPA. (1991) *Site Characterization for Subsurface Remediation*. EPA/625/4-91/026. Office of Research and Development. Washington, D.C.
- U.S. EPA. (1992) *Guidance for Data Useability in Risk Assessment (Part A)*. Office of Emergency and Remedial Response. Washington, D.C. <http://www.epa.gov/oswer/riskassessment/datause/parta.htm>
- U.S. EPA. (1992) *Guidance for Conducting Treatability Studies Under CERCLA*. EPA/540/R-92/071a. Office of Research and Development. Washington, D.C. <http://www.epa.gov/natlibra/ols.htm>
- U.S. EPA. (1992) *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies*. EPA/600/R-92/128. Office of Research and Development. Washington, D.C. <http://www.epa.gov/swrust1/cat/mason.pdf>
- U.S. EPA. (1992) *Standard Operating Safety Guides*. Office of Emergency and Remedial Response. Washington, D.C.
- U.S. EPA. (1992) *Statistical Analysis of Ground Water Monitoring Data at RCRA Facilities. Addendum to Interim Final Guidance*. Office of Solid Waste. Washington, D.C.
- U.S. EPA. (1992) *Supplemental Guidance to RAGS: Calculating the Concentration Term*. OSWER 9285.7-081. Office of Solid Waste and Emergency Response. Washington, D.C.
- U.S. EPA. (1993) *Engineering Bulletin: Landfill Covers*. EPA/540/S-93/500. Office of Solid Waste and Emergency and Remedial Response. Washington, D.C.
- U.S. EPA. (1993) *Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons*. EPA/600/R-93/089. Office of Research and Development. Washington, D.C. <http://www.epa.gov/natlibra/ols.htm>
- U.S. EPA. (1994) *Guidance Manual for the Integrated Exposure Uptake Biokinetic Model for Lead in Children*. EPA/540/R-93/081. Office of Solid Waste and Emergency Response. Washington, D.C. <http://www.epa.gov/superfund/lead/products.htm#guid>
- U.S. EPA. (1995) *Determination of Background Concentrations of Inorganics in Soils and Sediments at Hazardous Waste Sites*. EPA/540/S-96/500. R.P. Breckenridge and A.B. Crockett.

- U.S. EPA. (1995) *Land Use in the CERCLA Remedy Selection Process*. OSWER 9355.7-04. Office of Solid Waste and Emergency Response. Washington, D.C.
<http://www.epa.gov/superfund/community/relocation/landuse.htm>
- U.S. EPA. (1996) *Soil Screening Guidance: Technical Background Document*. EPA/540/R-95/128. Office of Solid Waste and Emergency Response. Washington, D.C.
<http://www.epa.gov/superfund/health/conmedia/soil/introtbd.htm>
- U.S. EPA. (1997) *Exposure Factors Handbook*. EPA/600/P-95/002Fa. Office of Research and Development. Washington, D.C. <http://www.epa.gov/ncea/pdfs/efh/front.pdf>
- U.S. EPA. (1997) *Guiding Principles for Monte Carlo Analysis*. EPA/630/R-97/001. Washington, D.C. <http://www.epa.gov/NCEA/pdfs/montcarl.pdf>
- U.S. EPA. (1997) *Health Effects Assessment Summary Tables: Annual FY 1997 Update*. EPA/540/R-97/036. Office of Solid Waste and Emergency Response. Washington, D.C.
- U.S. EPA. (1997) *Use of Probabilistic Techniques (Including Monte Carlo Analysis) Assessment*. Washington, D.C. <http://www.epa.gov/OSA/spc/pdfs/probpol.pdf>
- U.S. EPA. (1998) *Background Information on PCB Sources and Regulations*.
<http://www.epa.gov/grtlakes/bnsdocs/pcbsrce/pcbsrce.html>
- U.S. EPA. (1998) *Management of Remediation Waste Under RCRA*. EPA530-F-98-026. Office of Solid Waste and Emergency Response. Washington, D.C.
<http://www.epa.gov/Compliance/resources/policies/civil/rcra/remediawaste-rpt.pdf>
- U.S. EPA. (1999) *Contract Laboratory Program National Functional Guidelines for Organic Data Review*. EPA540/R-99/008. Office of Emergency and Remedial Response. Washington, D.C. <http://www.epa.gov/superfund/programs/clp/download/fgorg.pdf>
- U.S. EPA. (1999) *Risk Assessment Issue Paper: Status of Inhalation Cancer Unit Risk for Benzo(a)Pyrene*. National Center for Environmental Assessment, Superfund Technical Assistance Center. Cincinnati, OH.
- U.S. EPA. (1999) *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*. OSWER 9200.4-17P. Office of Solid Waste and Emergency Response. Washington, D.C.
<http://www.epa.gov/swerust1/directiv/d9200417.htm>
- U.S. EPA. (2000) *Guidance for Data Quality Assessment: Practical Methods for Data Analysis (EPA QA/G-9)*. EPA/600/R-96/084. Office of Environmental Information. Washington, D.C. http://www.clu-in.org/conf/tio/pasi_121603/g9-final.pdf
- U.S. EPA. (2000) *Hazardous Materials Incident Response Operations (165.5)*. Emergency Response Training Program. EPA-540-B-00-002. Office of Solid Waste and Emergency Response.
- U.S. EPA. (2000) *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures*. EPA/630/R-00/002. Office of Research and Development. Washington, D.C. <http://www.epa.gov/natlibra/ols.htm>

- U.S. EPA. (2001) *Priority PBT Profiles*. Persistent Bioaccumulative and Toxic Chemical Program, Office of Pollution Prevention and Toxics. Washington, D.C.
<http://www.epa.gov/pbt/pubs/cheminfo.htm>
- U.S. EPA. (2001) *Risk Assessment Guidance for Superfund, Volume III: Part A, Process for Conducting Probabilistic Risk Assessment*. Office of Emergency and Remedial Response. Washington, D.C. <http://www.epa.gov/oswer/riskassessment/rags3adt/>
- U.S. EPA. (2001) *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*, Office of Solid Waste and Emergency Response. Washington, D.C.
- U.S. EPA. (2002) *Calculating the Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*. OSWER 9285.6-10. Office of Emergency and Remedial Response. Washington, D.C. <http://www.epa.gov/oswer/riskassessment/pdf/ucl.pdf>
- U.S. EPA. (2002) *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance)*. Office of Solid Waste and Emergency Response. Washington, D.C.
- U.S. EPA. (2002) *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites*. EPA 540-R-01-003. Office of Emergency and Remedial Response. Washington, D.C.
- U.S. EPA. (2002) *Proven Alternatives for Aboveground Treatment of Arsenic in Groundwater*. EPA-542-S-02-002. Office of Solid Waste and Emergency Response.
http://www.epa.gov/tio/tsp/download/arsenic_issue_paper.pdf
- U.S. EPA. (2002) *RCRA Waste Sampling Draft Technical Guidance. Planning, Implementation and Assessment*. EPA530-D-02-002. Office of Solid Waste. Washington, D.C.
http://www.epa.gov/waste/hazard/testmethods/sw846/samp_guid.htm
- U.S. EPA. (2005) *Guidelines for Carcinogen Risk Assessment*. EPA/630/P-03/001F. Risk Assessment Forum. Washington, D.C.
<http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=116283>
- U.S. EPA. (2003) *Integrated Risk Information System*. Washington, D.C.
<http://www.epa.gov/iris>
- U.S. EPA. (2004) *Handbook of Groundwater Protection and Cleanup Policies for RCRA Corrective Action*. EPA/530/R-01/015. Office of Solid Waste and Emergency Response.
<http://www.epa.gov/osw/hazard/correctiveaction/resources/guidance/pdfs/gwhb041404.pdf>
- U.S. EPA. (2004) *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)*. EPA/540/R/99/005. Office of Emergency and Remedial Response. Washington, D.C.
- U.S. EPA. (2008) *RCRA Orientation Manual*. Office of Solid Waste/Communications, Information, and Resources Management Division. Washington, D.C.
<http://www.epa.gov/osw/inforesources/pubs/orientat/>

U.S. EPA. *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Update III (SW-846)*. Office of Solid Waste and Emergency Response. Washington, D.C.
<http://www.epa.gov/epawaste/hazard/testmethods/index.htm>

Van den Berg et. al. (1998) "Toxicity Equivalency Factors (TEFs) for PCBs, PCDDs & PCDFs for Humans and Wildlife". *Environmental Health Perspectives* 106 (12): 775-792.

Additional References

Chorssen, J.J. and V.T. Covello. (1989) *Risk Analysis: A Guide to Principles and Methods for Analyzing Health and Environmental Risks*. U.S. Council on Environmental Quality, Executive Office of the President.

Gieseking, J.E. (1975) *Soil Components Volume I: Organic Components*, pp. 97-105. Springer, New York.

Hahn, G.J. and Meeker, W.Q. (1991) *Statistical Intervals: A Guide for Practitioners*. New York, John Wiley & Sons, Inc.

International Joint Commission. (1999) "International Air Quality Advisory Board Workshop Presentation". *1999 Great Lakes Water Quality Forum*.

Kamrin, M.A. (1989) *Toxicology*. Lewis Publishers. Chelsea, MI.

Massachusetts Water Resources Authority Environmental Quality Department. (1999) *Annual Fish and Shellfish Report*.

Minnesota Pollution Control Agency. (1998) *PAH Fact Sheet*. Ground Water and Solid Waste.

Nelson, D.W. and L.E. Sommers. (1996) "Total Carbon, Organic Carbon and Organic Matter". *Methods of Soils Analysis Part 3: Chemical Methods*, pp.961-1069. A. Klute, ed. Soil Science Society of America.

Ohio EPA. (2000) *Waste Analysis Plan Guidance*. Division of Hazardous Waste Management. Columbus, OH. <http://epa.ohio.gov/portals/32/pdf/FinalGuidance.PDF>

U.S. Army Corps of Engineers. (1999) *Engineering and Design, Multi-Phase Extraction*. Department of the Army.
<http://140.194.76.129/publications/eng-manuals/em1110-1-4010/entire.pdf>

U.S. EPA. (1985) *Practical Guide for Groundwater Sampling*. EPA/600/2-85/104. Office of Research and Development. Ada, OK.

U.S. EPA. (1986) *RCRA Ground Water Monitoring Technical Enforcement Guidance Document*. OSWER 9950.1. Office of Solid Waste and Emergency Response. Washington, D.C.

U.S. EPA. (1989) *Minimum Technology Guidance on Final Covers for Landfills and Surface Impoundments*. EPA/530-SW-89-047. Office of Solid Waste and Emergency Response. Washington, D.C.

- U.S. EPA. (1989) *Stabilization/Solidification of CERCLA and RCRA Wastes. Physical Tests, Chemical Testing Procedures, Technology Screening, and Field Activities*. EPA/625/6-89/022. Risk Reduction Engineering Laboratory. Cincinnati, OH.
- U.S. EPA. (1991) *Risk Assessment Guidance for Superfund: Volume I: Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternative)*. OSWER 9285.7-01C. Office of Emergency and Remedial Response. Washington, D.C.
<http://www.epa.gov/oswer/riskassessment/ragsc/index.htm>
- U.S. EPA. (1992) *Estimating Potential for Occurrence of DNAPL at Superfund Sites*. OSWER 9355.4-07FS. Office of Research and Development. Ada, OK.
- U.S. EPA. (1992) *Guidelines for Exposure Assessment*. EPA/600/Z-92/001. Risk Assessment Forum. Washington, D.C. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=15263>
- U.S. EPA. (1994) *Chemical Hazard Evaluation for Management Strategies: A Method for Ranking and Scoring Chemicals by Potential Human Health and Environmental Impacts*. EPA/600/R-94/177. Office of Research and Development. Washington, D.C.
- U.S. EPA. (1996) *Guidelines for Reproductive Toxicity Risk Assessment*. EPA/630/R-96/009. Risk Assessment Forum. Washington, D.C.
<http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=2838>
- U.S. EPA. (1996) *Soil Screening Guidance: User's Guide*. EPA/540/R-96/018. Office of Solid Waste and Emergency Response. Washington, D.C.
<http://www.epa.gov/superfund/health/conmedia/soil/index.htm>
- U.S. EPA. (1997) *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments*. Interim Final. EPA/540/R-97-006. Solid Waste and Emergency Response. Washington, D.C.
- U.S. EPA. (2002) *A Review of the Reference Dose and Reference Concentration Processes*. EPA/630/P-02/002F. Risk Assessment Forum. Washington, D.C.
<http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=55365>
- U.S. EPA. (2002) *RCRA Waste Sampling Draft Technical Guidance*. EPA530-D-02-002. Office of Solid Waste and Emergency Response. Washington, D.C.
http://www.epa.gov/waste/hazard/testmethods/sw846/samp_guid.htm

Additional Web sites

ASTM, <http://www.astm.org/>

Federal Remediation Technologies Roundtable Web site, <http://www.frtr.gov/>

Clean Ohio Fund, <http://www.clean.ohio.gov/>

Ohio EPA. Division of Air Pollution Control, <http://www.epa.ohio.gov/dapc>

Ohio EPA, Division of Emergency and Remedial Response, Voluntary Action Program,
<http://www.epa.ohio.gov/derr/volunt/volunt.aspx>

Ohio EPA, Division of Hazardous Waste Management, <http://www.epa.ohio.gov/dhwm>

Ohio EPA Rules (Ohio Administrative Code and Ohio Revised Code),
http://www.epa.ohio.gov/Rules_and_Laws.aspx

Ohio EPA, Weekly Review, <http://www.epa.ohio.gov/actions.aspx>

Ohio State Board of Professional Engineers and Surveyors, <http://www.peps.ohio.gov/>

Remediation/Characterization Innovative Technologies, <http://clu-in.org/vendor/vendorinfo/>

SESOIL, <http://www.seview.com/aboutsesoil.htm>

Superfund Innovative Technology Evaluation, <http://www.epa.gov/nrmrl/lrpcd/site/index.html>

U.S. EPA, Clu-In, <http://www.clu-in.org/>

U.S. EPA, Code of Federal Regulations, <http://www.gpoaccess.gov/ecfr/>

U.S. EPA, CSMoS Ground Water Modeling Software,
<http://www.epa.gov/ada/csmos/models.html>

U.S. EPA, Enviromapper, <http://www.epa.gov/enviro/html/em/>

U.S. EPA, Federal Register, <http://www.epa.gov/fedrgstr/>

U.S. EPA, National Center for Environmental Assessment (NCEA), <http://cfpub.epa.gov/ncea/>

U.S. EPA, ProUCL, <http://www.epa.gov/nerlesd1/tsc/software.htm>

U.S. EPA, Quality Management Tools, <http://www.epa.gov/quality/qatools.html>

U.S. EPA, Region IX Preliminary Remediation Goals,
<http://www.epa.gov/region09/superfund/prg/index.html>

Appendix A

Generic Cleanup Numbers – Technical Background and Values

1.0 Introduction

This appendix explains what Generic Cleanup Numbers (GCNs) are, how the GCNs listed at the end of this appendix are generated, and how to apply the GCNs in the closure process. Also included are the descriptions and equations of the four types of GCNs, along with the exposure pathways and corresponding intake equations used in the calculations of the risk-based GCNs. Included in the GCN tables are MCLs, and MCL-based GCNs. The calculations for the MCL-based GCNs are the same as for the risk-based GCNs. In this appendix, the term “risk-based” is used to describe the GCNs that were calculated using solely risk assessment methods by DHWM. While MCLs are also risk numbers they are not developed based solely on risk assessment methods. In order to differentiate between the two types of GCNs, values calculated using a MCL are termed “MCL-based.” This information can be used not only to better understand the GCNs, but also in a site-specific risk assessment to establish risk-based cleanup standards that address all potential routes of exposure to humans. This can be done by using the intake equations presented in the text along with either site-specific exposure parameters or default parameters presented in Table A-2, combined to solve for a concentration as done in the GCN calculations. This information can also be used to determine risk levels based on exposures to humans for a site. For more information on conducting a human health risk assessment please see Chapters 6 and 7 of this document or U.S. EPA’s Risk Assessment Guidance for Superfund.

1.1 Generic Cleanup Numbers

DHWM believes that it is important to understand how GCNs are developed in order to apply them correctly at a closure unit. DHWM has calculated risk-based levels that when appropriately used, can be substituted for a site-specific risk assessment for use in meeting the closure performance standard. These levels are called Generic Cleanup Numbers or “GCNs.” GCNs are termed “generic” because they are created with generic default values. Risk-based GCNs are calculated with the same equations that are used to calculate risk. Because a GCN is a media concentration, it is the concentration variable that is solved for in the standard risk assessment equations and corresponds to a cancer risk goal of $1E-05$, or a noncancer hazard index of 1.0. This is sometimes called “backwards risk assessment.” DHWM also allows the use of MCL-based cleanup numbers for groundwater and soil values that are protective of leaching to ground water.

GCNs provide initial cleanup standards for individual chemicals provided that the media and exposure pathway assumptions for the site are the same as those used to create the GCNs. The GCNs have been calculated for chemicals commonly found in hazardous waste management units in Ohio. These values are generated based on human exposures in a residential exposure setting. The GCNs for each chemical have been calculated for both cancer and noncancer risks (where applicable). The concentrations calculated for each GCN are listed in separate cancer and noncancer risk columns. Table A-3 includes four different risk-based GCNs for each COC, as described below:

Ground water GCNs: that assumes no contaminated soil exists in the closure unit.

Three different soil GCNs:

- 1) **Soil GCNs that take into account potential leachability to ground water:** that assumes no dilution of contaminant concentration from soil pore water to ground water and therefore including a dilution attenuation factor (DAF) of 1 DAF. These soil GCNs assume that no current contamination in ground water exists.
- 2) **Soil GCNs that take into account potential leachability to ground water:** that includes a DAF of 20 to account for dilution of contaminant concentration from soil pore water to ground water. These soil GCNs also assume that no current ground water contamination exists.
- 3) **Soil GCNs for direct contact with soil:** that assumes ground water has not nor will not be impacted.

The pathways used to calculate the risk-based ground water, 1 DAF, and 20 DAF GCNs include ingestion of contaminants in drinking water, dermal contact with contaminants while showering, and inhalation of volatile contaminants while showering. The pathways used to calculate the direct contact soil GCNs include ingestion of contaminants in soils and dust, dermal contact with contaminants in soil, and inhalation of volatile contaminants and contaminant particulates from soil. The GCNs do not consider all exposure pathways encountered at specific hazardous waste sites. For example, some of the GCNs do not consider impacts to ground water (the direct contact soil GCNs). DHWM also uses U.S. EPA's MCLs as groundwater standards where appropriate. Soil numbers that are protective of leaching to groundwater were also calculated using MCLs and can be found in Table A-4. These soils numbers should also be used when MCLs are appropriate for the site. If it is determined that MCLs are not appropriate for the site risk-based GCNs should be used.

GCNs developed in this guidance provide numerous benefits to the regulated community. The GCNs can be used as cleanup levels in lieu of a site-specific risk evaluation where applicable (i.e., where only one media is contaminated, where no other exposure pathways exist other than those used to generate the GCNs, and the effect of chemical additivity is applied where multiple constituents of concern are found at a closure unit). GCNs can also be used for prioritizing areas of contamination at closure sites. Adjusted risk-based GCNs can be used to screen out individual chemicals from further consideration in a risk evaluation. If contaminant levels exist at a hazardous waste closure unit that are greater than the GCNs given in Table A-3, a site-specific investigation can be conducted to demonstrate that unacceptable human health risks may not exist given site-specific inputs.

The generic risk-based numbers cannot be used to determine if a waste is hazardous waste nor can they be used as substitutes for land disposal restriction levels. In addition, the GCNs do not account for ecological receptors, so are therefore not appropriate if there are ecological concerns in the closure unit.¹

The GCNs are based on a residential exposure scenario, they were not developed with the intention for use at units closing based on an industrial scenario. However, because residential scenario risk-based GCNs tend to be more conservative than industrial scenario risk-based standards, there isn't anything precluding their use at these types of closure units. Conversely,

¹ For more information on Ecological risk assessments please see Ohio EPA's (2003) *Guidance for Conducting RCRA Ecological Risk Assessments*.

facilities with industrial scenario based closure units may elect to conduct a site-specific risk assessment. This appendix also contains industrial intake equations, and default industrial exposure parameters that may be used in an industrial risk assessment.

DHWM will periodically add additional GCNs to or revise existing GCNs at the end of this appendix when new chemical information becomes available. For the most current version of the GCN table check DHWM's website. District personnel or facilities can request that a risk-based GCN be developed for a particular chemical. DHWM CO will generate the risk-based GCN if adequate information is available. Requests for additional GCNs should be directed to CO ERAS.

Figure A-1 summarizes proper and improper uses for GCNs. Figure A-2 is a flowchart on how to apply GCNs. Examples detailing some of the uses of the GCNs can be found in sections 6.0 through 8.0 of this document.

The GCNs can be used for:

- determining if remediation is necessary,
- providing initial cleanup goals for individual chemicals (provided that the media and exposure pathway assumptions for the site are the same as those used to create the GCNs),
- assisting in prioritizing areas of contamination,
- aiding in the definition of data quality objectives for closure sites by helping to establish cleanup standards,
- providing an alternative to site-specific risk evaluation in applicable situations (i.e., where soil and ground water are not both contaminated, no exposure pathways exist other than those used to generate the GCNs, additivity is applied to account for multiple chemicals, etc.), and
- providing a method by which chemicals can be screened from further evaluation in a site-specific or generic quantitative risk assessment (as long as the guidelines in this appendix are followed).

The GCNs are NOT to be used in the following manner:

- to determine nature and extent of contamination (conversely, nature and extent of contamination must be defined prior to using the GCNs),
- to screen out individual chemicals from further consideration in a risk assessment without first adjusting the GCNs as directed in this guidance,
- as ecological cleanup numbers,
- to determine if a waste is hazardous waste,
- as substitutes for land disposal restrictions,
- if the vapor intrusion pathway is likely to be complete, or
- if hazardous waste or other contaminant source is present.

Figure A-1: Correct and Incorrect Uses of GCNs For Closure

1.2 How to Determine if GCNs are Appropriate for the Closure Unit

In order to determine if relevant exposure pathways and site conditions are the same as those modeled in the GCN calculations, completion of a Conceptual Site Model (CSM) is suggested. A CSM will aid in determining whether or not the application of GCNs is appropriate for the unit in question. A CSM is a tool used to identify potential contaminant source areas, exposure

pathways, and receptors. A site-specific CSM should be developed by compiling existing information such as sampling data, historical records, hazardous waste generation and disposal information, hydrological information, land use considerations at and near the facility, and any other pertinent information. A CSM should have a diagram linking contaminant sources, release mechanisms, exposure pathways, routes, and receptors. A good CSM should summarize all current understanding of the contamination at a unit. Once a CSM is developed, use it to answer the following questions. Answering any question with a “yes” indicates that the risk-based GCNs cannot be used:

- 1) Does the unit currently have both a contaminated aquifer and contaminated soil as determined by sampling information?
- 2) If the upper-most aquifer may be affected by leaching (See ground water scoring matrix, CPRG; or Vadose Zone Modeling Guidance, 2004), are any of the constituents of concern inorganic metals for which no site-specific background information is available? (This is only applicable if the metal is to be eliminated from the risk assessment based on background levels, as many of the leaching numbers are below typical background levels.)
- 3) Do any other exposure pathways exist at the unit in addition to the following:
 - ingestion of contaminated soil
 - inhalation of volatiles and particulates from contaminated soil
 - dermal contact with contaminated soil
 - ingestion of contaminated ground water
 - inhalation of volatiles from contaminated ground water during showering
 - dermal contact with contaminated ground water during showering
- 4) Do any unusual conditions exist at the unit, including but not limited to:
 - large areas of contamination
 - high fugitive dust levels
 - nonaqueous phase liquids (NAPL)
 - cultivation of food crops
- 5) Are there constituents of concern present that are not listed in Tables A-3², A-4 and A-5? (If yes, GCNs can still be used for the unit, but for constituents of concern without GCNs, alternative remediation numbers must be used.)

As noted previously, a primary condition for using the GCNs is that all exposure pathways relevant to the unit should be included among those used to calculate the GCNs. If any exposure pathways exist that are not accounted for by the conceptual model used to create the GCNs, GCNs may not be used. In addition, conditions at the unit should be similar to those used to calculate the GCNs or else GCNs may not be used. For example, conditions such as large amounts of blowing dust, food crop growth in or below the unit area, etc. warrant a site-specific investigation. If a potential pathway of concern is not one of those used to generate the GCNs, a site-specific risk assessment should be performed, or alternative remediation numbers or strategies should be determined.

² Upon request, DHWM can generate GCNs for chemical not given in Table A-3 provided information is available. Please direct requests for GCNs to CO-ERAS.

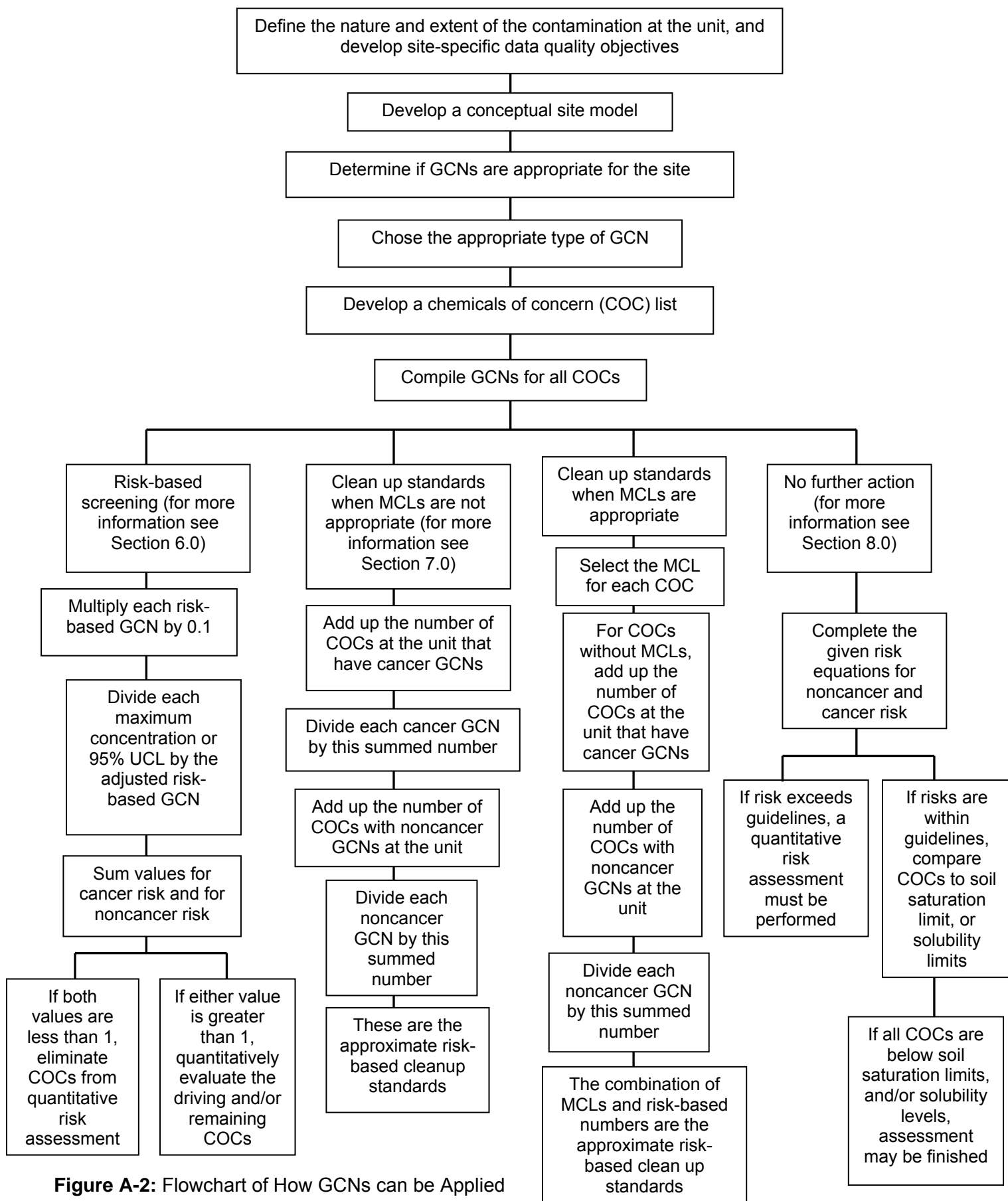


Figure A-2: Flowchart of How GCNs can be Applied

1.3 Determining Which Set of Risk-Based GCNs is Applicable

Once it is determined that risk-based GCNs are appropriate, the user must decide which type(s) of risk-based GCNs apply. The four choices are listed below and are described in detail later in this document:

- Direct contact soil GCNs.
- GCNs protective of leaching into ground water with no dilution or attenuation.
- GCNs protective of leaching into ground water with dilution and/or attenuation factored in.
- Ground water GCNs.

1.4 General Information About Risk-Based GCN Derivation

As stated in section 1.1 of this appendix, risk-based GCNs are calculated essentially the same way that risk is calculated, except solving for a different mathematical variable. In other words, the same models (i.e., mathematic equations) are used, but different variables are left unknown. Therefore, the equations in the sections below are sometimes used to calculate risk (also known as “forward” risk assessment), and were also used to calculate the risk-based GCNs.

The risk-based GCNs are generated using toxicity values, chemical-specific information (see Table A-5), and default exposure factors (found in Table A-2), most of which were adopted from U.S. EPA. These cleanup numbers estimate contaminant concentrations that are protective of human health over a chronic exposure period (6 years for a child, 30 years for an adult).

Please note that the default exposure factors used in the calculation of the GCNs may not match the recommendations found in Ohio EPA’s (2005) Vadose Zone Modeling in RCRA Closure because those recommendations are based on site-specific conditions and are not appropriate for the calculation of generic cleanup numbers.

1.4.1 Toxicity Values

The toxicity values, currently accepted by Ohio EPA, DHWM and given in Table A-5, are taken from a number of recognized sources. For noncarcinogenic reference doses (RfD) and carcinogenic slope factors (SF), values are obtained from the following hierarchy of sources:

- Integrated Risk Information System (IRIS)
- National Center for Environmental Assessment (NCEA)
- Agency for Toxic Substances and Disease Registry (ATSDR)
- U.S. EPA Criteria Documents
- Health Effects Assessment Tables (HEAST)

Where no toxicity values are available for a route of exposure, route-to-route extrapolations are sometimes used in generating the risk-based GCN concentrations in Table A-3. See Chapter 7 Section 7.3 of this document for more discussion on the selection of toxicity factors.

Route-to-route extrapolations are also used to adjust oral toxicity values where dermal exposures may be important. DHWM uses oral toxicity values, adjusted for oral absorption efficiency, to evaluate dermal exposures in developing risk-based GCNs. The oral toxicity values are first adjusted, using the oral absorption factor, to reflect that not all of the dose ingested is absorbed, that really just a fraction of the whole causes the toxicity. They are then adjusted, using the dermal absorption factor as an exposure parameter, to account for the portion of the dose that is actually absorbed through the skin. This method is considered by DHWM to be conservative and protective of human health and based on RAGS, Part E. The oral and dermal absorption factors used to adjust these oral toxicity values are provided in Table A-5.

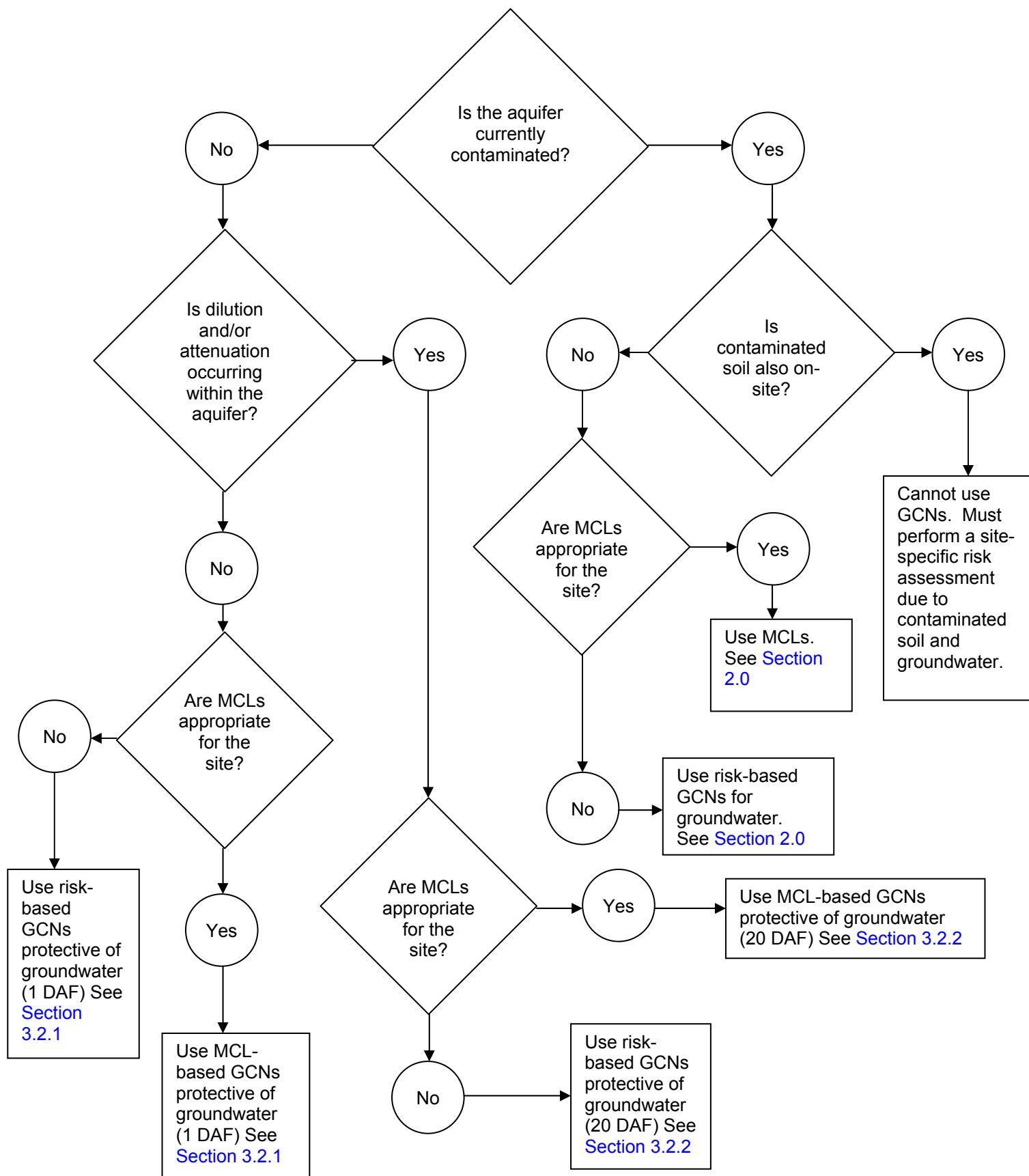


Figure A-3: Decision Tree for Choosing GCNs for a Site

1.5 Chemical Volatilization

Risks from exposure to air-borne chemicals from contaminated soil or ground water is evaluated only for organic chemicals that have a Henry's Law constant greater than or equal to 1E-05 atm-m³/mol and a molecular weight less than 200 g/mol.

2.0 Ground Water GCNs

If the use of MCLs is appropriate at the site, they can be used as cleanup numbers and can be found on Table A-4. When the use of MCLs is not appropriate for the ground water pathway risk-based ground water GCNs should be used. Ground water exposure pathways used to generate risk-based GCNs and intake equations for those pathways are presented in this section. Part of this presentation will focus on the equations used to calculate the ground water cancer and non cancer GCNs. In addition, the correct procedure for comparing solubility levels to the risk-based GCNs is discussed. Finally, information is provided on how the applicable ground water GCN for a constituent is chosen.

2.1 Ground Water Pathways for Risk-Based GCNs

Risk-based GCNs for ground water were developed assuming exposure via ingestion of contaminated ground water, dermal contact with contaminated ground water while showering, and inhalation of volatiles from contaminated ground water while showering, for a residential exposure scenario. For the calculation of the risk-based GCNs all chemicals are considered to contribute to dermal exposure (while showering) and all chemicals are evaluated for ingestion of ground water. However, inhalation exposure is considered only for those chemicals that are considered volatile based on certain physical/chemical parameters (see section 1.5 of this appendix).

If contamination from the unit has impacted ground water, then the GCNs for ground water can only be used if soil is not also contaminated or the source has been removed. For example, if a facility has a closure unit where soil contamination and ground water contamination are present, the unit must have a unit-specific risk assessment prepared in order to evaluate the impact to human health. For the same scenario, but where a ground water plume has extended past the property boundary into a residential area, risk-based ground water GCNs could be used to determine the impacts to human health for off-site residents.

2.1.1 Ground Water- Ingestion

The intake equations for ground water ingestion of chemicals that have oral slope factors and/or oral reference doses are listed below. Site-specific or default exposure parameters, found in Table A-2, can be used in these equations.

Equation A-1: Ingestion of Chemicals in Drinking Water Residential Scenario - Noncancer
$\text{Intake (mg / kg - d)} = \frac{\text{CW} \times \text{IRWc} \times \text{EFr} \times \text{EDc}}{\text{BWc} \times \text{ATn}}$

Equation A-2: Ingestion of Chemicals in Drinking Water Residential Scenario - Cancer

$$\text{Intake (mg / kg - d)} = \frac{\text{CW} \times \left(\frac{\text{EDc} \times \text{IRWc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IRWa}}{\text{BWa}} \right) \times \text{Efr}}{\text{ATc}}$$

Note: This is an age-adjusted factor. Using the default exposure factors for a child and an adult, the bracketed term (IFWadj) = 1.0857 [(l-yr)/(kg-d)].

2.1.2 Ground Water - Dermal Contact

The equations, found below, determine the exposure dose for dermal contact with water while showering. While these equations specifically deal with showering, the exposure parameters can be adjusted to represent dermal contact with water under different scenarios such as swimming, wading, or household chores in a site-specific risk assessment.

Equation A-3: Dermal Contact With Chemicals While Showering Residential Scenario - Noncancer

$$\text{Absorbed Dose(mg / kg - d)} = \frac{\text{CW} \times \text{SAWc} \times \text{PC} \times \text{ETc} \times \text{Efr} \times \text{EDc} \times \text{CFw}}{\text{BWc} \times \text{ATn}}$$

Equation A-4: Dermal Contact With Chemicals While Showering Residential Scenario - Cancer

$$\text{Absorbed Dose(mg / kg - d)} = \frac{\text{CW} \times \left(\frac{\text{SAWc} \times \text{EDc} \times \text{ETc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{SAWa} \times \text{ETa}}{\text{BWa}} \right) \times \text{PC} \times \text{Efr} \times \text{CFw}}{\text{ATc}}$$

Note: This is an age-adjusted factor. Using the default exposure factors for a child and an adult, the bracketed term (SFWadj) = 6219.43 [(cm²-yr)/(kg)].

2.1.3 Ground Water - Inhalation

The inhalation of volatile contaminants from contaminated ground water while showering can be a significant exposure pathway. This pathway is only assessed for volatile chemicals. Therefore, the risk equation incorporates a water-air relationship for those volatile chemicals as shown in Equation A-5 below.

2.1.3.1 Volatilization Factor for Water

For calculating air concentrations resulting from volatilization from contaminated ground water, a volatilization constant (VFW) is used. Equation A-5 is based upon the Andelman³ equation found below:

³ Equation A-5 and the default for f is from Andelman, J.B. (1990) "Total Exposure to Volatile Organic Compounds in Potable Water". Significance and Treatment of Volatile Organic Compounds in Water Supplies. Eq. 19, page 499. The Fw and the t defaults are from U.S. EPA's (1997) Exposure Factors Handbook. The Va default is from Giardino, N.J., E. Gumerman, J.B. Andelman, C.R. Wilkes, and M.J. Small. (1990) "Real-Time Measurements of Trichloroethylene in Domestic Bathrooms Using Contaminated Water."

Equation A-5: Calculation of Volatilization Factor for Water (VF _w)	
$VF_w = \frac{fF_w t}{V_a}$	
f	= Fraction Volatilization (0.75, (typical value ranges from 0.5-0.9))
F _w	= Water Flow Rate (771 L/hr, (50 th percentile, non-conserving shower heads))
t	= Time (0.25 hr, (50 th percentile))
V _a	= Bathroom Size (8.3 m ³ , (range of 8.3-9.8 m ³))
VF _w	= Volatilization Factor for Water (17.4 L/m ³)

The VF_w value determined by Equation A-5 can then be multiplied by the water concentration of a constituent (C_w) to yield the concentration of the constituent in air (C_a) as determined by Equation A-6. The C_a can then be used in the intake equations presented in A-7 and A-8 to calculate exposures from inhalation of contaminants while showering.

Equation A-6: Calculation of Concentration of Contaminant in Air	
$CA_w = VF_w \times C_w$	
CA _w	= Concentration of Contaminant in Air (mg/m ³)
VF _w	= Volatilization Factor for Water (L/m ³)
C _w	= Concentration of Contaminant in Water (mg/L)

Equation A-7: Inhalation of Airborne Chemicals While Showering Residential Scenario - Noncancer	
$\text{Intake (mg / kg - d)} = \frac{CA_w \times IW_c \times ET_c \times EFr \times ED_c}{BW_c \times AT_n}$	

Equation A-8: Inhalation of Airborne Chemicals While Showering Residential Scenario - Cancer	
$\text{Intake (mg / kg - d)} = \frac{CA_w \times \left(\frac{ED_c \times IW_c \times ET_c}{BW_c} + \frac{(ED_a - ED_c) \times IW_a \times ET}{BW_c} \right) \times EFr}{AT_c}$	
Note: This is an age-adjusted factor. Using the default exposure factors for a child and an adult, the bracketed term (InhFWadj) = 0.333 [m ³ -yr]/(kg-d)].	

2.2 Risk-Based Ground Water GCN Equations

Target risk-based ground water GCN concentrations found in Table A-3 are calculated using the equations listed below. Default exposure parameters from Table A-2 were used along with chemical-specific information found in Table A-5 in the generic calculations. The air concentrations associated with contaminated ground water are based on the equations presented in Equation A-6⁴ and the concentrations for ingestion of ground water are based on intake equations found in RAGS, Part A.

⁴ Andelman, J.B. (1990) "Total Exposure to Volatile Organic Compounds in Potable Water".

2.2.1 Ground Water Noncancer GCN Equations

Equation A-9: Calculation of ground water noncancer GCN for a volatile constituent that has both a RfDo and RfDi

$$\text{Concentration (mg/l)} = \frac{\text{THI}}{\left[\left(\frac{\left(\frac{\text{IRWc} \times \text{Efr} \times \text{EDc}}{\text{BWc} \times \text{ATn}} \right)}{\text{RfDo}} \right) + \left(\frac{\left(\frac{\text{SAWc} \times \text{PC} \times \text{ETc} \times \text{Efr} \times \text{EDc} \times \text{CFw}}{\text{BWc} \times \text{ATn}} \right)}{\text{RfDo} \times \text{O}_{\text{ABS}}} \right) + \left(\frac{\left(\frac{\text{IWc} \times \text{ETc} \times \text{Efr} \times \text{EDc} \times \text{VFw}}{\text{BWc} \times \text{ATn}} \right)}{\text{RfDi}} \right) \right]}$$

Equation A-10: Calculation of ground water noncancer GCN for a constituent that has a RfDo and is either non-volatile or does not have a RfDi

$$\text{Concentration (mg/l)} = \frac{\text{THI}}{\left[\left(\frac{\left(\frac{\text{IRWc} \times \text{Efr} \times \text{EDc}}{\text{BWc} \times \text{ATn}} \right)}{\text{RfDo}} \right) + \left(\frac{\left(\frac{\text{SAWc} \times \text{PC} \times \text{ETc} \times \text{Efr} \times \text{EDc} \times \text{CFw}}{\text{BWc} \times \text{ATn}} \right)}{\text{RfDo} \times \text{O}_{\text{ABS}}} \right) \right]}$$

Equation A-11: Calculation of ground water noncancer GCN for a constituent that is volatile, has a RfDi, and does not have a RfDo

$$\text{Concentration (mg/l)} = \frac{\text{THI}}{\left(\frac{\left(\frac{\text{IWc} \times \text{ETc} \times \text{Efr} \times \text{EDc} \times \text{VFw}}{\text{BWc} \times \text{ATn}} \right)}{\text{RfDi}} \right)}$$

2.2.2 Ground Water Cancer GCN Equations

Equation A-12: Calculation of ground water cancer GCN for a volatile constituent that has both a Sfo and Sfi.

$$\text{Concentration (mg / l)} = \frac{\text{TR}}{\left(\text{Sfo} \times \left(\frac{\left(\frac{\text{EDc} \times \text{IRWc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IRWa}}{\text{BWa}} \right) \times \text{Efr}}{\text{ATc}} \right) + \left(\frac{\text{Sfo}}{\text{O}_{\text{ABS}}} \right) \times \left(\frac{\left(\frac{\text{SAWc} \times \text{EDc} \times \text{ETc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{SAWa} \times \text{ETa}}{\text{BWa}} \right) \times \text{PC} \times \text{Efr} \times \text{CFw}}{\text{ATc}} \right) + \text{Sfi} \times \left(\frac{\left(\frac{\text{IWc} \times \text{EDc} \times \text{ETc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IWa} \times \text{ETa}}{\text{BWa}} \right) \times \text{Efr} \times \text{VFw}}{\text{ATc}} \right) \right)}$$

Equation A-13: Calculation of ground water cancer GCN for a constituent that has a Sfo and is either non-volatile or does not have a Sfi.

$$\text{Concentration (mg / l)} = \frac{\text{TR}}{\left(\text{Sfo} \times \left(\frac{\left(\frac{\text{EDc} \times \text{IRWc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IRWa}}{\text{BWa}} \right) \times \text{Efr}}{\text{ATc}} \right) + \left(\frac{\text{Sfo}}{\text{O}_{\text{ABS}}} \right) \times \left(\frac{\left(\frac{\text{SAWc} \times \text{EDc} \times \text{ETc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{SAWa} \times \text{ETa}}{\text{BWa}} \right) \times \text{PC} \times \text{Efr} \times \text{CFw}}{\text{ATc}} \right) \right)}$$

Equation A-14: Calculation of ground water cancer GCN for a constituent that is volatile, has a Sfi, and does not have a Sfo.

$$\text{Concentration (mg / l)} = \frac{\text{TR}}{\left(\text{Sfi} \times \left(\frac{\left(\frac{\text{IWc} \times \text{EDc} \times \text{ETc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IWa} \times \text{ETa}}{\text{BWa}} \right) \times \text{Efr} \times \text{VFw}}{\text{ATc}} \right) \right)}$$

2.3 Solubility

In order to meet the closure performance standard for a clean closure, all wastes must be removed from the closure unit. If a non-aqueous phase liquid (NAPL) is present, there is still waste present and decontamination is not possible unless the NAPL is removed. Therefore, a comparison is made between a chemical's solubility limits found in Table A-3 and the calculated risk-based GCNs. This ensures that if the risk-based GCN exceeds the solubility limit for a particular contaminant, then the solubility limit will be used as the generic cleanup number in lieu of the calculated risk-based GCN.

2.4 MCLs

The risk-based GCNs consider human exposure hazards to chemicals from contact with contaminated soils, air, and water. For water, additional numerical standards are available for many chemicals (e.g., MCLs, non-zero maximum contaminant level goals (MCLGs), and water quality standards (WQSs) for surface water). Table A-4 provides the MCL-based concentrations in ground water. When appropriate for a site, MCLs can be used as the cleanup standard.

2.5 Choosing the Generic Cleanup Number for Ground Water

If the use of MCLs is appropriate for the site, they should be used as the cleanup number when available. If MCLs are not appropriate for the site, the most conservative value, of either the cancer, noncancer, or solubility is used as the cleanup standard.

3.0 Soil - Migration to Ground Water

In this section you will find a description of the GCNs for soil that are protective of contaminants leaching into ground water, as well as a discussion on the correct Dilution Attenuation Factors (DAFs) to use. In addition, soil-water partitioning equations used to calculate the GCNs will be discussed, and finally, a description of how to select the most appropriate GCN will be given.

3.1 Dilution Attenuation Factor

Soil contamination may have the potential to leach and impact ground water resources above acceptable standards. Even if ground water contamination is not present, the future impact of contaminants remaining in soil is worthy of evaluation. One factor that must be considered is the degree of dilution and attenuation that may modify the leachate concentration as it migrates from the soil into the aquifer system. The effect of dilution and attenuation can be described through the use of a Dilution and Attenuation Factor (DAF). A DAF is defined as the ratio of contaminant concentration in soil leachate to the concentration in ground water at the receptor point. DHWM uses Soil Screening Guidance recommendations for applying DAFs. While Soil Screening Guidance equations allow for the calculation of site-specific DAF values, this generic approach allows for only two choices. A DAF of 1 assumes that little or no dilution or attenuation of leachates is occurring at a site. A DAF of 20 assumes that some dilution and/or attenuation of soil leachate is occurring at the unit. As a general guideline the following conditions would indicate the use of a DAF of 1 in site-specific risk assessments, or the use of GCNs from the 1 DAF column in Table A-3 or A-4 as appropriate:

- shallow water table
- sandy soil
- source size more than 30 acres
- hydraulic conductivity less than 1 darcy, 1E-03 cm/s, 1E-05 m/s, or 1E+02 gal/day/ft²

- any other conditions where little or no dilution or attenuation of soil leachate concentrations is expected.

If none of these conditions apply to the unit, then a 20 DAF may be used in site-specific risk assessments or GCNs may be selected from the 20 DAF column. If necessary, a site-specific dilution factor can be calculated using the methodology presented in Soil Screening Guidance or from *Vadose Zone Modeling in RCRA Closure guidance manual (2005)*.

3.2 Soil GCNs Protective of Leaching to Ground Water

The soil GCNs that take leachability into account are also protective of ground water. These GCNs were developed by first calculating cleanup numbers for ground water, or through the use of MCLs. Partitioning equations⁵ were then used to back-calculate soil GCNs based on the appropriate ground water standards. The soil GCNs are therefore protective of acceptable ground water concentrations based on the exposure pathways used in the calculations of the ground water cleanup number. It should be noted that these GCNs are also protective of any direct contact exposures to soil.

Migration of contaminants from soil to ground water can be envisioned as a two-stage process: (1) dissolving of the contaminant into soil solution and (2) transport of the contaminant to a receptor well. The GCNs for the contaminant migration to ground water considered both of these mechanisms and the GCNs were back-calculated from both MCLs and the lower of either solubility, or risk-based concentrations.

The GCN values are listed for a DAF of 1 and a DAF of 20. Justification for developing GCNs that correspond to DAF values of 1 and 20 is provided in Soil Screening Guidance and is based on data compiled by U.S. EPA. The partition equation (presented in Soil Screening Guidance document and below) was then used to calculate the total soil concentration (i.e., GCN) that corresponds to the leachate concentration. The methodology is based on conservative, simplifying assumptions about the release and transport of contaminants in the subsurface.

3.2.1 1 DAF GCNs

The more conservative GCNs are those calculated using a 1 DAF that assume no dilution or attenuation. Calculations of the 1 DAF GCN are based on ground water noncancer, ground water cancer, or solubility limits (Table A-3) and MCLs (Table A-4) as the target soil leachate concentration and is used in either Equation A-15 or A-16.

⁵ Partitioning equations can be found in Section 2.5 of U.S. EPA's (1996) Soil Screening Guidance: Technical Background Document.

3.2.1.1 Soil-Water Partitioning Equations

Below you will find the soil-water partitioning equations that are used to calculate the 1 DAF GCNs. More information on these equations can be found in Soil Screening Guidance.

Equation A-15: Soil-Water Partition Equation for Inorganic Contaminants	
$C_t = C_w \left(K_d + \frac{\theta_w + \theta_a H'}{\rho_b} \right)$	
C_t = Screening level in soil (mg/kg) C_w = Target soil leachate concentration (mg/L) K_d = Soil-water partition coefficient (L/kg)(Calculated from K_{oc} using $f_{oc}=0.002$) θ_w = Water-filled soil porosity (L_{water}/L_{soil})(0.3) θ_a = Air-filled soil porosity (L_{air}/L_{soil})(0.13) H' = Dimensionless Henry's law constant ρ_b = Dry soil bulk density (kg/L)(1.5)	
Equation Source: <i>Soil Screening Guidance: Technical Background Document</i> , Equation 22.	

Equation A-16: Soil-Water Partition Equation for Organic Contaminants	
$C_t = C_w \left((K_{oc} f_{oc}) + \frac{\theta_w + \theta_a H'}{\rho_b} \right)$	
C_t = Screening level in soil (mg/kg) C_w = Target soil leachate concentration (mg/L) K_{oc} = Soil organic carbon-water partition coefficient (L/kg) f_{oc} = Organic carbon content of soil (kg/kg)(0.002) θ_w = Water-filled soil porosity (L_{water}/L_{soil})(0.3) θ_a = Air-filled soil porosity (L_{air}/L_{soil})(0.13) H' = Dimensionless Henry's law constant ρ_b = Dry soil bulk density (kg/L)(1.5)	
Equation Source: <i>Soil Screening Guidance: Technical Background Document</i> , Equation 24.	

3.2.1.2 Choosing the GCN for Soil That is Protective of Leaching

The partitioning equations presented above can use a risk-based ground water concentration, a MCL, or a solubility level to calculate the GCNs. Risk-based values are also compared to Direct Contact GCNs to ensure that the DAF GCNs will be protective of the soil pathways. Because individual GCNs can be used as cleanup levels, the most appropriate of either the MCL-based, or the most conservative value, of either the cancer, noncancer, solubility-based 1 DAF GCN, or direct contact value should be used.

3.2.2 20 DAF GCNs

As discussed earlier in this document a DAF of 20 assumes that some dilution and attenuation is occurring at the site. Therefore, the GCN that uses a DAF of 20 also makes the assumption that some dilution and/or attenuation of soil leachates is occurring at the unit. The GCNs are calculated by multiplying the available 1 DAF GCNs by a DAF of 20 as shown in Equation A-17 found below.

Equation A-17: Calculation of 20 DAF Generic Cleanup Number		
$\text{Concentration (mg / kg)} = C_t \times \text{DAF}$		
C_t	=	Screening level in soil (mg/kg) from Equation L-12 or L-13
DAF	=	20 (unitless)

3.2.2.1 Choosing the GCN for Soil That is Protective of Leaching

As stated several times in previous sections, either the MCL-based 20 DAF GCN, or the lowest of either the cancer, noncancer, solubility-based 20 DAF GCN, or direct contact value, whichever is most appropriate, is used as the cleanup number.

4.0 Direct Contact GCNs

In this section the reader will find descriptions of the soil pathways that are used to generate the risk-based GCNs and those intake equations that are relevant for those pathways. A discussion of Diffusivity (Da), the Volatilization Factor (VF), development of soil cancer and non-cancer GCNs, and the correct evaluation of soil saturation limits and how they relate to risk-based GCNs are presented. The equations used to calculate these terms are also presented to provide the reader with some necessary background information. The GCNs for direct contact with soil were developed based upon the following routes of residential exposure:

- ingestion of contaminated soil,
- dermal contact with contaminated soil, and
- inhalation of volatiles and particulates from contaminated soil.

The direct contact soil GCNs should be used only if ground water is not likely to be impacted because these GCNs do not consider impacts to ground water. If it is unknown whether ground water could be impacted, the reader is referred to Appendix E of this document for guidance. If it is determined that the upper most aquifer may be impacted, the appropriate GCNs that are protective of leaching into ground water should be used (see Table A-3 or A-4).

Information may be present that can be used to develop site-specific risk-based GCNs for direct contact with contaminated soil. If site-specific GCNs are developed, the reader should note that the equations and default values presented for many of the variables in this appendix were adopted from the Soil Screening Guidance. Default parameters for other soil types can also be substituted into these equations. DHWM recommends that soil specific defaults, found in Vadose Zone Modeling in RCRA Closure, be used for site-specific GCN development. It is the responsibility of the facility to properly document all site-specific values used to develop site-specific GCNs.

4.1 Direct Contact Pathways

4.1.1 Soil - Ingestion

Calculations of risk-based GCNs for direct ingestion of soil are based primarily on the methodology presented in RAGS, Part B. This methodology back-calculates a protective soil concentration level from a target risk (for carcinogens) or hazard quotient (for noncarcinogens). A number of studies have shown that inadvertent ingestion of soil is common among children six years old and younger.⁶ Therefore, the approach includes an age-adjusted soil ingestion factor that takes into account the difference in daily soil ingestion rates, body weights, and exposure duration for children from zero to six years old and other persons from ages 7 to 31. The higher intake rate of soil by children combined with their lower body weights results in a lower, or more conservative, risk-based GCN as compared to an adult-only assumption.

Equation A-18: Ingestion of Chemicals in Soils and Dust Residential Scenario - Noncancer	
$\text{Intake}(\text{mg} / \text{kg} - \text{d}) = \frac{\text{CS} \times \text{EDc} \times \text{IRSc} \times \text{CFs} \times \text{FI} \times \text{Efr}}{\text{BWc} \times \text{ATn}}$	
Equation A-19: Ingestion of Chemicals in Soils and Dust Residential Scenario - Cancer	
$\text{Intake}(\text{mg} / \text{kg} - \text{d}) = \frac{\text{CS} \times \left(\frac{\text{EDc} \times \text{IRSc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IRSa}}{\text{BWa}} \right) \times \text{CFs} \times \text{FI} \times \text{Efr}}{\text{ATc}}$	
Note: This formula contains an age-adjusted ingestion factor. Using the default exposure parameters for a child and an adult, the bracketed term (IFSadj) = 114.286 [(mg-yr)/(kg-d)].	

4.1.2 Soil - Dermal Absorption

Much uncertainty surrounds the determination of hazards associated with skin contact with soils. One important data gap is the lack of U.S. EPA verified toxicity values for the dermal route of exposure. For the purpose of developing GCNs, it is assumed that dermal toxicity values can be route-to-route extrapolated from oral values. To perform the adjustment, oral RfDs are multiplied by the oral absorption factor for that specific chemical. For carcinogens, oral slope factors are divided by the oral absorption factor for that chemical. Consequently, all dermal toxicity values that are extrapolated from oral values have been calculated with an oral absorption factor (Table A-5). Default exposure values for dermal contact with soil have recently changed for two parameters: 1) skin surface area and 2) soil adherence. The currently recommended exposed surface areas are 5700 and 2800 cm²/day for adults and children, respectively. The currently recommended adherence factors are 0.07 and 0.2 mg/cm² for adults and children, respectively. More information on the dermal pathway and the justification for these changes are explained in detail in RAGS, Part E.

⁶ Calabrese, E.J., R. Barnes, E.J. Stanek, H. Pastides, C.E. Gilbert, P. Veneman, X. Wang, A. Lasztity, P.T. Kostek. (1989) "How Much Soil Do Young Children Ingest: An Epidemiologic Study", Davis, S., P. Walker. (1990) "Quantitative Estimates of Soil Ingestion in Normal Children Between the Ages of 2 and 7 Years: Population-base Estimates Using Aluminum, Silicon, and Titanium as Soil Tracer Elements", and Van Wijnen, J.H., P. Clausen, B. Brunekreef. (1990) "Estimated Soil Ingestion by Children".

Equation A-20: Dermal Contact With Chemicals in Soil Residential Scenario - Noncancer	
$\text{Absorbed Dose (mg / kg - d)} = \frac{\text{CS} \times \text{CFs} \times \text{SASc} \times \text{AFc} \times \text{ABS} \times \text{Efr} \times \text{EDc}}{\text{BWc} \times \text{ATn}}$	
Equation A-21: Dermal Contact With Chemicals in Soil Residential Scenario - Cancer	
$\text{Absorbed Dose (mg / kg - d)} = \frac{\text{CS} \times \text{CFs} \times \left(\frac{\text{EDc} \times \text{AFc} \times \text{SASc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{AFa} \times \text{SASa}}{\text{BWa}} \right) \times \text{ABS} \times \text{Efr}}{\text{ATc}}$	
<p>Note: This is an age-adjusted factor. Using the default exposure factors for a child and an adult, the bracketed term (SFSadj) = 360.8 [(mg-yr)/(kg-d)].</p>	

4.1.3 Soil - Inhalation

A review of toxicity data suggests that some chemicals pose a significant inhalation risk; therefore, risk-based soil GCNs also account for this route of exposure. The models used to calculate risk-based GCNs for inhalation of volatiles/particulates are updates of risk assessment methods presented in RAGS, Part B and are consistent with Soil Screening Guidance and the equations presented in this appendix. Please note that this pathway and the volatilization equations within this section do not account for vapor intrusion into buildings and must be addressed separately.

To address the soil-to-air pathways, the risk-based GCNs incorporate Volatilization Factors (VFs) for volatile and semivolatile contaminants and Particulate Emission Factors (PEFs) for all contaminants. These factors relate soil contaminant concentrations to air contaminant concentrations that may be inhaled on-site. The VF and PEF equations can be considered as two separate models: an emission model to estimate the release of volatile contaminants from the soil and a dispersion model to simulate the disbursement of a contaminant via particles in the atmosphere.

It should be noted that the box model in RAGS, Part B has been replaced with a dispersion term (Q/C in g/m²-s per kg/m³) derived from a modeling exercise using meteorological data from 29 locations across the United States. The Box model in RAGS may not be applicable to a broad range of site types and meteorology and does not use techniques developed for dispersion modeling by U.S. EPA. The dispersion model used in this guidance for both volatiles and particulates is the AREA-ST, an updated version of the Office of Air Quality Planning and Numbers, Industrial Source Complex Model (ISC3). This model, along with its user's guide, can be found at http://www.epa.gov/scram001/dispersion_alt.htm. However, DHWM has modified this model and uses different Q/C terms in the VF and PEF equations. DHWM has chosen to use Los Angeles as the 90th percentile data set for volatiles and Minneapolis as the 90th percentile data set for fugitive dusts. These are the defaults presented in Soil Screening Guidance, as updated in U.S. EPA's Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites, which allows for a conservative estimate of Q/C for use in the risk-based GCNs. In addition, a default source size of 0.5 acres was chosen for the GCN calculations which is consistent with the area over which DHWM typically averages contaminant concentrations at closure sites. You can also find U.S. EPA's Compilation of Emission Factors at <http://www.epa.gov/ttn/chief/ap42/>. If unusual site conditions exist such that the area source is substantially larger than the default source size, then an alternative Q/C should be applied and the risk-based GCNs in Table A-3 should not be used.⁷

⁷ U.S. EPA (1996) *Soil Screening Guidance: Technical Background Document*

4.1.3.1 Calculations of Intake Via Inhalation of Soil Contaminated With Volatile Organics

Of major importance in developing risk-based standards is the necessity to account for exposure to receptors by chemicals from all potential exposure pathways. Thus, intake of chemicals via the inhalation pathway should account for exposure to volatile (and some semi-volatile) chemicals transported in the vapor phase. At a minimum, any volatile and semi-volatile chemicals that have a Henry's Law Constant greater than 1E-05 (atm-m³/mol) and a molecular weight less than 200 g/mol require calculation of a Volatilization Factor (VF). To calculate exposure to vapor phase chemicals, an Apparent Diffusivity value (D_A) should first be calculated as detailed in Equation A-22.

Equation A-22: Calculation of Apparent Diffusivities (D _A)	
$D_A = \frac{\left((\theta_a^{10/3} \times D_i \times H') + (\theta_w^{10/3} \times D_w) \right) / n^2}{\rho_b K_d + \theta_w + \theta_a H'}$	
D _A	= Apparent diffusivity (cm ² /s)
θ _a	= Air-filled soil porosity (L _{air} /L _{soil})(0.28)
D _i	= Diffusivity in air (cm ² /s)(chemical specific)
H'	= Henry's Law Constant (dimensionless)(chemical specific)
θ _w	= Water-filled soil porosity (L _{water} /L _{soil})(0.15)
D _w	= Diffusivity in water (cm ² /s)(chemical specific)
n	= Total soil porosity (L _{pore} /L _{soil})(0.43)
ρ _b	= Dry soil bulk density (g/cm ³)(1.5)
K _d	= Soil to water partition coefficient (cm ³ /g) (chemical specific)
Equation Source: <i>Soil Screening Guidance: Technical Background Document</i> , Equation 6.	

The reader should note that chemical-specific values for D_i, H_N, and D_w, can also be found in the Soil Screening Guidance, Vadose Zone Modeling in RCRA Closure manual, or other peer-reviewed sources. In cases where Diffusivity Coefficients (D_i) are not provided in existing literature, D_i values can be calculated using Fuller's Method, as described in U.S. EPA's (1988) Superfund Exposure Assessment Manual (SEAM). Also, a surrogate value may be used for some chemicals that lack physical or chemical information. In such cases, a proxy chemical of similar structure should be used. If other default parameters are used for Equation A-22, a complete assessment and source citation of the appropriateness of the default parameters should be provided.

Note: K_d = K_{oc} x f_{oc}; where K_{oc} = soil organic carbon/water partition coefficient (chemical specific) and f_{oc} = organic carbon content of soil. The CPRG default values for f_{oc} are dependent upon application; for surficial soil applications (such as this one) a value of 0.6% is used, while for subsurface applications a value of 0.2% is used. Chapter 5 of Soil Screening Guidance discusses input parameters for modeling the movement of contaminants through the vadose zone. The information in this text indicates that an f_{oc} of 0.002 g/g (0.2%) is recommended because it, "better reflected average subsurface conditions at Superfund Sites. This value is approximately equal to the high value of organic carbon used in the HWIR modeling effort." Earlier in soil screening guidance, a 0.006 g/g (0.6%) default is used. Soil Screening Guidance cites the source for this default as Carsel and Parish (1988).⁸ This study suggests that this f_{oc} default value is applicable to the top 0.3 m of Class B soils. Class B soils

⁸ Carsel, R.F. and R.S. Parrish. (1988) Developing Joint Probability Distributions of Soil Water Retention Characteristics. *Water Resources Research*. 24(5):755-769.

are soils with moderate hydrologic characteristics whose average characteristics are well represented by a loam soil type. The use of this higher foc value is discussed as part of evaluating the volatilization factor in Soil Screening Guidance (page 25). However, the Soil Screening Guidance also uses the default 0.006 g/g foc value when determining soil saturation concentrations (C_{sat}). It must be noted that DHWM did not adopt this default value for foc. When calculating C_{sat}, DHWM is generally evaluating contamination beneath “the top 0.3 m of soil” and therefore has adopted a default value of 0.002 g/g for foc when calculating C_{sat}.

4.1.3.2 Volatilization Factor for Soils

Once a value for D_A has been calculated, a volatilization factor can be calculated as in Equation A-23 below. This soil-to-air volatilization factor is used to define the relationship between concentration of chemicals found in the soil and the volatilized contaminants in air.

Equation A-23: Calculation of Volatilization Factor (VF)	
$VF = \frac{Q}{C} \times \frac{(3.14 \times D_A \times T)^{1/2}}{(2 \times \rho_b \times D_A)} \times 10^{-4}$	
VF	= Volatilization Factor (m ³ /kg)
Q/C	= Inverse of the mean concentration at the center of a square source (g/m ² -s per kg/m ³)(68.81)
D _A	= Apparent diffusivity (cm ² /s)(from Equation J-1)
T	= Exposure Interval (residential = 9.5E+08)
ρ _b	= Dry soil bulk density (g/cm ³)(1.5)
Equation Source: <i>Soil Screening Guidance: Technical Background Document</i> , Equation 6.	

The VF term forms the basis for deriving risk-based soil GCNs for the inhalation pathway. The VF model is valid only if the soil contaminant concentration is at or below soil saturation. Above this level, the model cannot predict an accurate VF-based GCN, this is one reason the GCN values are set at or below these saturation levels. The reader should be aware that some chemicals may be solid at ambient temperatures. For these situations, a VF-based GCN cannot be determined.

Volatile chemicals are screened for inhalation exposures using a volatilization factor for soils (VF). The emission terms used in the VF are chemical-specific and were calculated from physical-chemical information obtained from several sources. The priority of these sources was as follows: Soil Screening Guidance, National Library of Medicine (Toxnet), U.S. EPA Region IV physical property values, and other sources which include U.S. EPA's (1996) *Superfund Chemical Data Matrix*, *Handbook of Environmental Fate and Exposure Data for Organic Chemicals* (P.H. Howard, Ed.;1989) U.S. EPA's (1991) *Subsurface Contamination Reference Guide*, and U.S. EPA's (1988) *Superfund Exposure Assessment Manual* (SEAM). A surrogate term may be required for some chemicals that lack physical-chemical information. In such cases, a chemical of similar structure and molecular weight can be substituted.

4.1.3.3 Calculation of Intake Via Inhalation of Particulates from Contaminated Soil - Particulate Emission Factor for Soils

The inhalation pathway also must account for inhalation of contaminants adhering to particulates. This exposure is addressed by determining a Particulate Emission Factor (PEF), which is calculated using Equation A-24. For the purposes of calculating the risk-based GCNs, inhalation of chemicals adsorbed to particles was assessed using a default PEF equal to 1.36E+09 m³/kg. This default value relates the contaminant concentration in soil with the

concentration of particles in the air due to fugitive dust emissions from contaminated soils. The generic PEF was derived using default values presented in Soil Screening Guidance (as updated by U.S. EPA's Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites) based on the relationship derived by Cowherd(1985) in Measurement of Particulate Emissions from Hazardous Waste Disposal Sites. This document expresses the assumptions and default values for a rapid assessment procedure applicable to a typical hazardous waste site where contamination in surface soil provides a relatively continuous and constant potential for emission over an extended period of time. This procedure will present an annual average emission rate based on wind erosion that should be compared with chronic health criteria. It is not appropriate for evaluating the potential for more acute exposures.

Equation A-24: Calculation of Particulate Emission Factor (PEF)		
$PEF = \frac{Q}{C} \times \frac{3600}{0.036 \times (1 - V) \times (U_m / U_t)^3 \times F_x}$		
PEF	=	Particulate Emission Factor (m ³ /kg)
Q/C	=	Inverse of the mean concentration at the center of a square source (g/m ² -s per kg/m ³)(93.77)
V	=	Fraction of vegetative cover (unitless)(0.50)
U _m	=	Mean annual windspeed (m/s)(4.69)
U _t	=	Equivalent threshold value of windspeed at 7m (m/s)(11.32)
F _x	=	Function dependent on U _m /U _t (unitless)(0.194)
Equation Source: <i>Soil Screening Guidance: Technical Background Document</i> , Equation 10.		

Note: The generic PEF applies to windborne emissions. It does not take into consideration dust emissions from traffic or other forms of mechanical disturbance that could lead to greater emissions than assumed here. With the exception of specific heavy metals, the PEF does not appear to significantly affect most risk-based soil GCNs. For more details regarding specific parameters used in the PEF model, the reader is referred to Soil Screening Guidance and U.S. EPA's Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Once the PEF and VF have been calculated, the concentration in air (CAs) term in Equations A-25 and A-26, can be calculated by dividing the concentration in soil (CS) term, expressed in mg/kg, by the VF (where appropriate for inhalation of volatiles) and/or by the PEF (where appropriate for the inhalation of particles).

Equation A-25: Inhalation of Volatiles and Particulates From Contaminated Soil Residential Scenario- Noncancer	
$\text{Intake (mg / kg - d)} = \frac{CAs \times IRAc \times EFr \times EDc}{BWc \times ATn}$	
Equation A-26: Inhalation of Volatiles and Particulates From Contaminated Soil Residential Scenario- Cancer	
$\text{Intake(mg / kg - d)} = \frac{CAs \times \left(\frac{EDc \times IRAc}{BWc} + \frac{(EDa - EDc) \times IRAc}{BWa} \right) \times EFr}{ATc}$	
Note: This is an age-adjusted factor. Using the default exposure factors for a child and an adult, the bracketed term (InhFSadj) = 10.857 [(m ³ -yr)/(kg-d)].	

4.2 Soil Saturation Concentration

The soil saturation concentration (C_{sat}) corresponds to the concentration where the soil contaminant may be present in a pure phase (i.e., nonaqueous phase liquids (NAPLs)). The soil saturation concentration equation presented in Equation A-27 is used to calculate C_{sat} for each volatile contaminant that has a risk-based GCN. As an update to RAGS, Part B, this equation takes into account the amount of a contaminant that is in the soil vapor phase in addition to the amount dissolved in the soil pore water and sorbed to soil particles.

In some instances risk-based soil cleanup levels may exceed soil saturation concentrations. Under these conditions, it is possible that health hazards and hazardous waste characteristics beyond chemical toxicity (e.g., ignitability) may exist. Moreover, the ability to accurately predict receptor intake levels from free phase chemical contamination based upon any of the preceding mathematical models (e.g., the VF equation) becomes highly problematic and is not acceptable. Therefore, chemical-specific C_{sat} values must be compared with each risk-based GCN. If the risk-based GCN exceeds the soil saturation concentration for a particular contaminant, then the soil saturation concentration must be used as the GCN in lieu of the risk-based number.

Equation A-27: Calculation of Soil Saturation Concentration		
$C_{\text{sat}} = \frac{S}{\rho_b} (K_d \rho_b + \theta_w + H' \theta_a)$		
C_{sat}	=	Soil saturation concentration (mg/kg)
S	=	Solubility in water (mg/L)(chemical-specific)
ρ_b	=	Dry soil bulk density (kg/L)(default $\rho_b = 1.5$)
K_d	=	Soil-water partition coefficient (L/kg) ⁹
θ_w	=	Water-filled soil porosity ($L_{\text{water}}/L_{\text{soil}}$)(default $\theta_w = 0.15$)
H'	=	Henry's Law Constant (dimensionless)(chemical-specific)
θ_a	=	Air-filled soil porosity ($L_{\text{air}}/L_{\text{soil}}$)(default $\theta_a = 0.28$)
Equation Source: <i>Soil Screening Guidance: Technical Background Document</i> , Equation 9.		

4.3 Direct Contact GCN Equations

The following equations are used to calculate the actual GCNs that are presented in Table A-3. Target soil concentrations found in Table A-3 are calculated for dermal contact with contaminants, inhalation of volatile contaminants and particulates from soil, and ingestion of soil in a residential scenario. Default exposure parameters from Table A-2 were used along with chemical-specific information in the generic calculations.

⁹ $K_d = K_{oc} \times f_{oc}$; where K_{oc} = soil organic carbon/water partition coefficient and f_{oc} = organic carbon content of soil. The CPRG default values for f_{oc} are dependent upon application; for surficial soil applications a value of 0.6% is used, while for subsurface applications (such as this one usually is) a value of 0.2% is used.

4.3.1 Direct Contact Noncancer GCN Equations

Equation A-28: Calculation of direct contact noncancer GCN for a constituent that has both a RfDo and RfDi.

$$\text{Concentration (mg / kg)} = \frac{\text{THI}}{\left[\left(\frac{\left(\frac{\text{EDc} \times \text{IRSc} \times \text{CFs} \times \text{FI} \times \text{Efr}}{\text{BWc} \times \text{ATn}} \right)}{\text{RfDo}} \right) + \left(\frac{\left(\frac{\text{CFs} \times \text{SASc} \times \text{AFc} \times \text{ABS} \times \text{Efr} \times \text{EDc}}{\text{BWc} \times \text{ATn}} \right)}{(\text{RfDo} \times \text{OABS})} \right) + \left(\frac{\left(\frac{\text{IRAc} \times \text{Efr} \times \text{EDc} \times \left(\frac{1}{\text{PEF}} + \frac{1}{\text{VF}} \right)}{\text{BWc} \times \text{ATn}} \right)}{\text{RfDi}} \right) \right]}$$

Equation A-29: Calculation of direct contact noncancer GCN for a constituent that has a RfDo and does not have a RfDi.

$$\text{Concentration (mg / kg)} = \frac{\text{THI}}{\left[\left(\frac{\left(\frac{\text{EDc} \times \text{IRSc} \times \text{CFs} \times \text{FI} \times \text{Efr}}{\text{BWc} \times \text{ATn}} \right)}{\text{RfDo}} \right) + \left(\frac{\left(\frac{\text{CFs} \times \text{SASc} \times \text{AFc} \times \text{ABS} \times \text{Efr} \times \text{EDc}}{\text{BWc} \times \text{ATn}} \right)}{(\text{RfDo} \times \text{OABS})} \right) \right]}$$

Equation A-30: Calculation of direct contact noncancer GCN for a constituent that has is volatile, has a RfDi, and does not have a RfDo.

$$\text{Concentration (mg / kg)} = \frac{\text{THI}}{\left(\frac{\left(\frac{\text{IRAc} \times \text{Efr} \times \text{EDc} \times \left(\frac{1}{\text{PEF}} + \frac{1}{\text{VF}} \right)}{\text{BWc} \times \text{ATn}} \right)}{\text{RfDi}} \right)}$$

4.3.2 Direct Contact Cancer GCN Equations

Equation A-31: Calculation of direct contact cancer GCN for a constituent that has a Sfo and a Sfi.

$$\text{Conc(mg/kg)} = \frac{\text{TR}}{\left[\text{Sfo} \times \left(\frac{\text{EDc} \times \text{IRSc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IRa}}{\text{BWa}} \right) \times \text{CFs} \times \text{FI} \times \text{Efr} \right] + \left[\frac{\text{Sfo}}{\text{O}_{\text{ABS}}} \times \left(\frac{\text{EDc} \times \text{AFc} \times \text{SASc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{AFa} \times \text{SASa}}{\text{BWa}} \right) \times \text{ABS} \times \text{Efr} \times \text{CFs} \right] + \left[\text{Sfi} \times \left(\frac{\text{EDc} \times \text{IRAc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IRaA}}{\text{BWa}} \right) \times \text{Efr} \times \left(\frac{1}{\text{PEF}} + \frac{1}{\text{VF}} \right) \right]}$$

Equation A-32: Calculation of direct contact cancer GCN for a constituent that has a Sfo and does not have a Sfi.

$$\text{Concentration(mg/kg)} = \frac{\text{TR}}{\left[\text{Sfo} \times \left(\frac{\left(\frac{\text{EDc} \times \text{IRAc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IRSa}}{\text{BWa}} \right) \times \text{CFs} \times \text{FI} \times \text{Efr}}{\text{ATc}} \right) + \left(\frac{\text{Sfo}}{\text{O}_{\text{ABS}}} \times \left(\frac{\left(\frac{\text{EDc} \times \text{AFc} \times \text{SASc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{AFa} \times \text{SASa}}{\text{BWa}} \right) \times \text{ABS} \times \text{Efr} \times \text{CFs}}{\text{ATc}} \right) \right]}$$

Equation A-33: Calculation of direct contact cancer GCN for a constituent that has a Sfi, and does not have a Sfo.

$$\text{Concentration(mg/kg)} = \frac{\text{TR}}{\left[\text{Sfi} \times \left(\frac{\left(\frac{\text{EDc} \times \text{IRAc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IRaA}}{\text{BWa}} \right) \times \text{Efr} \times \left(\frac{1}{\text{PEF}} + \frac{1}{\text{VF}} \right)}{\text{ATc}} \right) \right]}$$

4.4 Choosing the Cleanup Number - Residential Scenario

When choosing the most appropriate GCN the most conservative value is always used. The chosen GCNs are either the cancer or noncancer risk-based GCN, or the soil saturation concentration.

4.5 Choosing the Cleanup Number - Industrial Scenarios

As stated in Chapter 6, DHWM allows the consideration of reasonably-expected future land use as a factor in developing a project's data quality objectives and cleanup standards. In an industrial use scenario, industrial exposure assumptions must be developed to generate cleanup standards. A basic premise on the use of industrial exposure cleanup standards is that the assumptions used to generate the standards must be achieved throughout the closing unit. In addition, industrial exposure cleanup standards need to be tailored to the future use of the site. These standards should not be used unless there is significant confidence that the future land use will conform to the exposure assumptions used to calculate the cleanup standards. To ensure that future use of the site is consistent with the developed industrial use cleanup standards, an environmental covenant must be in place for the closing unit. Environmental Covenants are discussed further in Chapter 6 Section 6.2. Equations A-34 through A-36 are the intake equations that can be used to calculate cleanup standards for industrial use scenarios. The default exposure parameters for industrial use scenarios can be found in Table A-2.

Equation A-34: Ingestion of Chemicals in Soils and Dust Industrial Scenario
Noncancer & Cancer $\text{Intake (mg/kg-d)} = \frac{\text{CS} \times \text{EDi} \times \text{IRSi} \times \text{CFs} \times \text{FI} \times \text{EFi}}{\text{BWa} \times \text{AT}}$
Equation A-35: Dermal Contact With Chemicals in Soil Industrial Scenario
Noncancer & Cancer $\text{Absorbed Dose(mg/kg-d)} = \frac{\text{CS} \times \text{CFs} \times \text{SASi} \times \text{AFa} \times \text{ABS} \times \text{EFi} \times \text{EDi}}{\text{BWa} \times \text{AT}}$
Equation A-36: Inhalation of Volatiles and Particulates From Contaminated Soil Industrial Scenario
Noncancer & Cancer $\text{Intake (mg/kg-d)} = \frac{\text{CAs} \times \text{IRAi} \times \text{EFi} \times \text{EDi}}{\text{BWa} \times \text{AT}}$

5.0 Generic Cleanup Number Sample Calculations

This section presents an example of how to use the equations and default assumptions to calculate risk-based GCNs. To illustrate the proper calculation of GCNs, benzene was chosen as a typical chemical of concern. Benzene is an ideal chemical to use as an example because it has a risk-based GCN for each of exposure pathways represented in Table A-3. Example calculations are shown to generate a single chemical noncancer and cancer GCNs for ground water, and single chemical direct contact noncancer and cancer soil GCNs.

It should be noted that in order to recreate the GCNs exactly as presented at the end of this appendix, there can be no rounding of intermediate values in the GCN equations. All values in

the GCN tables were calculated with Excel and it uses six to eight significant figures in calculations, but then truncates the final number. The GCNs are listed with three significant figures for ease of use and general appearance. Below is a table that lists the defaults and chemical specific input variables used to calculate the GCNs for Benzene. A complete list of default exposure factors and their definitions can be found in Table A-2 and chemical-specific default values are in Table A-5.

Table A-1: Input Variables for Calculating Risk-Based GCNs for Benzene			
Symbol	Value & Units	Symbol	Value & Units
RfDo	4.0E-03 (mg/kg-day)	ETc	1 hour
RfDi	8.57E-03 (mg/kg-day)	FI	1
Sfo	5.5E-02 (mg/kg-day) ⁻¹	IRAA	20 m ³ /day
Sfi	2.7E-02 (mg/kg-day) ⁻¹	IRAc	10 m ³ /day
TR	0.00001	IRSa	100 mg/day
THI	1.0	IRSc	200 mg/day
ABS	0.01	IRWa	2 L/day
AFa	0.07 mg/cm ²	IRWc	1 L/day
AFc	0.2 mg/cm ²	IWa	0.83 m ³ /hr
ATc	25550 days	IWc	0.42 m ³ /hr
ATn	2190 days	Oabs	0.9
BWa	70	PC	1.47E-02 cm/hr
BWc	15 kg	PEF	1.36E+09 m ³ /kg
CFs	0.000001	SASa	5700 cm ²
CFw	0.001	SASc	2800 cm ²
EDa	30 years	SAWa	18000 cm ²
EDc	6 years	SAWc	6600 cm ²
EFr	350 days/year	VF	2,714 m ³ /kg
ETa	0.58 hours	VFw	17.4 m ³ /kg

Exhibit A-1: Calculation of ground water noncancer GCN for benzene

$$GCN(mg/l) = \frac{THI}{\left[\left(\frac{\left(\frac{IRWc \times EFr \times EDc}{BWc \times ATn} \right)}{RfDo} \right) + \left(\frac{\left(\frac{SAWc \times PC \times ETc \times EFr \times EDc \times CFw}{BWc \times ATn} \right)}{RfDo \times O_{ABS}} \right) + \left(\frac{\left(\frac{IWc \times ETc \times EFr \times EDc \times VFw}{BWc \times ATn} \right)}{RfDi} \right) \right]}$$

$$GCN(mg/l) = \frac{1.0}{\left[\left(\frac{\left(\frac{1 \times 350 \times 6}{15 \times 2190} \right)}{0.004} \right) + \left(\frac{\left(\frac{6600 \times 0.0147 \times 1 \times 350 \times 6 \times 0.001}{15 \times 2190} \right)}{0.004 \times 0.9} \right) + \left(\frac{\left(\frac{0.42 \times 1 \times 350 \times 6 \times 17.4}{15 \times 2190} \right)}{0.00857} \right) \right]}$$

GCN = 1.38 E-2 mg/l

Exhibit A-2: Calculation of ground water cancer GCN for benzene

$$GCN(mg/l) = \frac{TR}{\left(Sfo \times \left(\frac{\left(\frac{EDc \times IRWc}{BWc} + \frac{(EDa - EDc) \times IRWa}{BWa} \right) \times EFr}{ATc} \right) + \left(\frac{Sfo}{O_{ABS}} \times \left(\frac{\left(\frac{SAWc \times EDc \times ETc}{BWc} + \frac{(EDa - EDc) \times SAWa \times ETa}{BWa} \right) \times PC \times EFr \times CFw}{ATc} \right) + Sfi \times \left(\frac{\left(\frac{IWc \times EDc \times ETc}{BWc} + \frac{(EDa - EDc) \times IWa \times ETa}{BWa} \right) \times EFr \times VFw}{ATc} \right) \right) \right)}$$

$$GCN(mg/l) = \frac{0.00001}{\left(0.055 \times \left(\frac{\left(\frac{6 \times 1}{15} + \frac{(30 - 6) \times 2}{70} \right) \times 350}{25550} \right) + \left(\frac{0.055}{0.9} \times \left(\frac{\left(\frac{6600 \times 6 \times 1}{15} + \frac{(30 - 6) \times 18000 \times 0.58}{70} \right) \times 0.0147 \times 350 \times 0.001}{25550} \right) + 0.0273 \times \left(\frac{\left(\frac{0.42 \times 6 \times 1}{15} + \frac{(30 - 6) \times 0.83 \times 0.58}{70} \right) \times 350 \times 17.4}{25550} \right) \right) \right)}$$

GCN = 3.27 E-3 mg/l

Exhibit A-3: Calculation of direct contact noncancer GCN for benzene

$$GCN(mg/kg) = \frac{THI}{\left[\left(\frac{\left(\frac{EDc \times IRSc \times CFs \times FI \times EFr}{BWc \times ATn} \right)}{RfDo} \right) + \left(\frac{\left(\frac{CFs \times SASc \times AFc \times ABS \times EFr \times EDc}{BWc \times ATn} \right)}{(RfDo \times OABS)} \right) + \left(\frac{\left(\frac{IRAc \times EFr \times EDc \times \left(\frac{1}{PEF} + \frac{1}{VF} \right)}{BWc \times ATn} \right)}{RfDi} \right) \right]}$$

$$GCN(mg/kg) = \frac{1.0}{\left[\left(\frac{\left(\frac{6 \times 200 \times 0.000001 \times 1 \times 350}{15 \times 2190} \right)}{0.004} \right) + \left(\frac{\left(\frac{0.000001 \times 2800 \times 0.2 \times 0.01 \times 350 \times 6}{15 \times 2190} \right)}{(0.004 \times 0.9)} \right) + \left(\frac{\left(\frac{10 \times 350 \times 6 \times \left(\frac{1}{1360000000} + \frac{1}{2714} \right)}{15 \times 2190} \right)}{0.00857} \right) \right]}$$

GCN= 32.5 mg/kg

Exhibit A-4: Calculation of direct contact cancer GCN for benzene

$$\text{Conc(mg/kg)} = \left[\left(\text{Sfo} \times \left(\frac{\text{EDc} \times \text{IRSc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IRA}}{\text{BWa}} \times \text{CFs} \times \text{FI} \times \text{EFr} \right) \right) + \left(\frac{\text{Sfo}}{\text{O}_{\text{ABS}}} \times \left(\frac{\text{EDc} \times \text{AFc} \times \text{SASc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{AFa} \times \text{SASa}}{\text{BWa}} \right) \times \text{ABS} \times \text{EFr} \times \text{CFs} \right) \right] + \left[\text{Sfix} \times \left(\frac{\text{EDc} \times \text{IRAc}}{\text{BWc}} + \frac{(\text{EDa} - \text{EDc}) \times \text{IRaA}}{\text{BWa}} \right) \times \text{EFr} \times \left(\frac{1}{\text{PEF}} \right) + \left(\frac{1}{\text{VF}} \right) \right]$$

$$\text{GCN(mg/kg)} = \left[\left(0.055 \times \left(\frac{6 \times 200}{15} + \frac{(30 - 6) \times 100}{70} \times 0.000001 \times 1 \times 350 \right) \right) + \left(\frac{0.055}{0.9} \times \left(\frac{6 \times 0.2 \times 2800}{15} + \frac{(30 - 6) \times 0.07 \times 5700}{70} \right) \times 0.10 \times 3500 \times 0.000001 \right) \right] + \left[0.0273 \times \left(\frac{6 \times 10}{15} + \frac{(30 - 6) \times 20}{70} \right) \times 350 \times \left(\frac{1}{136000000} \right) + \left(\frac{1}{2714} \right) \right]$$

GCN= 6.31 mg/kg

6.0 Using Risk-Based GCNs to Screen Chemicals from a Risk Assessment

Chemicals can be eliminated from a risk assessment by comparing the maximum exposure point concentration or the appropriate 95% UCL for the unit to the cancer and noncancer GCN values multiplied by 0.1 to adjust the risk goal. Any chemical with a maximum concentration that is lower than both the adjusted cancer and noncancer GCN values may be eliminated from further consideration, provided that the cumulative risk of all eliminated chemicals does not exceed a screening risk goal of 1E-06 for carcinogens and a hazard index of 1.0 for noncarcinogens. This screening process is applicable to a maximum of 10 chemicals for the cancer pathway and/or 10 chemicals for the noncancer pathway. Also refer back to Chapter 7, Section 7.4 for more information on screening chemicals from a risk assessment.

How to Screen Chemicals From a Risk Assessment...

- 1) Create a list of COCs for the unit.
- 2) Determine which type of GCN is applicable.
- 3) Select the GCNs for all pertinent COCs.
- 4) Adjust the risk goal of each risk-based GCN by multiplying each GCN by 0.1.

To calculate the cancer risk with a multiple chemical adjustment to screen out chemicals from a risk assessment...

- 1) Divide each exposure point concentration by the adjusted GCN for cancer for that COC.
- 2) Add up the quotients.
- 3) Multiply the sum by 1E-06.
- 4) If the cancer risk exceeds 1E-06, then any chemicals driving the risk should be retained in the quantitative risk assessment.

To calculate the hazard index with a multiple chemical adjustment to screen out chemicals from a risk assessment...

- 1) Divide each exposure point concentration by the adjusted GCN for noncancer for that COC.
- 2) Add up the quotients.
- 3) Compare the sum to the noncancer risk goal.
- 4) If the hazard quotient exceeds 1.0 then any chemicals driving the risk should be retained in the quantitative risk assessment.

Figure A-4: Steps for Screening Chemicals from a Risk Assessment

Exhibit A-5: Example - How GCNs Can Be Used to Screen a Chemical From a Risk Assessment

Example site ABC has a closure unit with several COCs that are listed below. Based on information from the CSM for the unit, site ABC chooses the direct contact soil GCNs. The risk goal for each GCN is adjusted by multiplying by 0.1.

COC	Maximum Concentration (mg/kg)	Noncancer GCN	Adjusted Noncancer GCN	Cancer GCN	Adjusted Cancer GCN
acetonitrile	0.71	476	47.6	N/A	N/A
butanol	2.4	7390	739	N/A	N/A
BEHP	2	724	72.4	202	20.2
chlorobenzene	3	148	14.8	N/A	N/A
naphthalene	2.3	69	6.9	N/A	N/A
MCPP	3.5	49.5	4.95	N/A	N/A
barium	650	5170	517	N/A	N/A
cadmium	3.5	63.5	6.35	14500	1450

Next, site ABC applies the screening values in the risk equations to determine which, if any, chemicals can be screened out due to low risk values:

Noncancer Screening Hazard Index:

$$\frac{0.71}{47.6} + \frac{2.4}{739} + \frac{2}{72.4} + \frac{3}{14.8} + \frac{2.3}{6.9} + \frac{3.5}{4.95} + \frac{650}{517} + \frac{3.5}{6.35} = 3.1$$

Cancer Screening Risk Goal:

$$\frac{2}{20.2} + \frac{3.5}{1450} = 0.10 \times (1 \times 10^{-6}) = 1.0\text{E-}7$$

The cancer screening risk goal needed to eliminate the COCs for site ABC is met ($1.0\text{E-}07 < 1.0\text{E-}6$), but the noncancer screening hazard index to eliminate the COCs is exceeded ($3.09 > 1.0$). Site ABC looks at the contribution of each chemical to the total screening noncancer hazard index and sees that MCPP contributes 0.71, barium contributes 1.26, and cadmium contributes 0.55 to the screening hazard index of 3.1. Therefore, if MCPP, barium and cadmium are excluded from the risk equation, then the new hazard index is calculated to be 0.58. In this example the largest contributing chemicals have been retained for quantitative risk assessment, such that the sum for any non-retained chemicals (e.g., 0.58 above) is below 1.0. Because barium is not carcinogenic, the cancer risk goal remains the same. Therefore, MCPP, barium, and cadmium are the only chemicals on the COC list for site ABC that need to be evaluated in a quantitative risk assessment.

If a sum of 1.0 is exceeded then any COC that singularly is above 1.0 must be retained. Also, some combination of the other COCs that singularly do not exceed 1.0 but contribute to a cumulative hazard index that is above 1.0 will need to be retained if the cumulative hazard index is above 1.0. If the cancer risk had been exceeded then any COC that singularly is above the risk goal must be retained, and some combination of the other COCs that singularly do not exceed the risk goal but contribute to the cumulative risk will need to be retained. Please note that when using the GCNs or adjusted GCNs, analytical detection levels must also be considered. Any compound, or breakdown compound, potentially present at the unit must have detection levels below the GCNs (or adjusted GCNs) whether it has been detected or not. This may be problematic for some highly toxic compounds (i.e., vinyl chloride).

7.0 Risk-based GCNs as Cleanup Numbers

Once the risk-based GCNs have been determined to be applicable at the closure unit, they may be used to determine cleanup numbers. The figure below lists the steps for using the GCNs found in four columns labeled "Single Chemical Cleanup No. in Table A-3.

Once the nature and extent of contamination is defined, all chemicals should be remediated to below the calculated cleanup levels unless they meet any of the following conditions:

- the frequency of detection is less than 5% (investigation of "hot spots" may be warranted if this is the case)
- the 95% upper confidence limit (UCL) or maximum concentration of the compound is below the site-specific background for the compound (for inorganic metals only)¹⁰
- the adjusted GCN for a constituent is greater than the MCL or solubility limit, then the constituent should be remediated to the MCL if one is available.

For the inorganic metals, some of the GCNs are below natural background levels of the constituent. If any inorganic metals exist on-site as COCs, site-specific background information for that metal should be provided in order to exclude it from the risk assessment. Organic compounds cannot be excluded from risk assessments or remediation based on background levels for the purpose of using GCNs. If MCLs are appropriate for the site they should be used as the cleanup numbers.

¹⁰

For the purposes of screening chemicals from a risk assessment, alternate metal standards (AMSs) may not be used. This is a conservative measure used to ensure that the risk from natural compounds is not above risk levels acceptable to the DHWM, owing to large statewide variation of naturally occurring metal concentrations.

Exhibit A-6: Example - How GCNs Can be Used as Cleanup Standards

Example site QRS has a closure unit for which they are seeking cleanup standards. The site has the following contamination:

COC	Maximum Concentration (mg/kg)	Noncancer GCN	Adjusted Noncancer GCN	Cancer GCN	Adjusted Cancer GCN
butanol	2.4	0.325	0.046	N/A	N/A
BEHP	2	501	71.6	87.8	87.8
chlorobenzene	3	0.0193	0.003	N/A	N/A
naphthalene	2.3	0.00763	0.001	N/A	N/A
MCPP	3.5	0.00403	0.001	N/A	N/A
barium	650	41.2	5.9	N/A	N/A
cadmium	3.5	0.466	0.07	N/A	N/A

Based on information gathered from the CSM, compare site maximum concentrations (or the 95% UCL of a constituent) to the risk-based 1 DAF GCNs because the site is large and there is an on-site aquifer that may become contaminated if the contamination is left in place. Because there are 7 chemicals of concern with noncancer GCNs and 1 chemical of concern with a GCN for cancer, divide each noncancer GCN by 7 and the GCN for cancer by 1 to arrive at approximate cleanup standards. Next, analyze any exceedences. Compare site concentrations to adjusted GCNs and determine which contaminant(s), if any, need to be addressed. It is determined, based upon review of the concentrations and the associated adjusted GCNs at site QRS, that the remediation efforts should focus on removing butanol, chlorobenzene, naphthalene, and MCPP from the soil. In addition, it is decided to obtain site-specific background data regarding the concentrations of barium and cadmium in the soil, and to remediate the metals separately if necessary. Different combinations of contaminant reduction may allow risk levels to be met at a particular site, and considerations such as appropriate remedy type for a particular contaminant class may decide how final risk goals are achieved.

8.0 Using Risk-Based GCNs to Determine that No Further Action is Necessary at a Unit

Once the nature and extent of contamination is established, and it is determined that risk-based GCNs are applicable at the closure unit, the GCNs can be used to determine if no further action is necessary at the unit. The figure below describes the step used to determine if no further action is necessary at the unit using risk-based GCNs.

If the unit meets acceptable cancer risk levels (less than or equal to $1E-05$) and acceptable noncancer risk levels (less than or equal to 1.0) based on GCNs, and no COCs are present above soil saturation concentrations for soil, or solubility limits for ground water, then no further remediation may be necessary.

When MCLs are applicable, compare the exposure point concentration to the corresponding MCL or MCL-based GCN. If all concentrations are at or below the appropriate GCN then no further remediation may be necessary.

To use risk-based GCNs to determine that no further action is necessary at a unit...

- 1) Create a list of COCs for the unit.
- 2) Determine the exposure point concentration for each COC (i.e., the 95% UCL or maximum concentration as appropriate)
- 3) Determine which type of risk-based GCN is applicable.
- 4) Select the GCNs for all pertinent COCs from Table A-3.
- 5) Set up two equations, one to determine the cancer risk and the other to determine the noncancer risk.
The *cancer* equation is:
$$\text{Risk} = [(\text{conca}/\text{GCNa}) + (\text{concb}/\text{GCNb}) + \dots + (\text{concn}/\text{GCNn})] \times 10^{-5}$$

The *noncancer* equation is:
$$\text{Hazard Index (1)} = (\text{conca}/\text{GCNa}) + (\text{concb}/\text{GCNb}) + \dots + (\text{concn}/\text{GCNn})$$
- 6) First calculate the cancer risk posed by the unit...
 - Divide each exposure point concentration by the GCN for cancer for that COC.
 - Add up the quotients.
 - Multiply the sum by 1E-05.
 - This is the cancer risk for the unit.
- 7) If the cancer risk is less than or equal to 1E-05, then acceptable cancer risk levels at the unit have been met and the noncancer risk should be calculated. If this number is greater than 1E-05, then the contamination at the unit is above the acceptable cancer risk level. Remediation of contaminants to below this level or a site-specific risk assessment must be done to demonstrate that the unit does not pose an unacceptable risk
- 8) Next, calculate the noncancer risk posed by the unit...
 - Divide the exposure point concentration for each COC by the noncancer GCN for that COC
 - Add up the quotients.
 - This is the noncancer risk for the unit.
- 9) If this number is less than or equal to 1.0, then the unit has met the risk goal established by DHWM. If this number is greater than 1.0, then the unit is above the acceptable noncancer risk level and remediation of contaminants to below this level should be done, or a site-specific risk assessment must be done to demonstrate that the unit does not pose an unacceptable risk.
- 10) For soils, all of the concentrations of COCs should be compared to the soil saturation concentrations provided in Table A-3. If any chemical is present at levels above the soil saturation concentration, then it must be remediated to the soil saturation concentration, even if the risk is otherwise acceptable. If no soil saturation limit is given in Table A-3, then comparison to soil saturation concentrations is not necessary.
- 11) For ground water, all concentrations should be compared to the solubility limits provided in Table A-3. If any chemical is present at levels above the solubility limit, then it must be remediated to the solubility limit, even if the risk is otherwise acceptable. If no solubility limit is given in Table A-3 (i.e., the chemical is miscible with water), then comparison to the solubility limit is not necessary.
- 12) Lastly, all of the ground water concentrations of COCs must be compared to the MCLs provided in Table A-3. If any chemical is present at levels above the MCL, then it must be remediated to the MCL, even if the risk is otherwise acceptable. If no MCL is given in Table A-3, comparison to maximum contaminant levels is not necessary.

Figure A-5: Steps for using GCNs to Determine that No Further Action is Necessary at a Unit

Exhibit A-7: Example - How GCNs Can Be Used to Demonstrate That No Further Action is Required

Example site XYZ has contamination at low levels after remediation was performed and its stakeholders would like to know if the remediation was adequate or if further remediation will be required. Based on the CSM, it is determined that risk-based GCNs are applicable at the unit. Next, it is determined that an aquifer exists on-site that may become impacted through leaching if any contamination is left in place, but that some dilution and attenuation of soil leachates is occurring at the unit. It is decided that it is appropriate to use the risk-based GCNs from the 20 DAF column based on subsurface conditions (as compared to criteria mentioned earlier in this appendix). As part of the remediation process, samples were collected that determined the nature and extent of the contamination before and after remediation, as well as background information on the inorganic metals found on-site. The COCs for site XYZ are then listed along with the exposure point concentration after remediation for each COC based on sampling information. The GCNs from Table A-3 from the columns labeled “Single Chemical Noncancer Protective of Ground water (20 DAF)” and “Single Chemical Cancer Protective of Ground water (20 DAF)” are listed. A table that looks like the following is created:

COC	Exposure Point Concentration (mg/kg)	Noncancer GCN	Cancer GCN
acetone	0.7	32.5	N/A
benzene	0.002	0.0934	0.022
benzo(a)pyrene	0.06	N/A	0.5
bromoform	0.04	2.29	0.625
mercury	0.12	1.39	N/A

The equation to determine cancer risk at the unit is set up as follows:

$$((0.002/0.022) + (0.06/0.5) + (0.04/0.625)) \times 1\text{E-}05 = 2.75\text{E-}06$$

This is determined to be an acceptable cancer risk level at the unit. Included in the sampling information is information on background concentrations of mercury at the site. The 95% UCL of the background concentration of mercury at the site is calculated to be 0.12 mg/kg. The exposure point concentration found at the unit is 0.12 mg/kg. Therefore, mercury is not included in the noncancer risk equation.

The noncancer risk equation is set up as follows:

$$(0.7/32.5) + (0.002/0.0934) + (0.04/2.29) = 0.06$$

It is determined that both the cancer risk and the noncancer risk at site XYZ are below acceptable levels. The concentrations of COCs in the soil are then compared to the soil saturation concentrations for those COCs. All the COCs are found to be at concentrations below the soil saturation concentrations. The remediation is declared successful and the package, including all sampling and analysis results, is submitted to DHWM.

9.0 Exposure Factors

Default exposure factors used in the development of the risk-based GCNs were obtained primarily from U.S. EPA's (1991) *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Supplemental Guidance "Standard Default Exposure Factors"* and from more recent information from U.S. EPA's Office of Solid Waste and Emergency Response and U.S. EPA's Office of Research and Development. See Table A-2 for default factors used in the calculations of the risk-based GCNs.

Because contact rates may be different for children and adults, carcinogenic risks during the first 30 years of life were calculated using age-adjusted factors (denoted in Table A-2 with an "adj" subscript). Use of age-adjusted factors is especially important for soil ingestion exposures, which are higher during childhood and decrease with age. However, for purposes of combining exposure risks from multiple pathways, additional age-adjusted factors are used for inhalation and dermal exposures. These factors approximate the integrated exposure from birth until age 30 and combine contact rates, body weights, and exposure durations for two age groups - small children and adults. Age-adjusted factors were obtained from RAGS, Part B or developed by analogy. Exposure factors for noncarcinogenic contaminants in soil are evaluated for children separately from adults. In order to remain protective, only exposures to children are considered in the calculation of the noncancer GCNs, therefore no age-adjusted factor is used. The focus on children is considered protective of the higher daily intake rates of soil by children and their lower body weight. For maintaining consistency when evaluating soils, dermal and inhalation exposures are also based on childhood contact rates.

Table A-2: Default Exposure Factors for Residential and Industrial Land Use			
Symbol	Definition (units)	Default	Reference
RfDo	Reference dose oral (mg/kg-d)	See Table A-3	chemical-specific
RfDi	Reference dose inhaled (mg/kg-d)	See Table A-3	chemical-specific
RfDd	Reference dose dermal (mg/kg-d)	RfDo multiplied by the oral absorption factor	chemical-specific
SFo	Cancer slope factor oral (mg/kg-d) ⁻¹	See Table A-3	chemical-specific
SFi	Cancer slope factor inhaled (mg/kg-d) ⁻¹	See Table A-3	chemical-specific
SFd	Cancer slope factor dermal (mg/kg-d) ⁻¹	--	SFo divided by the oral absorption factor
TR	Target cancer risk (unitless)	1E-06	--
THI	Target hazard index (unitless)	1.0	--

Table A-2: Default Exposure Factors for Residential and Industrial Land Use			
Symbol	Definition (units)	Default	Reference
ABS	Dermal absorption factor (unitless)	0.001 - Inorganics 0.10 - SVOCs 0.13 - PAHs 0.14 - PCBs 0.01 - VOCs 0.03 - Arsenic, DDT, Dioxins 0.04 - Chlordane, Lindane 0.05 - 2,4-D 0.25 - Pentachlorophenol	U.S. EPA, Region 4 RAGS, Part E RAGS, Part E RAGS, Part E U.S. EPA, Region 4 RAGS, Part E RAGS, Part E RAGS, Part E RAGS, Part E
AFa	Adherence factor, adult (mg/cm ²)	0.07	RAGS, Part E
AFc	Adherence factor, child (mg/cm ²)	0.2	RAGS, Part E
ATc	Averaging time - carcinogens (days)	25550	RAGS, Part A
ATn	Averaging time - noncarcinogens (days)	ED*365 Child, residential = 2,190 Adult, residential = 10,950 Adult, industrial = 9,125	--
BWa	Body weight, adult (kg)	70	RAGS, Part A
BWc	Body weight, child (kg)	15	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
CAs	Concentration in air, from soil (mg/m ³)	Cs divided by PEF and VF	Soil Screening Guidance
CAw	Concentration in air, showering (mg/m ³)	CW*VFw	Soil Screening Guidance
CFs	Conversion factor, soil (unitless)	0.000001	--
CFw	Conversion factor, water (unitless)	0.001	--
C _{sat}	Soil saturation concentration (mg/kg)	See Table A-3	Soil Screening Guidance
CS	Concentration in soil (mg/kg)	Exposure Point Concentration	Refer to Ch 7 Section 7.2 Exposure Point Concentration For Soil.
CW	Concentration in water (mg/l)	Exposure Point Concentration	Refer to Ch 7 Section 7.2 Exposure Point Concentration For Soil.
EDa	Exposure duration, adult residential (years)	30	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03

Table A-2: Default Exposure Factors for Residential and Industrial Land Use			
Symbol	Definition (units)	Default	Reference
EDc	Exposure duration, child (years)	6	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
EDi	Exposure duration, industrial (years)	25	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
EFi	Exposure frequency, industrial (d/y)	250	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
EFr	Exposure frequency, residential (d/y)	350	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
ETa	Exposure time, showering adult (hours)	0.58	RAGS, Part E
ETc	Exposure time, showering child (hours)	1	RAGS, Part E
FI	Fraction ingested, soil (unitless)	1	See ¹¹
IRAA	Inhalation rate, soil adult residential (m ³ /d)	20	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
IRAc	Inhalation rate, soil child (m ³ /d)	10	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
IRAi	Inhalation rate, soil industrial (m ³ /d)	7	See ¹²
IRSa	Soil ingestion, adult residential (mg/d)	100	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
IRSc	Soil ingestion, child (mg/d)	200	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
IRSi	Soil ingestion, industrial (mg/d)	50	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
IRWa	Drinking water ingestion, adult (L/d)	2	RAGS, Part A

¹¹ Because risk assessments conducted for hazardous waste closures attempt to quantify exposure to a hazardous waste unit (and not a property or entire site), the hazardous waste unit is considered to be the exposure unit. Therefore, the fraction ingested term should always be 1.

¹² 7m³/d is equivalent to the adult inhalation rate of 20 m³/d divided by 3. This assumes only 8 hours of exposure per day at work, rather than 24 hours of exposure per day (at a residence).

Table A-2: Default Exposure Factors for Residential and Industrial Land Use			
Symbol	Definition (units)	Default	Reference
IRWc	Drinking water ingestion, child (L/d)	1	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
IWa	Inhalation rate, showering adult (m ³ /hour)	0.83	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
IWc	Inhalation rate, showering child (m ³ /hr)	0.42	U.S.EPA Supplemental Guidance to RAGS, OSWER 9285.6-03
Kd	Soil-water distribution coefficient (L/kg)	See Table A-5	Chemical-specific, Soil Screening Guidance
Oabs	Oral absorption factor (unitless)	0.2 - Inorganics 0.5 - SVOCs 0.58 - PAHs 0.8 - PCBs 0.5 - VOCs 0.5 - Dioxins, and Dibenzofurans Or Chemical Specific	U.S. EPA, Region 4 RAGS, Part E RAGS, Part E RAGS, Part E RAGS, Part E RAGS, Part E
PC	Permeability constant (cm/hr)	See Table A-5	RAGS, Part E
PEF	Particulate emission factor (m ³ /kg)	1,360,000,000 (1.36E+09)	Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites
SASa	Skin surface area, soil, residential adult (cm ²)	5700	RAGS, Part E
SASc	Skin surface area, child (cm ²)	2800	RAGS, Part E
SASi	Skin surface area, industrial (cm ²)	3300	RAGS, Part E
SAWa	Skin surface area, water, adult (cm ²)	18000	RAGS, Part E
SAWc	Skin surface area, water, child (cm ²)	6600	RAGS, Part E
VF	Volatilization factor for soil (m ³ /kg)	See Table A-4	Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites
VFw	Volatilization factor for water (L/m ³)	17.4	Andelman, 1990
Age-adjusted factors for carcinogens ¹³			
IFSadj	Ingestion factor, soils ([mg*yr]/[kg*d])	114.286	RAGS, Part B

¹³ Exposure duration for lifetime residents is assumed to be 30 years total. For carcinogens, exposures are combined for children (6 years) and adults (24 years).

Table A-2: Default Exposure Factors for Residential and Industrial Land Use			
Symbol	Definition (units)	Default	Reference
SFSadj	Skin contact factor, soils ([mg*yr]/[kg*d])	360.8	By analogy to RAGS, Part B
InhFSadj	Inhalation factor, soils ([m ³ *yr]/[kg*d])	10.857	By analogy to RAGS, Part B
IFWadj	Ingestion factor, water ([l*yr]/[kg*d])	1.0857	By analogy to RAGS, Part B
SFWadj	Skin contact factor, water ([l*yr]/[kg*d])	6219.43	By analogy to RAGS, Part B
InhFWadj	Inhalation factor, water ([m ³ *yr]/[kg*d])	0.333	By analogy to RAGS, Part B

10.0 Additional References¹⁴

Calabrese, E.J., R. Barnes, E.J. Stanek, H. Pastides, C.E. Gilbert, P. Veneman, X. Wang, A. Lasztity, P.T. Kosteck. (1989) "How Much Soil Do Young Children Ingest: An Epidemiologic Study." *Regulatory Toxicology and Pharmacy* 10: 123-137.

Cowherd, C. (1985) *Measurement of Particulate Emissions from Hazardous Waste Disposal Sites*. 78th Annual Meeting of the Air Pollution Control Association. Detroit, MI.

Davis, S. and P. Walker. (1990) "Quantitative Estimates of Soil Ingestion in Normal Children Between the Ages of 2 and 7 Years: Population-base Estimates Using Aluminum, Silicon, and Titanium as Soil Tracer Elements." *Archives of Environmental Health* 45(2): 112-122.

Howard, P.H. (1989) *Handbook of Environmental Fate and Exposure Data for Organic Chemicals*. Lewis Publishers. Chelsea, MI.

U.S. EPA. (1991) *Subsurface Contamination Reference Guide*. EPA/540/2-90/011. Office of Emergency and Remedial Response. Washington, D.C.
<http://www.epa.gov/natlibra/ols.htm>

U.S. EPA. (1996) *Soil Screening Guidance: User's Guide*. EPA/540/R-96/018. Office of Solid Waste and Emergency Response. Washington, D.C.
<http://www.epa.gov/natlibra/ols.htm>

U.S. EPA. (1996) *Superfund Chemical Data Matrix*. EPA/540/R96/028. Office of Emergency and Remedial Response. Washington, D.C. <http://www.epa.gov/natlibra/ols.htm>

¹⁴ Other references cited in this appendix can be found in Chapters 8 and 10 of this document.

U.S. EPA. (1998) *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities, Peer Review Draft*. EPA/530/D-98/001. Office of Solid Waste and Emergency Response. Washington, D.C. <http://www.epa.gov/epaoswer/hazwaste/combust/risk.htm>

U.S. EPA. (1997) *Exposure Factors Handbook*. EPA/600/P-95/002Fa. Office of Research and Development. Washington, D.C. <http://www.epa.gov/ncea/pdfs/efh/front.pdf>

U.S. EPA, National Center for Environmental Assessment (NCEA), <http://cfpub.epa.gov/ncea/>

U.S. EPA. (2001) *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*. Office of Solid Waste and Emergency Response. Washington, D.C. http://www.epa.gov/superfund/resources/soil/ssg_main.pdf

Van Wijnen, J.H., P. Clausen, B. Brunekreef. (1990) "Estimated Soil Ingestion by Children." *Environmental Research* 51: 147-162.

11.0 Generic Cleanup Number Values

The following tables contain the GCNs, periodic updates to these tables can be found at the following link: http://epa.ohio.gov/portals/32/pdf/Removed_CPRG_Appendices.pdf.

- **[Table A-3: Risk-Based Generic Cleanup Numbers](#)**
- **[Table A-4: MCL-Based Generic Cleanup Numbers](#)**
- **[Table A-5: Chemical Specific Values for the Generic Cleanup Numbers](#)**

October 2009														
Table A-3: Residential Risk Based Generic Cleanup Numbers (GCNs) for Ohio Hazardous Waste Closures														
CONTAMINANT	1 Calculated Soil Saturation Limit (SAT) (mg/kg)	2 Single Chemical Noncancer Direct Contact Soil (mg/kg)	3 Single Chemical Cancer Direct Contact Soil (mg/kg)	4 Single Chemical Direct Contact Soil (mg/kg)	5 Single Chemical Noncancer Protective Of Ground Water (1 DAF) (mg/kg)	6 Single Chemical Cancer Protective Of Ground Water (1 DAF) (mg/kg)	7 Single Chemical Protective Of Ground Water (1 DAF) (mg/kg)	8 Single Chemical Noncancer Protective Of Ground Water (20 DAF) (mg/kg)	9 Single Chemical Cancer Protective Of Ground Water (20 DAF) (mg/kg)	10 Single Chemical Protective Of Ground Water (20 DAF) (mg/kg)	11 Solubility (SOL) (mg/l)	12 Single Chemical Noncancer Ground Water Concentration (mg/l)	13 Single Chemical Cancer Ground Water Concentration (mg/l)	14 Single Chemical Ground Water Concentration (mg/l)
Acenaphthene	4.20E+01	2.84E+03		4.20E+01 sat	4.80E+00		4.80E+00 nc	9.60E+01		4.20E+01 sat	4.24E+00	4.80E-01		4.80E-01 nc
Acetone	1.01E+05	4.87E+04		4.87E+04 nc	1.62E+00		1.62E+00 nc	3.25E+01		3.25E+01 nc	1.00E+06	8.07E+00		8.07E+00 nc
Acetonitrile	1.32E+05	4.76E+02		4.76E+02 nc	8.44E-03		8.44E-03 nc	1.69E-01		1.69E-01 nc	1.00E+06	3.64E-02		3.64E-02 nc
Acetophenone	7.36E+02	3.77E-01		3.77E-01 nc	2.68E-06		2.68E-06 nc	5.37E-05		5.37E-05 nc	6.13E+03	1.22E-05		1.22E-05 nc
Acrolein	2.27E+04	7.29E-02		7.29E-02 nc	2.51E-06		2.51E-06 nc	5.03E-05		5.03E-05 nc	2.12E+05	1.22E-05		1.22E-05 nc
Acrylonitrile	1.23E+04	9.38E+00	2.61E+00	2.61E+00 ca	3.01E-04	9.86E-05	9.86E-05 ca	6.02E-03	1.97E-03	1.97E-03 ca	7.35E+04	1.13E-03	3.70E-04	3.70E-04 ca
Aldrin	1.76E+01	1.49E+00	2.30E-01	2.30E-01 ca	9.75E-03	9.17E-04	9.17E-04 ca	1.95E-01	1.83E-02	1.83E-02 ca	1.80E-01	9.99E-05	9.40E-06	9.40E-06 ca
Aluminum		1.99E+04		1.99E+04 nc	4.71E-01		4.71E-01 nc	9.41E+00		9.41E+00 nc		2.06E+00		2.06E+00 nc
Aluminum phosphide		8.02E+00		8.02E+00 nc	1.88E-04		1.88E-04 nc	3.76E-03		3.76E-03 nc	1.92E+05	8.23E-04		8.23E-04 nc
Aniline	6.87E+03	3.46E+02	6.87E+02	3.46E+02 nc	3.07E-02	3.32E-02	3.07E-02 nc	6.15E-01	6.64E-01	6.15E-01 nc	3.66E+04	1.07E-01	1.15E-01	1.07E-01 nc
Anthracene	2.56E+00	1.42E+04		2.56E+00 sat	9.85E+01		2.56E+00 sat	1.97E+03		2.56E+00 sat	4.34E-02	1.66E+00		4.34E-02 sol
Antimony		3.07E+01		3.07E+01 nc	5.41E-03		5.41E-03 nc	1.08E-01		1.08E-01 nc		1.20E-04		1.20E-04 nc
Aroclor 1016	3.09E+01	3.63E+00	2.06E+00	2.06E+00 ca	2.74E-02	8.73E-03	8.73E-03 ca	5.49E-01	1.75E-01	1.75E-01 ca	9.06E-01	8.02E-04	2.55E-04	2.55E-04 ca
Aroclor 1221	7.51E+00		1.94E+00	1.94E+00 ca		1.69E-03	1.69E-03 ca		3.39E-02	3.39E-02 ca	5.90E-01		1.32E-04	1.32E-04 ca
Aroclor 1232	2.91E+01		2.06E+00	2.06E+00 ca		4.11E-03	4.11E-03 ca		8.23E-02	8.23E-02 ca	1.45E+00		2.04E-04	2.04E-04 ca
Aroclor 1242	1.41E+01		2.06E+00	2.06E+00 ca		5.65E-03	5.65E-03 ca		1.13E-01	1.13E-01 ca	7.03E-01		2.80E-04	2.80E-04 ca
Aroclor 1248	8.55E-01		2.06E+00	8.55E-01 sat		3.83E-03	3.83E-03 ca		7.66E-02	7.66E-02 ca	1.70E-02		7.60E-05	7.60E-05 ca
Aroclor 1254	5.96E+00	1.04E+00	2.06E+00	1.04E+00 nc	7.07E-03	8.41E-03	7.07E-03 nc	1.41E-01	1.68E-01	1.41E-01 nc	7.00E-02	8.29E-05	9.87E-05	8.29E-05 nc
Aroclor 1260	1.12E+01		2.06E+00	2.06E+00 ca		3.71E-02	3.71E-02 ca		7.43E-01	7.43E-01 ca	2.70E-02		8.97E-05	8.97E-05 ca
Arsenic		2.15E+01	3.87E+00	3.87E+00 ca	1.17E-01	1.12E-02	1.12E-02 ca	2.35E+00	2.25E-01	2.25E-01 ca		4.66E-03	4.46E-04	4.46E-04 ca
Barium and compounds		5.17E+03		5.17E+03 nc	4.12E+01		4.12E+01 nc	8.25E+02		8.25E+02 nc		1.00E+00		1.00E+00 nc
Benz[a]anthracene	7.48E+00		5.12E+00	5.12E+00 ca	-	1.27E-01	1.27E-01 ca		2.54E+00	2.54E+00 ca	9.40E-03		1.60E-04	1.60E-04 ca
Benzene	4.55E+02	3.25E+01	6.31E+00	6.31E+00 ca	4.67E-03	1.10E-03	1.10E-03 ca	9.34E-02	2.20E-02	2.20E-02 ca	1.75E+03	1.38E-02	3.27E-03	3.27E-03 ca
Benzo[e]pyrene	1.82E+05	1.49E+02	1.70E-02	1.70E-02 ca	2.10E+01	1.31E-03	1.31E-03 ca	4.20E+02	2.62E-02	1.70E-02 dc	4.00E+02	4.62E-02	2.89E-06	2.89E-06 ca
Benzo[a]pyrene	3.30E+00		5.12E-01	5.12E-01 ca		2.50E-02	2.50E-02 ca		5.00E-01	5.00E-01 ca	1.62E-03		1.23E-05	1.23E-05 ca
Benzo[b]fluoranthene	3.69E+00		5.12E+00	3.69E+00 sat		2.67E-01	2.67E-01 ca		5.35E+00	3.69E+00 sat	1.50E-03		1.09E-04	1.09E-04 ca
Benzo[k]fluoranthene	1.97E+00		5.12E+01	1.97E+00 sat		2.67E+00	1.97E+00 sat		5.35E+01	1.97E+00 sat	8.00E-04		1.09E-03	8.00E-04 sol
Benzoic acid	3.54E+02	1.98E+05		3.54E+02 sat	1.17E+01		1.17E+01 nc	2.35E+02		2.35E+02 nc	3.50E+03	5.83E+01		5.83E+01 nc
Beryllium	3.31E+02	1.11E+02	1.09E+04	1.11E+02 nc	1.27E+01		1.27E+01 nc	2.55E+02		1.11E+02 dc		1.61E-02		1.61E-02 nc
Bis(2-chloro-1-methylethyl)ether	3.31E+02	1.98E+03	2.96E+01	2.96E+01 ca	1.67E-01	7.53E-04	7.53E-04 ca	3.35E+00	1.51E-02	1.51E-02 ca	1.70E+03	5.69E-01	2.56E-03	2.56E-03 ca
Bis(2-chloroethyl)ether	2.26E+03		3.56E+00	3.56E+00 ca		2.13E-05	2.13E-05 ca		4.26E-04	4.26E-04 ca	1.72E+04	-	9.23E-05	9.23E-05 ca
Bis(2-ethylhexyl)phthalate	1.03E+04	7.24E+02	2.02E+02	2.02E+02 ca	5.01E+02	8.78E-01	8.78E-01 ca	1.00E+04	1.76E+03	2.02E+02 dc	3.40E-01	1.66E-02	2.91E-03	2.91E-03 ca
Bromodichloromethane	1.50E+03	1.48E+03	9.69E+01	9.69E+01 ca	9.30E-02	3.25E-03	3.25E-03 ca	1.86E+00	6.50E-02	6.50E-02 ca	6.74E+03	2.95E-01	1.03E-02	1.03E-02 ca
Bromoform	8.63E+02	1.48E+03	7.61E+02	7.61E+02 ca	1.14E-01	3.12E-02	3.12E-02 ca	2.29E+00	6.25E-01	6.25E-01 ca	3.10E+03	3.04E-01	8.31E-02	8.31E-02 ca
Butanol	8.43E+03	7.39E+03		7.39E+03 nc	3.25E-01		3.25E-01 nc	6.50E+00		6.50E+00 nc	7.40E+04	1.52E+00		1.52E+00 nc
n-Butylbenzene	6.92E+01	7.39E+02		6.92E+01 sat	2.38E-01		2.38E-01 nc	4.77E+00		4.77E+00 nc	1.18E+01	4.03E-02		4.03E-02 nc
sec-Butylbenzene	7.99E+01	7.39E+02		7.99E+01 sat	1.48E-01		1.48E-01 nc	2.95E+00		2.95E+00 nc	1.76E+01	3.23E-02		3.23E-02 nc
tert-Butylbenzene	1.36E+02	7.39E+02		1.36E+02 sat	2.49E-01		2.49E-01 nc	4.99E+00		4.99E+00 nc	2.95E+01	5.37E-02		5.37E-02 nc
Butyl benzyl phthalate	3.10E+02	9.90E+03		3.10E+02 sat	2.28E+02		2.28E+02 nc	4.55E+03		3.10E+02 sat	2.69E+00	1.98E+00		1.98E+00 nc
Cadmium and compounds**		6.35E+01	1.45E+04	6.35E+01 nc	4.66E-01		4.66E-01 nc	9.32E+00		9.32E+00 nc		6.19E-03		6.19E-03 nc
Carbazole	5.15E+01		1.87E+02	5.15E+01 sat		1.65E-01	1.65E-01 ca		3.29E+00	3.29E+00 ca	7.48E+00		2.36E-02	2.36E-02 ca
Carbon disulfide	5.04E+02	3.52E+02		3.52E+02 nc	1.30E-01		1.30E-01 nc	2.59E+00		2.59E+00 nc	1.19E+03	3.25E-01		3.25E-01 nc
Carbon tetrachloride	5.40E+02	1.77E+00	2.49E+00	1.77E+00 nc	7.13E-04	1.04E-03	7.13E-04 nc	1.43E-02	2.09E-02	1.43E-02 nc	7.93E+02	1.09E-03	1.59E-03	1.09E-03 nc
Chlordane	1.34E+01	3.42E+01	1.58E+01	1.34E+01 sat	9.48E-01	2.49E-01	2.49E-01 ca	1.90E+01	4.98E+00	4.98E+00 ca	5.60E-02	3.95E-03	1.04E-03	1.04E-03 ca
p-Chloroaniline	1.23E+03	1.98E+02		1.98E+02 nc	1.95E-02		1.95E-02 nc	3.90E-01		3.90E-01 nc	5.30E+03	5.86E-02		5.86E-02 nc
Chlorobenzene	2.67E+02	1.48E+02		1.48E+02 nc	1.93E-02		1.93E-02 nc	3.86E-01		3.86E-01 nc	4.72E+02	2.97E-02		2.97E-02 nc
Chlorobenzilate	2.30E+01	9.90E+01		2.30E+01 sat	5.27E-02		5.27E-02 nc	1.05E+00		1.05E+00 nc	1.00E+01	2.20E-02		2.20E-02 nc
Chloroethane	1.34E+03	5.28E+03	2.07E+03	1.34E+03 sat	8.55E-01	6.23E-02	6.23E-02 ca	1.71E+01	1.25E+00	1.25E+00 ca	5.74E+03	2.97E+00	2.17E-01	2.17E-01 ca
Chloroform	1.64E+03	2.64E+02	2.20E+00	2.20E+00 ca	2.56E-02	4.47E-04	4.47E-04 ca	5.12E-01	8.94E-03	8.94E-03 ca	7.92E+03	8.75E-02	1.53E-03	1.53E-03 ca
Chloromethane	1.04E+03	5.54E+01		5.54E+01 nc	1.43E-02		1.43E-02 nc	2.85E-01		2.85E-01 nc	5.32E+03	5.50E-02		5.50E-02 nc
2-Chloronaphthalene	7.14E+01	3.96E+03		7.14E+01 sat	3.80E+00		3.80E+00 nc	7.61E+01		7.14E+01 sat	1.17E+01	6.13E-01		6.13E-01 nc
2-Chlorophenol	1.93E+04	2.48E+02		2.48E+02 nc	6.92E-02		6.92E-02 nc	1.38E+00		1.38E+00 nc	2.20E+04	7.08E-02		7.08E-02 nc
Chromium III		9.59E+04		9.59E+04 nc	2.80E+07		9.59E+04 dc	5.60E+08		9.59E+04 dc		1.56E+01		1.56E+01 nc
Chromium VI		2.10E+02	2.18E+03	2.10E+02 nc	5.90E-01		5.90E-01 nc	1.18E+01		1.18E+01 nc		3.07E-02		3.07E-02 nc
Chrysene	1.27E+00		5.12E+02	1.27E+00 sat		1.27E+01	1.27E+00 sat		2.54E+02	1.27E+00 sat	1.60E-03		1.60E-02	1.60E-02 sol
Cobalt		1.37E+03	9.33E+03	1.37E+03 nc	1.39E+01		1.39E+01 nc	2.79E+02		2.79E+02 nc		3.08E-01		3.08E-01 nc
Copper		2.86E+03		2.86E+03 nc	1.99E+01		1.99E+01 nc	3.98E+02		3.98E+02 nc		5.63E-01		5.63E-01 nc
Cyanide, Free	2.91E+05	1.54E+03		1.54E+03 nc	8.83E-02		8.83E-02 nc	1.77E+00		1.77E+00 nc	1.00E+06	3.03E-01		3.03E-01 nc
Cyclohexane	8.62E+01	2.32E+03		8.62E+01 sat	3.85E+00		3.85E+00 nc	7.70E+01		7.70E+01 nc	5.50E+01	3.66E+00		3.66E+00 nc
Dalapon	5.29E+04	1.49E+03		1.49E+03 nc	8.90E-06		8.90E-06 nc	1.78E-04		1.78E-04 nc	5.02E+05	4.33E-05		4.33E-05 nc
Dibenz[ah]anthracene	1.89E+01		5.12E-01	5.12E-01 ca		5.71E-02	5.71E-02 ca		1.14E+00	5.12E-01 dc	2.49E-03		7.51E-06	7.51E-06 ca
Dibenzofuran	3.59E+01	1.90E+02		3.59E+01 sat	2.59E-01		2.59E-01 nc	5.17E+00		5.17E+00 nc	4.22E+00	3.01E-02		3.01E-02 nc

Table A-3: Residential Risk Based Generic Cleanup Numbers (GCNs) for Ohio Hazardous Waste Closures																		
CONTAMINANT	1 Calculated Soil Saturation Limit (SAT)	2 Single Chemical Noncancer Direct Contact Soil	3 Single Chemical Cancer Direct Contact Soil	4 Single Chemical Direct Contact Soil	5 Single Chemical Noncancer Protective Of Ground Water (1 DAF)	6 Single Chemical Cancer Protective Of Ground Water (1 DAF)	7 Single Chemical Protective Of Ground Water (1 DAF)	8 Single Chemical Noncancer Protective Of Ground Water (20 DAF)	9 Single Chemical Cancer Protective Of Ground Water (20 DAF)	10 Single Chemical Protective Of Ground Water (20 DAF)	11 Solubility (SOL)	12 Single Chemical Noncancer Ground Water Concentration	13 Single Chemical Cancer Ground Water Concentration	14 Single Chemical Ground Water Concentration				
	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/l)	(mg/l)	(mg/l)	(mg/l)				
Dibromochloromethane	6.04E+02	1.48E+03	7.15E+01	7.15E+01	ca	9.91E-02	2.55E-03	2.55E-03	ca	1.98E+00	5.10E-02	ca	2.60E+03	3.01E-01	7.75E-03	7.75E-03	ca	
1,2-Dibromoethane	5.20E+02	6.41E+02	1.62E-01	1.62E-01	ca	3.04E-02	1.17E-05	1.17E-05	ca	6.07E-01	2.33E-04	ca	3.91E+03	1.32E-01	5.07E-05	5.07E-05	ca	
Dichloroacetic acid	2.16E+04	1.98E+02	7.83E+01	7.83E+01	ca	2.16E-02	4.64E-03	4.64E-03	ca	4.31E-01	9.28E-02	ca	8.63E+04	6.16E-02	1.33E-02	1.33E-02	ca	
1,2-Dichlorobenzene	2.10E+02	1.90E+02		1.90E+02	nc	2.60E-02		2.60E-02	nc	5.19E-01		nc	1.56E+02	1.80E-02		1.80E-02	nc	
1,3-Dichlorobenzene	9.02E+01	6.65E+01		6.65E+01	nc	6.82E-03		6.82E-03	nc	1.36E-01		nc	1.25E+02	8.42E-03		8.42E-03	nc	
1,4-Dichlorobenzene	9.98E+01	1.52E+03	3.41E+01	3.41E+01	ca	3.02E-01	6.58E-03	6.58E-03	ca	6.03E+00	1.32E-01	ca	7.38E+01	2.09E-01	4.56E-03	4.56E-03	ca	
3,3-Dichlorobenzidine	4.81E+00		8.70E+00	4.81E+00	sat		2.15E-03	2.15E-03	ca		4.30E-02	ca	3.11E+00		1.31E-03	1.31E-03	ca	
Dichlorodifluoromethane	7.10E+02	1.00E+02		1.00E+02	nc	2.00E-01		2.00E-01	nc	4.00E+00		nc	2.80E+02	1.17E-01		1.17E-01	nc	
(DDD) Dichlorodiphenyldichloroethane	1.80E+02		2.34E+01	2.34E+01	ca		1.74E+00	1.74E+00	ca		3.48E+01	2.34E+01	dc	9.00E-02		8.71E-04	8.71E-04	ca
(DDE) Dichlorodiphenyldichloroethane	1.07E+03		1.65E+01	1.65E+01	ca		2.45E+00	2.45E+00	ca		4.90E+01	1.65E+01	dc	1.20E-01		2.74E-04	2.74E-04	ca
(DDT) Dichlorodiphenyltrichloroethane	1.32E+02	3.48E+01	1.65E+01	1.65E+01	ca	9.89E+00	2.78E+00	2.78E+00	ca	1.98E+02	1.65E+01	dc	2.50E-02	1.88E-03	5.29E-04	5.29E-04	ca	
1,1-Dichloroethane	1.04E+03	5.01E+02		5.01E+02	nc	7.14E-02		7.14E-02	nc	1.43E+00		nc	5.06E+03	2.52E-01		2.52E-01	nc	
1,2-Dichloroethane	1.21E+03	8.48E+00	2.75E+00	2.75E+00	ca	7.09E-04	2.77E-04	2.77E-04	ca	1.42E-02	5.53E-03	ca	8.52E+03	2.98E-03	1.16E-03	1.16E-03	ca	
1,1-Dichloroethylene	9.39E+02	1.23E+02		1.23E+02	nc	4.24E-02		4.24E-02	nc	8.49E-01		nc	2.25E+03	1.03E-01		1.03E-01	nc	
1,2-Dichloroethylene (cis)	7.08E+02	7.39E+02		7.08E+02	sat	4.06E-02		4.06E-02	nc	8.11E-01		nc	3.50E+03	1.42E-01		1.42E-01	nc	
1,2-Dichloroethylene (trans)	1.74E+03	6.88E+01		6.88E+01	nc	1.25E-02		1.25E-02	nc	2.50E-01		nc	6.30E+03	3.70E-02		3.70E-02	nc	
1,2-Dichloroethylene (mixture)	2.56E+03	1.17E+02		1.17E+02	nc	2.58E-02		2.58E-02	nc	5.15E-01		nc	3.50E+03	3.21E-02		3.21E-02	nc	
2,4-Dichlorophenol	1.77E+03	1.49E+02		1.49E+02	nc	1.82E-02		1.82E-02	nc	3.63E-01		nc	4.50E+03	3.68E-02		3.68E-02	nc	
(2,4-D) 2,4-Dichlorophenoxyacetic acid	9.48E+01	6.74E+02		9.48E+01	sat	3.58E-02		3.58E-02	nc	7.16E-01		nc	6.77E+02	1.49E-01		1.49E-01	nc	
1,2-Dichloropropane	1.04E+03	6.28E+00	8.84E+01	6.28E+00	nc	7.61E-04	2.95E-03	7.61E-04	nc	1.52E-02	5.91E-02	nc	4.40E+03	2.35E-03	9.12E-03	2.35E-03	nc	
1,3-Dichloropropene	9.15E+02	1.62E+01	7.66E+00	7.66E+00	ca	4.20E-03	1.30E-03	1.30E-03	ca	8.40E-02	2.59E-02	ca	2.80E+03	1.19E-02	3.66E-03	3.66E-03	ca	
Dieldrin	8.37E+00	2.48E+00	2.45E-01	2.45E-01	ca	2.19E-02	1.23E-03	1.23E-03	ca	4.37E-01	2.46E-02	ca	1.95E-01	5.08E-04	2.86E-05	2.86E-05	ca	
Diethyl phthalate	7.30E+02	3.96E+04		7.30E+02	sat	9.23E+00		9.23E+00	nc	1.85E+02		nc	1.08E+03	1.19E+01		1.19E+01	nc	
Dimethyl phthalate	4.64E+02	4.95E+05		4.64E+02	sat	3.31E+01		3.31E+01	nc	6.63E+02		nc	4.00E+03	1.53E+02		1.53E+02	nc	
N,N-Dimethylformamide	1.14E+05	4.95E+03		4.95E+03	nc	3.34E-01		3.34E-01	nc	6.68E+00		nc	1.00E+06	1.56E+00		1.56E+00	nc	
2,4-Dimethylphenol	4.08E+03	9.90E+02		9.90E+02	nc	1.67E-01		1.67E-01	nc	3.35E+00		nc	7.87E+03	2.71E-01		2.71E-01	nc	
Di-n-butyl phthalate	7.60E+02	4.95E+03		7.60E+02	sat	6.50E+01		6.50E+01	nc	1.30E+03		nc	1.12E+01	9.55E-01		9.55E-01	nc	
meta-Dinitrobenzene	2.00E+02	4.95E+00		4.95E+00	nc	7.64E-04		7.64E-04	nc	1.53E-02		nc	5.00E+02	1.53E-03		1.53E-03	nc	
ortho-Dinitrobenzene	8.35E+01	4.95E+00		4.95E+00	nc	9.89E-04		9.89E-04	nc	1.98E-02		nc	1.52E+02	1.52E-03		1.52E-03	nc	
2,4-Dinitrophenol	2.79E+02	9.83E+01		9.83E+01	nc	6.13E-03		6.13E-03	nc	1.23E-01		nc	2.79E+03	3.07E-02		3.07E-02	nc	
2,4-Dinitrotoluene	7.86E+01	9.94E+01	5.78E+00	5.78E+00	ca	1.17E-02	5.89E-04	3.73E-04	ca	2.35E-01	1.18E-02	ca	2.70E+02	3.00E-02	9.54E-04	9.54E-04	ca	
2,6-Dinitrotoluene	4.34E+01	4.91E+01	5.71E+00	5.71E+00	ca	5.12E-03	3.25E-04	3.25E-04	ca	1.02E-01	6.50E-03	ca	1.82E+02	1.51E-02	9.60E-04	9.60E-04	ca	
Di-n-octyl phthalate	2.44E+01	1.98E+03		2.44E+01	sat	2.46E+01		2.44E+01	sat	4.91E+02		sat	2.00E-02	2.01E-02		2.00E-02	sol	
1,4-Dioxane	1.02E+05		4.88E+02	4.88E+02	ca		1.23E-02	1.23E-02	ca		2.47E-01	ca	1.00E+06		6.09E-02	6.09E-02	ca	
Endosulfan II	2.23E+00	2.97E+02		2.23E+00	sat	3.98E-01		3.98E-01	nc	7.96E+00		sat	5.10E-01	8.89E-02		8.89E-02	nc	
Endrin	6.18E+00	1.49E+01		6.18E+00	sat	8.71E-02		8.71E-02	nc	1.74E+00		nc	2.50E-01	3.51E-03		3.51E-03	nc	
Ethylbenzene	1.50E+02	1.83E+03		1.50E+02	sat	3.60E-01		3.60E-01	nc	7.19E+00		nc	1.69E+02	3.77E-01		3.77E-01	nc	
Ethylene glycol	1.02E+05	1.48E+05		1.02E+05	sat	6.31E+00		6.31E+00	nc	1.26E+02		nc	1.00E+06	3.12E+01		3.12E+01	nc	
Fluoranthene	4.41E+01	1.90E+03		4.41E+01	sat	3.20E+01		3.20E+01	nc	6.40E+02		sat	2.06E-01	1.49E-01		1.49E-01	nc	
Fluorene	5.48E+01	1.90E+03		5.48E+01	sat	7.65E+00		7.65E+00	nc	1.53E+02		sat	1.98E+00	2.75E-01		2.75E-01	nc	
Fluoride		4.68E+03		4.68E+03	nc	2.13E-01		2.13E-01	nc	4.26E+00		nc	1.69E+00	9.32E-01		9.32E-01	nc	
Formaldehyde	6.96E+04	1.48E+04	2.01E+06	1.48E+04	nc	8.37E-01		8.37E-01	nc	1.67E+01		nc	4.00E+05	3.05E+00		3.05E+00	nc	
Formic acid	1.02E+05	9.90E+04		9.90E+04	nc	6.29E+00		6.29E+00	nc	1.26E+02		nc	1.00E+06	3.11E+01		3.11E+01	nc	
Heptachlor	5.10E+02	2.48E+01	8.70E-01	8.70E-01	ca	6.70E+00	1.41E-01	1.41E-01	ca	1.34E+02	2.82E+00	dc	1.80E-01	2.37E-03	4.99E-05	4.99E-05	ca	
Heptachlor Epoxide	3.33E+01	6.44E-01	4.30E-01	4.30E-01	ca	2.66E-02	9.93E-03	9.93E-03	ca	5.31E-01	1.99E-01	ca	2.00E-01	1.59E-04	5.96E-05	5.96E-05	ca	
Hexachloro-1,3-butadiene	2.77E+01	9.90E+00	5.02E+01	9.90E+00	nc	1.65E-02	4.87E-02	1.65E-02	nc	3.29E-01	9.75E-01	ca	2.54E+00	1.50E-03	4.44E-03	1.50E-03	nc	
Hexachlorobenzene	6.83E+02	3.96E+01	2.45E+00	2.45E+00	ca	2.70E-01	1.01E-02	1.01E-02	ca	5.40E+00	2.03E-01	ca	6.20E+00	2.45E-03	9.21E-05	9.21E-05	ca	
a-Hexachlorocyclohexane	5.12E+00	3.96E+02	6.22E-01	6.22E-01	ca	2.87E-01	2.50E-04	2.50E-04	ca	5.75E+00	4.99E-03	ca	2.00E+00	1.08E-01	9.38E-05	9.38E-05	ca	
b-Hexachlorocyclohexane	6.29E-01		2.18E+00	6.29E-01	sat		8.92E-04	8.92E-04	ca		1.78E-02	ca	2.40E-01		3.28E-04	3.28E-04	ca	
Hexachlorocyclopentadiene	7.21E+02	2.96E+02		2.96E+02	nc	1.16E+01		1.16E+01	nc	2.32E+02		nc	1.80E+00	2.89E-02		2.89E-02	nc	
Hexachloroethane	1.84E+02	4.95E+01	2.80E+02	4.95E+01	nc	4.12E-02	1.32E-01	4.12E-02	nc	8.25E-01	2.64E+00	ca	5.00E+01	1.09E-02	3.49E-02	1.09E-02	nc	
n-Hexane	1.35E+02	1.70E+02																

See Closure Plan Review Guidance

October 2009														
Table A-3: Residential Risk Based Generic Cleanup Numbers (GCNs) for Ohio Hazardous Waste Closures														
CONTAMINANT	1 Calculated Soil Saturation Limit (SAT)	2 Single Chemical Noncancer Direct Contact Soil	3 Single Chemical Cancer Direct Contact Soil	4 Single Chemical Direct Contact Soil	5 Single Chemical Noncancer Protective Of Ground Water (1 DAF)	6 Single Chemical Cancer Protective Of Ground Water (1 DAF)	7 Single Chemical Protective Of Ground Water (1 DAF)	8 Single Chemical Noncancer Protective Of Ground Water (20 DAF)	9 Single Chemical Cancer Protective Of Ground Water (20 DAF)	10 Single Chemical Protective Of Ground Water (20 DAF)	11 Solubility (SOL)	12 Single Chemical Noncancer Ground Water Concentration	13 Single Chemical Cancer Ground Water Concentration	14 Single Chemical Ground Water Concentration
	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
MCPP	1.70E+02	4.95E+01		4.95E+01	nc	4.03E-03		4.03E-03	nc	8.06E-02		8.06E-02	nc	1.36E-02
Mercury and compounds	3.13E+00	6.68E+00		3.13E+00	sat	6.94E-02		6.94E-02	nc	1.39E+00		1.39E+00	nc	1.33E-03
Methacrylonitrile	5.43E+03	7.39E+00		7.39E+00	nc	4.78E-04		4.78E-04	nc	9.55E-03		9.55E-03	nc	1.53E-03
Methanol	1.02E+05	3.70E+04		3.70E+04	nc	1.57E+00		1.57E+00	nc	3.15E+01		3.15E+01	nc	7.79E+00
Methoxychlor	8.80E+00	2.48E+02		8.80E+00	sat	9.89E+00		8.80E+00	sat	1.98E+02		8.80E+00	sat	4.50E-02
Methyl bromide	2.57E+03	3.87E+00		3.87E+00	nc	6.38E-04		6.38E-04	nc	1.28E-02		1.28E-02	nc	2.62E-03
Methyl ethyl ketone	5.59E+04	2.32E+04		2.32E+04	nc	5.94E-01		5.94E-01	nc	1.19E+01		1.19E+01	nc	2.30E+00
Methylene chloride	1.82E+03	9.34E+02	9.02E+01	9.02E+01	ca	8.78E-02	9.46E-03	9.46E-03	ca	1.76E+00	1.89E-01	1.89E-01	ca	4.09E-02
Methyl isobutyl ketone	6.59E+03	5.01E+03		5.01E+03	nc	3.24E-01		3.24E-01	nc	6.49E+00		6.49E+00	nc	7.27E-01
Methyl tert-butyl ether	5.94E+03	5.09E+03		5.09E+03	nc	3.45E-01		3.45E-01	nc	6.91E+00		6.91E+00	nc	1.61E+00
Methylmethacrylate	4.65E+03	4.22E+03		4.22E+03	nc	1.64E-01		1.64E-01	nc	3.28E+00		3.28E+00	nc	4.19E-01
1-Methylnaphthalene	1.21E+02	3.32E+03		1.21E+02	sat	2.59E+00		2.59E+00	nc	5.17E+01		5.17E+01	nc	5.39E-01
2-Methylnaphthalene	2.19E+02	1.90E+02		1.90E+02	nc	2.79E-01		2.79E-01	nc	5.58E+00		5.58E+00	nc	3.10E-02
2-Methylphenol	7.34E+03	2.48E+03		2.48E+03	nc	2.70E-01		2.70E-01	nc	5.40E+00		5.40E+00	nc	7.07E-01
4-Methylphenol	2.42E+04	2.48E+02		2.48E+02	nc	7.60E-02		7.60E-02	nc	1.52E+00		1.52E+00	nc	7.12E-02
Mirex	4.08E+03	9.90E+00		9.90E+00	nc	1.42E+02		9.90E+00	dc	2.84E+03		9.90E+00	dc	2.96E-03
Naphthalene	1.27E+02	6.90E+01		6.90E+01	nc	7.63E-03		7.63E-03	nc	1.53E-01		1.53E-01	nc	1.82E-03
Nickel (soluble salts)		1.42E+03		1.42E+03	nc	1.97E+01		1.97E+01	nc	3.95E+02		3.95E+02	nc	3.03E-01
Nickel Refinery Dust			1.09E+05	1.09E+05	ca			1.09E+05	dc			1.09E+05	dc	0.00E+00
2-Nitroaniline	3.02E+02	1.48E+02		1.48E+02	nc	1.35E-02		1.35E-02	nc	2.71E-01		2.71E-01	nc	4.43E-02
Nitrobenzene	4.79E+02	1.51E+01		1.51E+01	nc	3.44E-04		3.44E-04	nc	6.88E-03		6.88E-03	nc	1.05E-03
N-Nitrosodi-n-propylamine	1.46E+03		5.59E-01	5.59E-01	ca		2.32E-05	2.32E-05	ca		4.63E-04	4.63E-04	ca	9.34E-05
N-Nitrosodiphenylamine	9.41E+01	9.90E+02	7.99E+02	9.41E+01	sat	7.26E-01	3.26E-01	3.26E-01	ca	1.45E+01	6.51E+00	6.51E+00	ca	1.17E-01
Pentachlorobenzene	1.40E-01	3.96E+01		1.40E-01	sat	7.98E-04		7.98E-04	nc	1.60E-02		1.60E-02	nc	3.94E-03
Pentachloronitrobenzene	2.21E+01	1.49E+02		2.21E+01	sat	1.47E+00		1.47E+00	nc	2.94E+01		2.21E+01	sat	3.66E-02
Pentachlorophenol	2.50E+03	1.20E+03	2.61E+01	2.61E+01	ca	3.22E-01	4.12E-03	4.12E-03	ca	6.44E+00	8.24E-02	8.24E-02	ca	2.98E-03
Phenol	1.30E+04	1.49E+04		1.30E+04	sat	1.14E+00		1.14E+00	nc	2.28E+01		2.28E+01	nc	4.43E+00
Polychlorinated Biphenyls (PCBs)	4.33E+01	1.04E+00	2.06E+00	1.04E+00	nc	7.88E-03	9.19E-03	7.88E-03	nc	1.58E-01	1.84E-01	1.58E-01	nc	1.27E-04
n-Propylbenzene	3.59E+01	7.39E+02		3.59E+01	sat	1.24E-01		1.24E-01	nc	2.48E+00		2.48E+00	nc	7.79E-02
Pyrene	2.84E+01	1.42E+03		2.84E+01	sat	2.39E+01		2.39E+01	nc	4.78E+02		2.84E+01	sat	1.14E-01
Pyridine	2.00E+05	4.74E+01		4.74E+01	nc	4.62E-03		4.62E-03	nc	9.23E-02		9.23E-02	nc	1.54E-02
Quinoline	6.34E+04		1.25E+00	1.25E+00	ca		4.33E-05	4.33E-05	ca		8.66E-04	8.66E-04	ca	2.11E-04
Selenium		3.87E+02		3.87E+02	nc	4.01E-01		4.01E-01	nc	8.01E+00		8.01E+00	nc	7.65E-02
Silver		3.65E+02		3.65E+02	nc	6.58E-01		6.58E-01	nc	1.32E+01		1.32E+01	nc	7.74E-02
Silver Cyanide		7.29E+03		7.29E+03	nc	2.81E-01		4.81E-02	sol	5.61E+00		9.61E-01	sol	2.30E-01
Silvex	7.42E+02	3.96E+02		3.96E+02	nc	5.59E-01		5.59E-01	nc	1.12E+01		1.12E+01	nc	1.04E-01
Styrene	5.19E+02	4.29E+03		5.19E+02	sat	8.46E-01		8.46E-01	nc	1.69E+01		1.69E+01	nc	4.80E-01
2,3,7,8 -TCDD (Dioxin)	9.26E-02		3.58E-05	3.58E-05	ca		2.20E-06	2.20E-06	ca		4.40E-05	3.58E-05	dc	4.58E-10
1,2,4,5-Tetrachlorobenzene	1.96E+00	1.49E+01		1.96E+00	sat	6.62E-03		6.62E-03	nc	1.32E-01		1.32E-01	nc	5.95E-01
1,1,1,2-Tetrachloroethane	1.01E+03	2.22E+03	2.28E+01	2.28E+01	ca	3.92E-01	4.01E-03	4.01E-03	ca	7.84E+00	8.02E-02	8.02E-02	ca	1.10E+03
1,1,2,2-Tetrachloroethane	8.95E+02	4.44E+03	4.11E+00	4.11E+00	ca		2.07E-04	2.07E-04	ca		4.14E-03	4.14E-03	ca	2.97E+03
Tetrachloroethylene (PCE)	1.10E+02	4.26E+01	4.86E+01	4.26E+01	nc	1.19E-02	5.59E-03	5.59E-03	ca	2.38E-01	1.12E-01	1.12E-01	ca	2.00E+02
2,3,4,6-Tetrachlorophenol	1.27E+03	1.49E+04		1.27E+03	sat	3.15E+01		3.15E+01	nc	6.29E+02		6.29E+02	nc	1.00E+02
Tetrahydrofuran	4.10E+04	1.75E+03	1.23E+02	1.23E+02	ca	4.10E-02	3.61E-03	3.61E-03	ca	8.20E-01	7.22E-02	7.22E-02	ca	3.00E+05
Thallium		6.24E+00		6.24E+00	nc	8.85E-02		8.85E-02	nc	1.77E+00		1.77E+00	nc	1.24E-03
Toluene	2.71E+02	3.54E+03		2.71E+02	sat	4.03E-01		4.03E-01	nc	8.05E+00		8.05E+00	nc	5.26E+02
Toxaphene	3.80E+02	4.95E+01	3.56E+00	3.56E+00	ca	5.63E+00	2.29E-01	2.29E-01	ca	1.13E+02	4.58E+00	3.56E+00	dc	7.40E-01
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	1.10E+02	2.26E+04		8.14E+02	sat	4.77E+01		4.77E+01	nc	9.53E+02		8.14E+02	sat	1.70E+02
1,2,4-Trichlorobenzene	1.10E-01	6.93E+01		1.10E-01	sat	8.92E-03		8.92E-03	nc	1.78E-01		1.10E-01	sat	3.00E-02
1,1,1-Trichloroethane	6.01E+02	1.96E+03		6.01E+02	sat	4.85E-01		4.85E-01	nc	9.70E+00		9.70E+00	nc	1.33E+03
1,1,2-Trichloroethane	9.16E+02	2.96E+02	7.21E+00	7.21E+00	ca	1.75E-02	5.67E-04	5.67E-04	ca	3.50E-01	1.13E-02	1.13E-02	ca	4.42E+03
Trichloroethylene (TCE)	5.62E+02	2.84E+01	3.43E+01	2.84E+01	nc	6.24E-03	8.49E-03	6.24E-03	nc	1.25E-01	1.70E-01	1.25E-01	nc	1.10E+02
Trichlorofluoromethane	1.04E+03	3.41E+02		3.41E+02	nc	2.86E-01		2.86E-01	nc	5.71E+00		5.71E+00	nc	1.00E+03
2,4,5-Trichlorophenol	3.96E+03	4.95E+03		3.96E+03	sat	3.29E+00		3.29E+00	nc	6.59E+01		6.59E+01	nc	1.20E+03
2,4,6-Trichlorophenol	6.90E+02		3.56E+02	3.56E+02	ca		4.22E-02	4.22E-02	ca		8.44E-01	8.44E-01	ca	8.00E+02
2,4,5 -Trichlorophenoxyacetic acid (2,4,5-T)	1.26E+02	4.95E+02		1.26E+02	sat	6.68E-02		6.68E-02	nc	1.34E+00		1.34E+00	nc	2.68E+02
1,2,3-Trichloropropane	4.49E+02	9.55E+01	8.58E-01	8.58E-01	ca	3.96E-03	3.14E-05	3.14E-05	ca	7.93E-02	6.29E-04	6.29E-04	ca	1.75E+03
Triethylamine	2.33E+04	6.34E+01		6.34E+01	nc	1.78E-03		1.78E-03	nc	3.55E-02		3.55E-02	nc	7.37E+04
1,2,4-Trimethylbenzene	9.05E+01	2.21E+01		2.21E+01	nc	5.98E-03		5.98E-03	nc	1.20E-01		1.20E-01	nc	5.70E+01
1,3,5-Trimethylbenzene	7.17E+01	1.79E+01		1.79E+01	nc	5.59E-03		5.59E-03	nc	1.12E-01		1.12E-01	nc	4.82E+01
1,3,5-Trinitrobenzene	1.08E+02	1.49E+03		1.08E+02	sat	1.90E-01		1.90E-01	nc	3.80E+00		3.80E+00	nc	3.50E+02
Vanadium		6.33E+02		6.33E+02	nc	6.98E+00		6.98E+00	nc	1.40E+02		1.40E+02	nc	1.12E-01

Table A-3: Residential Risk Based Generic Cleanup Numbers (GCNs) for Ohio Hazardous Waste Closures														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	
CONTAMINANT	Calculated Soil Saturation Limit (SAT)	Single Chemical Noncancer Direct Contact Soil	Single Chemical Cancer Direct Contact Soil	Single Chemical Direct Contact Soil	Single Chemical Noncancer Protective Of Ground Water (1 DAF)	Single Chemical Cancer Protective Of Ground Water (1 DAF)	Single Chemical Protective Of Ground Water (1 DAF)	Single Chemical Noncancer Protective Of Ground Water (20 DAF)	Single Chemical Cancer Protective Of Ground Water (20 DAF)	Solubility (SOL)	Single Chemical Noncancer Ground Water Concentration	Single Chemical Cancer Ground Water Concentration	Single Chemical Ground Water Concentration	
	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	
Vinyl acetate	2.29E+03	4.22E+02		4.22E+02	nc	2.57E-02		2.57E-02	nc	5.14E-01		5.14E-01	nc	
Vinyl chloride	9.49E+02	3.86E+01	1.48E+00	1.48E+00	ca	8.46E-03	1.34E-04	1.34E-04	ca	2.76E+03	2.54E-02	4.01E-04	nc	
Xylene (mixed)	1.70E+02	2.70E+02		1.70E+02	sat	6.22E-02		6.22E-02	nc	1.24E+00		1.24E+00	nc	
m-Xylene	1.56E+02	1.06E+02		1.06E+02	nc	6.16E-02		6.16E-02	nc	1.23E+00		1.23E+00	nc	
o-Xylene	1.54E+02	2.68E+02		1.54E+02	sat	5.59E-02		5.59E-02	nc	1.12E+00		1.12E+00	nc	
p-Xylene	1.73E+02	2.44E+02		1.73E+02	sat	5.95E-02		5.95E-02	nc	1.19E+00		1.19E+00	nc	
Zinc	2.31E+04	2.31E+04		2.31E+04	nc	2.87E+02		2.87E+02	nc	5.73E+03		5.73E+03	nc	

Table A-4: MCL-Based Generic Cleanup Numbers

CONTAMINANT	1 Maximum Contaminant Level (MCL) (mg/l)	2 Single Chemical MCL- Based Protective of Ground Water (1 DAF) (mg/kg)	3 Single Chemical MCL- Based Protective of Ground Water (20 DAF) (mg/kg)
Antimony	6.00E-03	2.72E-01	5.43E+00
Arsenic	1.00E-02	NA	NA
Barium and compounds	2.00E+00	NA	NA
Benzene	5.00E-03	1.69E-03	3.38E-02
Benzo[a]pyrene	2.00E-04	4.08E-01	8.16E+00
Beryllium	4.00E-03	3.16E+00	6.32E+01
Bis(2-ethylhexyl)phthalate	6.00E-03	1.81E+02	3.62E+03
Bromodichloromethane	1.00E-01	3.16E-02	6.31E-01
Bromoform	1.00E-01	3.76E-02	7.52E-01
Cadmium and compounds**	5.00E-03	3.77E-01	7.53E+00
Carbon tetrachloride	5.00E-03	3.28E-03	6.56E-02
Chlordane	2.00E-04	4.80E-02	9.61E-01
Chlorobenzene	1.00E-01	6.51E-02	1.30E+00
Chromium III	1.00E-01	NA	NA
Chromium VI	1.00E-01	NA	NA
Cyanide, Free	2.00E-01	5.83E-02	1.17E+00
Dalapon	2.00E-01	4.11E-02	8.22E-01
Dibromochloromethane	1.00E-01	3.29E-02	6.58E-01
1,2-Dibromoethane	5.00E-05	1.15E-05	2.30E-04
Dichloroacetic acid	6.00E-02	2.10E-02	4.20E-01
1,2-Dichlorobenzene	6.00E-01	8.64E-01	1.73E+01
1,4-Dichlorobenzene	7.50E-02	1.08E-01	2.16E+00
1,2-Dichloroethane	5.00E-03	1.19E-03	2.38E-02
1,1-Dichloroethylene	7.00E-03	2.87E-03	5.75E-02
1,2-Dichloroethylene (cis)	7.00E-02	2.00E-02	4.00E-01
1,2-Dichloroethylene (trans)	1.00E-01	3.38E-02	6.77E-01
(2,4-D) 2,4-Dichlorophenoxyacetic acid	7.00E-02	1.68E-02	3.36E-01
1,2-Dichloropropane	5.00E-03	1.62E-03	3.24E-02
Endrin	2.00E-03	4.96E-02	9.92E-01
Ethylbenzene	7.00E-01	6.68E-01	1.34E+01
Fluoride	4.00E+00	NA	NA
Heptachlor	4.00E-04	1.13E+00	2.26E+01
Heptachlor Epoxide	2.00E-04	3.33E-02	6.66E-01
Hexachlorobenzene	1.00E-03	1.10E-01	2.20E+00
Hexachlorocyclopentadiene	5.00E-02	2.00E+01	4.00E+02
Lindane	2.00E-04	4.72E-04	9.44E-03
Mercury and compounds	2.00E-03	1.04E-01	2.09E+00
Methoxychlor	4.00E-02	7.82E+00	1.56E+02
Methylene chloride	5.00E-03	1.16E-03	2.31E-02
Pentachlorophenol	1.00E-03	1.38E-03	2.77E-02
Polychlorinated Biphenyls (PCBs)	5.00E-04	3.10E-02	6.20E-01
Selenium	5.00E-02	2.62E-01	5.23E+00
Silvex	5.00E-02	2.70E-01	5.40E+00
Styrene	1.00E-01	1.76E-01	3.52E+00
2,3,7,8 -TCDD (Dioxin)	3.00E-08	1.44E-04	2.88E-03
Tetrachloroethylene (PCE)	5.00E-03	2.88E-03	5.75E-02
Thallium	2.00E-03	NA	NA
Toluene	1.00E+00	5.88E-01	1.18E+01
Toxaphene	3.00E-03	1.54E+00	3.09E+01
1,2,4-Trichlorobenzene	7.00E-02	2.64E-01	5.27E+00
1,1,1-Trichloroethane	2.00E-01	9.62E-02	1.92E+00
1,1,2-Trichloroethane	5.00E-03	1.52E-03	3.03E-02
Trichloroethylene (TCE)	5.00E-03	2.84E-03	5.69E-02
Vinyl chloride	2.00E-03	6.66E-04	1.33E-02
Xylene (mixed)	1.00E+01	1.04E+01	2.09E+02

Please note that this information may have been updated since this table was published, and a more current version of this table may be available on DHWM's website.

Legend:

MCL = Maximum Contaminant Level

NA = Not Applicable

Notes:

1 - Maximum Contaminant Levels (MCLs) based on federal primary drinking water standards (OAC 3745-81-11 and 3745-81-12).

2 - Single chemical cleanup number for ingestion of soil and ground water based on the Maximum Contaminant Level with no dilution or attenuation.

3 - Single chemical cleanup number for ingestion of soil and ground water based on the Maximum Contaminant Level with some dilution and attenuation.

Table A-5: Chemical Specific Values for the Generic Cleanup Numbers

CONTAMINANT	Dermal Absorption Factor (unitless)	Oral Absorption Factor (unitless)	Permeability Constant (cm/hr)	Koc (l/kg)	Kd Values (l/kg)	Henry's Law Constant at 25° C (atms-m3/mole)	Henry's Law Constant (unitless)	SFo (mg/kg-day) ⁻¹	S o u r c e (mg/kg-day)	RfDo (mg/kg-day)	S o u r c e (mg/kg-day) ⁻¹	SFi (mg/kg-day) ⁻¹	S o u r c e (mg/kg-day)	RfDi (mg/kg-day)	S o u r c e (mg/kg-day)	Particulate Emission Factor (m ³ /kg)	Volatilization Factor (m ³ /kg)
Acenaphthene	0.13	0.58	8.39E-02	4.90E+03	9.80E+00	1.55E-04	6.36E-03			6.0E-02	i					1.36E+09	2.85E+05
Acetone	0.01	0.74	5.20E-04	5.75E-01	1.15E-03	3.88E-05	1.59E-03			9.0E-01	i			8.9E+00	a	1.36E+09	1.25E+04
Acetonitrile	0.01	0.5	5.57E-04	1.60E+01	3.20E-02	3.45E-05	1.41E-03							1.7E-02	i	1.36E+09	1.79E+04
Acetophenone	0.10	0.5	3.71E-03	1.00E+01	2.00E-02	1.04E-05	4.26E-04			1.0E-01	i			5.7E-06	w	1.36E+09	4.23E+04
Acrolein	0.01	0.5	7.58E-04	3.00E+00	6.00E-03	1.22E-04	4.99E-03			5.0E-04	i			5.7E-06	i	1.36E+09	8.20E+03
Acrylonitrile	0.01	0.5	1.17E-03	3.30E+01	6.60E-02	1.38E-04	5.66E-03	5.4E-01	i	1.0E-03	h	2.4E-01	i	5.7E-04	i	1.36E+09	1.21E+04
Aldrin	0.10	0.5	2.80E-01	4.87E+04	9.74E+01	1.70E-04	6.97E-03	1.7E+01		3.0E-05	i	1.7E+01	i			1.36E+09	nv
Aluminum	0.001	0.001	1.00E-03	1.43E+01	2.86E-02					1.0E+00	n			1.4E-03	n	1.36E+09	
Aluminum phosphide	0.001	0.001	1.00E-03	1.43E+01	2.86E-02					4.0E-04	i					1.36E+09	
Aniline	0.10	0.5	1.87E-03	4.38E+01	8.76E-02	2.02E-06	8.28E-05	5.7E-03	i	7.0E-03	n			2.9E-04	i	1.36E+09	nv
Anthracene	0.13	0.58	1.60E-01	2.95E+04	5.90E+01	6.50E-05	2.67E-03			3.0E-01	i					1.36E+09	7.77E+05
Antimony	0.001	0.15	1.00E-03	1.43E+01	4.50E+01	2.45E-02	1.00E+00			4.0E-04	i			5.7E-05	w	1.36E+09	
Aroclor 1016	0.14	0.8	4.43E-02	1.70E+04	3.40E+01	2.30E-04	9.43E-03	2.0E+00	i	7.0E-05	i	4.0E-01	i			1.36E+09	nv
Aroclor 1221	0.14	0.8	6.67E-02	6.31E+03	1.26E+01	4.10E-04	1.68E-02	2.0E+00	i			4.0E-01	i			1.36E+09	1.96E+05
Aroclor 1232	0.14	0.8	9.09E-02	1.00E+04	2.00E+01	3.10E-04	1.27E-02	2.0E+00	i			4.0E-01	i			1.36E+09	nv
Aroclor 1242	0.14	0.8	2.82E-02	1.00E+04	2.00E+01	3.10E-04	1.27E-02	2.0E+00	i			4.0E-01	i			1.36E+09	nv
Aroclor 1248	0.14	0.8	4.78E-01	2.51E+04	5.02E+01	1.60E-04	6.56E-03	2.0E+00	i			4.0E-01	i			1.36E+09	nv
Aroclor 1254	0.14	0.8	3.36E-01	4.25E+04	8.50E+01	3.40E-04	1.39E-02	2.0E+00	i	2.0E-05	i	4.0E-01	i			1.36E+09	nv
Aroclor 1260	0.14	0.8	3.84E-01	2.07E+05	4.14E+02	7.40E-05	3.03E-03	2.0E+00	i			4.0E-01	i			1.36E+09	nv
Arsenic	0.03	0.95	1.00E-03		2.50E+01			1.5E+00	i	3.0E-04	i	1.5E+01	i			1.36E+09	
Barium and compounds	0.001	0.07	1.00E-03		4.10E+01					7.0E-02	i			1.4E-04	h	1.36E+09	
Benz[a]anthracene	0.13	0.58	4.83E-01	3.98E+05	7.96E+02	3.35E-06	1.37E-04	7.3E-01	n*			7.3E-01	n*			1.36E+09	nv
Benzene	0.01	0.9	1.47E-02	5.89E+01	1.18E-01	5.55E-03	2.28E-01	5.5E-02	i	4.0E-03	i	2.7E-02	i	8.6E-03	i	1.36E+09	2.71E+03
Benzidine	0.10	0.5	1.13E-03	2.27E+05	4.54E+02	5.20E-11	2.13E-09	2.3E+02	i	3.0E-03	i	2.3E+02	i			1.36E+09	nv
Benzo[a]pyrene	0.13	0.58	6.60E-01	1.02E+06	2.04E+03	1.13E-06	4.63E-05	7.3E+00	i			7.3E+00	n*			1.36E+09	nv
Benzo[b]fluoranthene	0.13	0.58	7.57E-01	1.23E+06	2.46E+03	1.11E-04	4.55E-03	7.3E-01	n*			7.3E-01	n*			1.36E+09	nv
Benzo[k]fluoranthene	0.13	0.58	7.57E-01	1.23E+06	2.46E+03	8.29E-07	3.40E-05	7.3E-02	n*			7.3E-02	n*			1.36E+09	nv
Benzoic acid	0.10	0.5	5.54E-03	5.76E-01	1.15E-03	1.54E-06	6.31E-05			4.0E+00	i					1.36E+09	nv
Beryllium	0.001	0.007	1.00E-03		7.90E+02	1.54E-02	6.31E-01			2.0E-03	i	8.4E+00	i	5.7E-03	i	1.36E+09	
Bis(2-chloro-1-methylethyl)ether	0.10	0.5	7.56E-03	4.70E+01	9.40E-02	7.40E-05	3.03E-03	7.0E-02	h	4.0E-02	i	3.5E-02	h			1.36E+09	3.26E+04
Bis(2-chloroethyl)ether	0.10	0.5	1.58E-03	1.55E+01	3.10E-02	1.80E-05	7.38E-04	1.1E+00	i			1.2E+00	i			1.36E+09	3.32E+05
Bis(2-ethylhexyl)phthalate	0.10	0.25	6.77E-01	1.51E+07	3.02E+04	1.02E-07	4.18E-06	1.4E-02	i	2.0E-02	i					1.36E+09	nv
Bromodichloromethane	0.01	0.5	4.66E-03	5.50E+01	1.10E-01	1.60E-03	6.56E-02	6.2E-02	i	2.0E-02	i					1.36E+09	8.20E+03
Bromoform	0.01	0.5	2.17E-03	8.71E+01	1.74E-01	5.35E-04	2.19E-02	7.9E-03	i	2.0E-02	i	3.9E-03	i			1.36E+09	nv
Butanol	0.01	0.5	2.22E-03	6.92E+00	1.38E-02	8.81E-06	3.61E-04			1.0E-01	i					1.36E+09	nv
n-Butylbenzene	0.01	0.5	2.18E-01	2.83E+03	5.66E+00	1.31E-02	5.37E-01			1.0E-02	n					1.36E+09	1.13E+04
sec-Butylbenzene	0.01	0.5	2.91E-01	2.15E+03	4.30E+00	1.86E-02	7.63E-01			1.0E-02	n					1.36E+09	8.27E+03
tert-Butylbenzene	0.01	0.5	1.45E-01	2.20E+03	4.40E+00	1.32E-02	5.41E-01			1.0E-02	n					1.36E+09	1.15E+04
Butyl benzyl phthalate	0.10	0.5	4.42E-02	5.75E+04	1.15E+02	1.26E-06	5.17E-05			2.0E-01	i					1.36E+09	nv
Cadmium and compounds**	0.001	0.025	1.00E-03		7.50E+01	3.08E-02	1.26E+00			5.0E-04	i	6.3E+00	i	5.7E-05	x	1.36E+09	
Carbazole	0.13	0.58	4.30E-02	3.39E+03	6.78E+00	1.53E-08	6.27E-07	2.0E-02	h							1.36E+09	nv
Carbon disulfide	0.01	0.5	1.24E-02	4.57E+01	9.14E-02	3.03E-02	1.24E+00			1.0E-01	i			2.0E-01	i	1.36E+09	1.18E+03
Carbon tetrachloride	0.01	0.85	1.39E-02	1.74E+02	3.48E-01	3.04E-02	1.25E+00	1.3E-01	i	7.0E-04	i	5.3E-02	i	5.7E-04	n	1.36E+09	2.05E+03
Chlordane	0.04	0.8	1.19E-01	1.20E+05	2.40E+02	4.86E-05	1.99E-03	3.5E-01	i	5.0E-04	i	3.5E-01	i	2.0E-04	i	1.36E+09	nv
p-Chloroaniline	0.10	0.5	5.09E-03	6.61E+01	1.32E-01	3.31E-07	1.36E-05			4.0E-03	i					1.36E+09	nv
Chlorobenzene	0.01	0.2	2.87E-02	2.87E+02	4.38E-01	3.70E-03	1.52E-01			2.0E-02	i			1.7E-02	n	1.36E+09	6.23E+03
Chlorobenzilate	0.10	0.5	3.22E-02	1.10E+03	2.20E+00	7.20E-08	2.95E-06			2.0E-03	i					1.36E+09	nv
Chloroethane	0.01	0.5	6.06E-03	2.40E+01	4.80E-02	1.11E-02	4.55E-01	2.9E-03	n	4.0E-01	n			2.9E+00	i	1.36E+09	1.44E+03
Chloroform	0.01	1.0	6.29E-03	3.98E+01	7.96E-02	3.67E-03	1.50E-01	1.0E-02	i	1.0E-02	i	8.1E-02	i	9.8E-02	a	1.36E+09	2.64E+03
Chloromethane	0.01	0.5	3.30E-03	1.40E+01	2.80E-02	8.82E-03	3.62E-01							2.6E-02	i	1.36E+09	1.38E+03
2-Chloronaphthalene	0.10	0.5	7.88E-02	3.00E+03	6.00E+00	3.20E-04	1.31E-02			8.0E-02	i					1.36E+09	1.09E+05
2-Chlorophenol	0.10	0.5	7.93E-03	3.88E+02	7.76E-01	3.91E-04	1.60E-02			5.0E-03	i					1.36E+09	3.00E+04
Chromium III	0.001	0.013	1.00E-03		1.80E+06					1.5E+00	i			1.5E+00	r	1.36E+09	
Chromium VI	0.001	0.025	2.00E-03		1.90E+01					3.0E-03	i	4.2E+01	i	2.9E-05	i	1.36E+09	
Chrysene	0.13	0.58	4.83E-01	3.98E+05	7.96E+02	9.46E-05	3.88E-03	7.3E-03	n*			7.3E-03	n*			1.36E+09	nv

Table A-5: Chemical Specific Values for the Generic Cleanup Numbers

CONTAMINANT	Dermal Absorption Factor (unitless)	Oral Absorption Factor (unitless)	Permeability Constant (cm/hr)	Koc (l/kg)	Kd Values (l/kg)	Henry's Law Constant at 25 ^o C (atms-m3/mole)	Henry's Law Constant (unitless)	SFo (mg/kg-day) ⁻¹	S o u r c e (mg/kg-day)	RfDo (mg/kg-day)	S o u r c e (mg/kg-day) ⁻¹	SFi (mg/kg-day)	S o u r c e (mg/kg-day)	RfDi (mg/kg-day)	S o u r c e (mg/kg-day)	Particulate Emission Factor (m ³ /kg)	Volatilization Factor (m ³ /kg)
Cobalt	0.001	0.18	4.00E-04		4.50E+01					2.0E-02	n	9.8E+00	n	5.7E-06	n	1.36E+09	
Copper	0.001	0.24	1.00E-03		3.50E+01	2.45E-02	1.00E+00			3.7E-02	h					1.36E+09	
Cyanide, Free	0.001	0.2	1.00E-03	2.71E+00	5.42E-03	2.42E-02	9.92E-01			2.0E-02	i					1.36E+09	7.13E+02
Cyclohexane	0.01	0.5	9.98E-02	1.60E+02	3.20E-01	1.50E-01	6.15E+00							1.7E+00	i	1.36E+09	8.69E+02
Dalapon	0.10	0.5	8.21E+02	2.73E+00	5.46E-03	6.30E-08	2.58E-06			3.0E-02	i					1.36E+09	nv
Dibenz[ah]anthracene	0.13	0.58	1.14E+00	3.80E+06	7.60E+03	1.47E-08	6.03E-07	7.3E+00	n*			7.3E+00	n*			1.36E+09	nv
Dibenzofuran	0.13	0.58	9.49E-02	4.20E+03	8.40E+00	2.10E-04	8.61E-03			4.0E-03	x					1.36E+09	1.20E+05
Dibromochloromethane	0.01	0.5	2.92E-03	6.31E+01	1.26E-01	7.83E-04	3.21E-02	8.4E-02	i	2.0E-02	i					1.36E+09	nv
1,2-Dibromoethane	0.01	0.5	2.76E-03	1.40E+01	2.80E-02	6.50E-04	2.67E-02	2.0E+00	i	9.0E-03	i	2.1E+00	i	2.1E+00	i	1.36E+09	5.36E+03
Dichloroacetic acid	0.10	0.5	1.22E-03	7.50E+01	1.50E-01	6.80E-08	2.79E-06	5.0E-02	i	4.0E-03	i					1.36E+09	nv
1,2-Dichlorobenzene	0.01	0.5	4.37E-02	6.17E+02	1.23E+00	1.90E-03	7.79E-02			9.0E-02	i			8.6E-03	n	1.36E+09	1.45E+04
1,3-Dichlorobenzene	0.01	0.5	5.09E-02	3.00E+02	6.00E-01	2.83E-03	1.16E-01			9.0E-04	n					1.36E+09	8.45E+03
1,4-Dichlorobenzene	0.01	1.0	4.31E-02	6.17E+02	1.23E+00	2.43E-03	9.96E-02	2.4E-02	h	3.0E-02	n	2.2E-02	n	2.3E-01	i	1.36E+09	1.29E+04
3,3-Dichlorobenzidine	0.10	0.5	1.26E-02	7.24E+02	1.45E+00	4.00E-09	1.64E-07	4.5E-01	i							1.36E+09	nv
Dichlorodifluoromethane	0.01	0.5	8.88E-03	3.56E+02	7.12E-01	3.43E-01	9.23E+00			2.0E-01	i			5.7E-02	h	1.36E+09	1.13E+03
(DDD) Dichlorodiphenyldichloroethane	0.03	0.7	2.71E-01	1.00E+06	2.00E+03	4.00E-06	1.64E-04	2.4E-01	i							1.36E+09	nv
(DDE) Dichlorodiphenyldichloroethane	0.03	0.7	7.60E-01	4.47E+06	8.94E+03	2.10E-05	8.61E-04	3.4E-01	i							1.36E+09	nv
(DDT) Dichlorodiphenyltrichloroethane	0.03	0.7	3.35E-01	2.63E+06	5.26E+03	8.10E-06	8.61E-04	3.4E-01	i	5.0E-04	i	3.4E-01	i			1.36E+09	nv
1,1-Dichloroethane	0.01	0.5	6.71E-03	3.16E+01	6.32E-02	5.62E-03	2.30E-01			1.0E-01	h			1.4E-01	h	1.36E+09	2.41E+03
1,2-Dichloroethane	0.01	1.0	4.13E-03	1.74E+01	3.48E-02	9.79E-04	4.01E-02	9.1E-02	i	3.0E-02	n	9.1E-02	i	1.4E-03	n	1.36E+09	3.89E+03
1,1-Dichloroethylene	0.01	0.5	1.16E-02	5.89E+01	1.18E-01	2.61E-02	1.07E+00			5.0E-02	i			5.7E-02	i	1.36E+09	1.42E+03
1,2-Dichloroethylene (cis)	0.01	0.5	7.67E-03	3.55E+01	7.10E-02	4.08E-03	1.67E-01			1.0E-02	n					1.36E+09	2.88E+03
1,2-Dichloroethylene (trans)	0.01	0.5	1.06E-02	5.25E+01	1.05E-01	9.38E-03	3.85E-01			2.0E-02	i			2.0E-02	a	1.36E+09	2.31E+03
1,2-Dichloroethylene (mixture)	0.01	0.5	7.67E-03	2.90E+02	5.80E-01	7.30E-03	2.76E-01			9.0E-03	h			2.0E-02	a	1.36E+09	4.53E+03
2,4-Dichlorophenol	0.10	0.5	2.09E-02	1.47E+02	2.94E-01	3.16E-06	1.30E-04			3.0E-03	i					1.36E+09	nv
(2,4-D) 2,4-Dichlorophenoxyacetic acid	0.05	0.9	6.56E-03	2.00E+01	4.00E-02	8.60E-06	4.18E-07			1.0E-02	i					1.36E+09	nv
1,2-Dichloropropane	0.01	0.5	7.37E-03	5.70E+01	1.14E-01	4.90E-03	1.15E-01	6.8E-02	h	9.0E-02	a			1.1E-03	i	1.36E+09	3.66E+03
1,3-Dichloropropene	0.01	0.5	7.92E-03	4.57E+01	9.14E-02	1.77E-02	7.26E-01	1.0E-01	i	3.0E-02	i	1.4E-02	i	5.7E-03	i	1.36E+09	1.83E+03
Dieldrin	0.10	0.5	4.08E-02	2.14E+04	4.28E+01	1.51E-05	6.19E-04	1.6E+01	i	5.0E-05	i	1.6E+01	i			1.36E+09	nv
Diethyl phthalate	0.10	0.5	3.93E-03	2.88E+02	5.76E-01	4.50E-07	1.85E-05			8.0E-01	i					1.36E+09	nv
Dimethyl phthalate	0.10	0.5	1.47E-03	8.00E+00	1.60E-02	2.00E-07	4.31E-06			1.0E+01	h			1.0E+01	h	1.36E+09	nv
N,N-Dimethylformamide	0.10	0.5	1.33E-04	7.00E+00	1.40E-02	7.40E-08	3.03E-06			1.0E-01	h			8.6E-03	i	1.36E+09	nv
2,4-Dimethylphenol	0.10	0.5	1.18E-02	2.09E+02	4.18E-01	2.00E-06	8.20E-05			2.0E-02	i					1.36E+09	nv
Di-n-butyl phthalate	0.10	0.5	4.83E-02	3.39E+04	6.78E+01	9.38E-10	3.85E-08			1.0E-01	i					1.36E+09	nv
meta-Dinitrobenzene	0.10	0.5	1.75E-03	1.50E+02	3.00E-01	4.90E-08	1.53E-05			1.0E-04	i					1.36E+09	nv
ortho-Dinitrobenzene	0.10	0.5	2.00E-03	2.25E+02	4.49E-01	8.39E-08	3.44E-06			1.0E-04	n					1.36E+09	nv
2,4-Dinitrophenol	0.10	0.5	1.56E-03	1.20E-02	2.40E-05	4.43E-07	1.82E-05			2.0E-03	i					1.36E+09	nv
2,4-Dinitrotoluene	0.10	0.5	3.21E-03	9.55E+01	1.91E-01	9.26E-08	3.80E-06	6.8E-01	i	2.0E-03	i					1.36E+09	nv
2,6-Dinitrotoluene	0.10	0.5	2.60E-03	6.92E+01	1.38E-01	7.47E-07	3.06E-05	6.8E-01	i	1.0E-03	h					1.36E+09	nv
Di-n-octyl phthalate	0.10	0.5	2.28E+00	6.10E+05	1.22E+03	6.68E-05	1.82E-05			4.0E-02	n					1.36E+09	nv
1,4-Dioxane	0.03	0.5	3.38E-04	1.23E+00	2.46E-03	4.80E-06	1.97E-04	1.1E-02	i							1.36E+09	nv
Endosulfan II	0.10	0.5	4.24E-03	2.14E+03	4.28E+00	1.12E-05	4.59E-04			6.0E-03	i					1.36E+09	nv
Endrin	0.10	0.5	2.55E-02	1.23E+04	2.46E+01	7.52E-06	3.08E-04			3.0E-04	i					1.36E+09	nv
Ethylbenzene	0.01	0.5	4.76E-02	3.63E+02	7.26E-01	7.88E-03	3.23E-01			1.0E-01	i			2.9E-01	i	1.36E+09	5.36E+03
Ethylene glycol	0.01	0.5	9.01E-05	1.00E+00	2.00E-03	6.00E-08	2.46E-06			2.0E+00	i					1.36E+09	nv
Fluoranthene	0.13	0.58	2.80E-01	1.07E+05	2.14E+02	1.61E-05	6.60E-04			4.0E-02	i					1.36E+09	nv
Fluorene	0.13	0.58	1.12E-01	1.38E+04	2.76E+01	6.36E-05	2.61E-03			4.0E-02	i					1.36E+09	5.08E+05
Fluoride	0.001	0.9	1.00E-03	1.43E+01	2.86E-02					6.0E-02	i					1.36E+09	
Formaldehyde	0.01	0.5	1.83E-03	3.70E+01	7.40E-02	3.40E-07	1.39E-05			2.0E-01	i	4.6E-02	i	2.9E-03	a	1.36E+09	nv
Formic acid	0.10	0.5	3.85E-04	1.00E+00	2.00E-03	1.67E-07	6.85E-06			2.0E+00	h			8.6E+00	n	1.36E+09	nv
Heptachlor	0.10	0.5	1.74E-01	1.41E+06	2.82E+03	1.48E+00	6.07E+01	4.5E+00	i	5.0E-04	i	4.6E+00	i			1.36E+09	nv
Heptachlor Epoxide	0.10	0.5	2.09E-02	8.32E+04	1.66E+02	9.50E-06	3.90E-04	9.1E+00	i	1.3E-05	i	9.1E+00	i			1.36E+09	nv
Hexachloro-1,3-butadiene	0.10	0.5	8.21E-02	5.37E+03	1.07E+01	8.15E-03	3.34E-01	7.8E-02	i	2.0E-04	h	7.7E-02	i			1.36E+09	nv
Hexachlorobenzene	0.10	0.5	3.11E-01	5.50E+04	1.10E+02	1.32E-03	5.41E-02	1.6E+00	i	8.0E-04	i	1.6E+00	i			1.36E+09	nv

Table A-5: Chemical Specific Values for the Generic Cleanup Numbers

CONTAMINANT	Dermal Absorption Factor (unitless)	Oral Absorption Factor (unitless)	Permeability Constant (cm/hr)	Koc (l/kg)	Kd Values (l/kg)	Henry's Law Constant at 25° C (atms-m3/mole)	Henry's Law Constant (unitless)	SFo (mg/kg-day) ⁻¹	S o u r c e (mg/kg-day)	RfDo (mg/kg-day)	S o u r c e (mg/kg-day) ⁻¹	SFi (mg/kg-day) ⁻¹	S o u r c e (mg/kg-day)	RfDi (mg/kg-day)	S o u r c e (mg/kg-day)	Particulate Emission Factor (m ³ /kg)	Volatilization Factor (m ³ /kg)
a-Hexachlorocyclohexane	0.10	0.5	1.20E-02	1.23E+03	2.46E+00	1.06E-05	4.35E-04	6.3E+00	i	8.0E-03	a	6.3E+00	i			1.36E+09	nv
b-Hexachlorocyclohexane	0.10	0.5	1.22E-02	1.26E+03	2.52E+00	7.43E-07	3.05E-05	1.8E+00	i			1.9E+00	i			1.36E+09	nv
Hexachlorocyclopentadiene	0.10	0.5	1.70E-01	2.00E+05	4.00E+02	2.70E-02	1.11E+00			6.0E-03	i			5.7E-05	i	1.36E+09	nv
Hexachloroethane	0.10	0.5	3.27E-02	1.78E+03	3.56E+00	3.89E-03	1.59E-01	1.4E-02	i	1.0E-03	i	1.4E-02	i			1.36E+09	nv
n-Hexane	0.01	0.5	1.96E-01	1.50E+02	3.00E-01	1.83E+00	7.42E+01			1.1E+01	n			2.0E-01	i	1.36E+09	5.45E+02
Hydrogen sulfide	0.001	0.2	1.25E-04	1.43E+01	2.86E-02	2.30E-02	3.55E-01							5.7E-04	i	1.36E+09	8.05E+02
Indeno[1,2,3-cd]pyrene	0.13	0.58	1.10E+00	3.47E+06	6.94E+03	1.60E-06	6.56E-05	7.3E-01	n*			7.3E-01	n*			1.36E+09	nv
Iron	0.001	0.2	1.00E-03		2.50E-01					3.0E-01	n					1.36E+09	
Isobutyl alcohol	0.01	0.5	1.93E-03	6.20E+01	1.24E-01	9.78E-06	4.01E-04			3.0E-01	i					1.36E+09	nv
Isophorone	0.10	0.5	3.53E-03	4.68E+01	9.36E-02	6.64E-06	2.72E-04	9.5E-04	i	2.0E-01	i			2.0E-01	r	1.36E+09	nv
Isopropylbenzene	0.01	0.5	8.76E-02	8.20E+02	1.64E+00	1.15E-02	4.72E-01			1.0E-01	i			1.1E-01	i	1.36E+09	6.56E+03
Lead	See Closure Plane Review Guidance																
Lindane	0.04	0.5	1.06E-02	1.08E+03	2.16E+00	3.50E-06	1.44E-04	1.3E+00	h	3.0E-04	i					1.36E+09	nv
Manganese	0.001	0.04	1.00E-03		6.50E+01					1.4E-01	i			1.4E-05	i	1.36E+09	
MCPA	0.10	0.5	1.67E-02	5.00E+01	1.00E-01	4.80E-10	1.97E-08			5.0E-04	i					1.36E+09	nv
MCPP	0.10	0.5	1.16E-02	4.86E+01	9.72E-02	1.82E-08	7.46E-07			1.0E-03	i					1.36E+09	nv
Mercury and compounds	0.001	0.74	1.00E-03		5.20E+01	1.14E-02	4.67E-01			8.6E-05	r			8.6E-05	i	1.36E+09	nv
Methacrylonitrile	0.01	0.5	1.88E-03	5.60E+01	1.12E-01	2.47E-04	1.01E-02			1.0E-04	i					1.36E+09	1.08E+04
Methanol	0.01	0.5	3.25E-04	1.00E+00	2.00E-03	4.40E-06	1.80E-04			5.0E-01	i					1.36E+09	nv
Methoxychlor	0.10	0.5	4.14E-02	9.77E+04	1.95E+02	1.58E-05	6.48E-04			5.0E-03	i					1.36E+09	nv
Methyl bromide	0.01	0.5	2.84E-03	1.05E+01	2.10E-02	6.24E-03	2.56E-01			1.4E-03	i			1.4E-03	i	1.36E+09	1.84E+03
Methyl ethyl ketone	0.01	0.5	9.72E-04	2.90E+01	5.80E-02	4.70E-05	1.93E-03			6.0E-01	i			1.4E+00	i	1.36E+09	2.17E+04
Methylene chloride	0.01	1.0	3.54E-03	1.17E+01	2.34E-02	2.19E-03	8.98E-02	7.5E-03	i	6.0E-02	i	1.6E-03	i	3.0E-01	a	1.36E+09	2.48E+03
Methyl isobutyl ketone	0.01	0.5	3.19E-03	1.23E+02	2.46E-01	1.38E-04	5.66E-03			8.0E-02	h			8.6E-01	i	1.36E+09	2.42E+04
Methyl tert-butyl ether	0.01	0.5	2.12E-03	6.00E+00	1.20E-02	5.87E-04	2.41E-02			8.6E-01	r			8.6E-01	i	1.36E+09	4.12E+03
Methylmethacrylate	0.01	0.5	3.55E-03	9.50E+01	1.90E-01	3.20E-04	1.31E-02			1.4E+00	i			2.0E-01	i	1.36E+09	1.41E+04
1-Methylnaphthalene	0.13	0.58	9.08E-02	2.30E+03	4.60E+00	5.14E-04	2.11E-02			7.0E-02	a					1.36E+09	6.39E+04
2-Methylnaphthalene	0.13	0.58	8.94E-02	4.40E+03	8.80E+00	5.18E-04	2.12E-02			4.0E-03	i					1.36E+09	8.79E+04
2-Methylphenol	0.10	0.5	8.09E-03	9.12E+01	1.82E-01	1.20E-06	4.92E-05			5.0E-02	i					1.36E+09	nv
4-Methylphenol	0.10	0.5	7.50E-03	4.34E+02	8.68E-01	1.00E-06	4.10E-05			5.0E-03	h					1.36E+09	nv
Mirex	0.10	0.5	4.26E-03	2.40E+07	4.80E+04	5.16E-04	2.12E-02			2.0E-04	i					1.36E+09	nv
Naphthalene	0.13	0.58	5.01E-02	2.00E+03	4.00E+00	4.83E-04	1.98E-02			2.0E-02	i			8.6E-04	i	1.36E+09	5.55E+04
Nickel (soluble salts)	0.001	0.04	2.00E-04	1.43E+01	6.50E+01					2.0E-02	i			2.6E-05	a	1.36E+09	
Nickel Refinery Dust	0.001	0.04	2.00E-04		6.50E+01							8.4E-01	i			1.36E+09	
2-Nitroaniline	0.10	0.5	4.44E-03	5.27E+01	1.05E-01	1.81E-08	7.42E-07			3.0E-03	n			2.9E-05	n	1.36E+09	nv
Nitrobenzene	0.10	0.5	5.31E-03	6.46E+01	1.29E-01	2.40E-05	9.84E-04			5.0E-04	i			5.7E-04	h	1.36E+09	4.37E+04
N-Nitrosodi-n-propylamine	0.10	0.5	2.48E-03	2.40E+01	4.80E-02	2.25E-06	9.23E-05	7.0E+00	i							1.36E+09	nv
N-Nitrosodiphenylamine	0.10	0.5	1.50E-02	1.29E+03	2.58E+00	5.00E-06	2.05E-04	4.9E-03	i	2.0E-02	n					1.36E+09	nv
Pentachlorobenzene	0.10	0.5	1.65E-01	3.16E+03	1.42E-06	7.10E-04	2.91E-02			8.0E-04	i					1.36E+09	nv
Pentachloronitrobenzene	0.10	0.5	2.14E-02	2.00E+04	4.00E+01	3.50E-05	1.44E-03			3.0E-03	i					1.36E+09	nv
Pentachlorophenol	0.25	0.76	1.17E-01	5.92E+02	1.18E+00	2.44E-08	1.00E-06	1.2E-01	i	3.0E-02	i					1.36E+09	nv
Phenol	0.10	0.5	4.47E-03	2.88E+01	5.76E-02	3.97E-07	1.63E-05			3.0E-01	i					1.36E+09	nv
Polychlorinated Biphenyls (PCBs)	0.14	0.8	1.77E-01	3.09E+04	6.18E+01	7.36E-04	3.02E-02	2.0E+00	i	2.0E-05	a	4.0E-01	i			1.36E+09	nv
n-Propylbenzene	0.01	0.5	7.64E-02	6.76E+02	1.35E+00	1.05E-02	4.31E-01			1.0E-02	n					1.36E+09	6.71E+03
Pyrene	0.13	0.58	2.75E-01	1.05E+05	2.10E+02	1.10E-05	4.51E-04			3.0E-02	i					1.36E+09	nv
Pyridine	0.13	0.58	1.47E-03	5.00E+01	1.00E-01	1.10E-05	4.51E-04			1.0E-03	i					1.36E+09	5.32E+04
Quinoline	0.13	0.58	6.55E-03	2.84E+00	5.68E-03	1.70E-06	6.97E-05	3.0E+00	i							1.36E+09	nv
Selenium	0.001	0.3	1.00E-03		5.00E+00	9.74E-03	3.99E-01			5.0E-03	i					1.36E+09	
Silver	0.001	0.04	6.00E-05		8.30E+00					5.0E-03	i					1.36E+09	
Silver Cyanide	0.001	0.04	1.00E-03	4.50E+00	9.00E-03					1.0E-01	i					1.36E+09	
Silvex	0.10	0.5	1.58E-02	2.60E+03	5.20E+00	9.06E-09	3.71E-07			8.0E-03	i					1.36E+09	nv
Styrene	0.01	0.5	3.60E-02	7.76E+02	1.55E+00	2.75E-03	1.13E-01			2.0E-01	i			2.9E-01	i	1.36E+09	1.33E+04
2,3,7,8 -TCDD (Dioxin)	0.03	0.5	7.67E-01	2.40E+06	4.80E+03	5.00E-05	2.05E-03	1.5E+05	h			1.5E+05	h			1.36E+09	nv
1,2,4,5-Tetrachlorobenzene	0.10	0.5	1.06E-01	1.59E+03	3.18E+00	1.00E-03	4.10E-02			3.0E-04	i					1.36E+09	nv
1,1,1,2-Tetrachloroethane	0.01	0.5	1.56E-02	3.99E+02	7.98E-01	2.70E-03	1.11E-01	2.6E-02	i	3.0E-02	i	2.6E-02	i			1.36E+09	9.76E+03

Table A-5: Chemical Specific Values for the Generic Cleanup Numbers

CONTAMINANT	Dermal Absorption Factor (unitless)	Oral Absorption Factor (unitless)	Permeability Constant (cm/hr)	Koc (l/kg)	Kd Values (l/kg)	Henry's Law Constant at 25° C (atms-m3/mole)	Henry's Law Constant (unitless)	SFo (mg/kg-day) ⁻¹	S o u r c e (mg/kg-day)	RfDo (mg/kg-day)	S o u r c e (mg/kg-day) ⁻¹	SFi (mg/kg-day)	S o u r c e (mg/kg-day)	RfDi (mg/kg-day)	S o u r c e (mg/kg-day)	Particulate Emission Factor (m ³ /kg)	Volatilization Factor (m ³ /kg)
1,1,2,2-Tetrachloroethane	0.01	0.5	6.88E-03	9.93E+01	1.99E-01	3.45E-04	1.41E-02	2.0E-01	i	6.0E-02	n	2.0E-01	i			1.36E+09	1.44E+04
Tetrachloroethylene (PCE)	0.01	0.5	1.08E-02	1.55E+02	3.10E-01	1.84E-02	7.54E-01	5.2E-02	n	1.0E-02	i	2.0E-03	n	1.1E-02	n	1.36E+09	2.53E+03
2,3,4,6-Tetrachlorophenol	0.10	0.5	6.89E-02	6.30E+03	1.26E+01	1.30E-06	5.33E-05			3.0E-01	i					1.36E+09	nv
Tetrahydrofuran	0.01	0.5	1.26E-03	1.80E+01	3.60E-02	7.10E-05	2.91E-03	7.6E-03	n	2.0E-01	n	6.8E-03	n	8.6E-02	n	1.36E+09	1.47E+04
Thallium	0.001	1.0	1.00E-03		7.10E+01					8.0E-05	i					1.36E+09	nv
Toluene	0.01	0.5	3.16E-02	1.82E+02	3.64E-01	6.64E-03	2.72E-01			8.0E-02	i			1.4E+00	i	1.36E+09	3.95E+03
Toxaphene	0.10	0.5	3.25E-02	2.57E+05	5.14E+02	6.00E-06	2.46E-04	1.1E+00	i	1.0E-03	a	1.1E+00	i			1.36E+09	nv
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	0.01	0.5	1.72E-02	3.16E+02	6.32E-01	5.30E-01	2.17E+01			3.0E+01	i			8.6E+00	h	1.36E+09	1.70E+03
1,2,4-Trichlorobenzene	0.01	0.5	6.77E-02	1.78E+03	3.56E+00	1.42E-03	5.82E-02			1.0E-02	i			1.1E-03	n	1.36E+09	4.29E+04
1,1,1-Trichloroethane	0.01	0.9	1.23E-02	1.10E+02	2.20E-01	1.72E-02	7.05E-01			2.8E-01	n			6.3E-01	n	1.36E+09	2.20E+03
1,1,2-Trichloroethane	0.01	0.5	6.40E-03	5.01E+01	1.00E-01	9.13E-04	3.74E-02	5.7E-02	i	4.0E-03	i	5.6E-02	i			1.36E+09	6.44E+03
Trichloroethylene (TCE)	0.01	0.5	1.79E-02	1.66E+02	3.32E-01	1.03E-02	4.22E-01	1.1E-02	x	6.0E-03	n	6.0E-03	x	6.0E-03	r	1.36E+09	3.24E+03
Trichlorofluoromethane	0.01	0.5	1.26E-02	9.70E+01	1.94E-01	9.70E-02	3.98E+00			3.0E-01	i			2.0E-01	h	1.36E+09	1.11E+03
2,4,5-Trichlorophenol	0.10	0.5	4.66E-02	1.60E+03	3.20E+00	4.33E-06	1.78E-04			1.0E-01	i					1.36E+09	nv
2,4,6-Trichlorophenol	0.10	0.5	3.44E-02	3.81E+02	7.62E-01	7.79E-06	3.19E-04	1.1E-02	i			1.1E-02	i			1.36E+09	nv
2,4,5-Trichlorophenoxyacetic acid (2,4,5-T)	0.10	0.5	2.57E-02	1.86E+02	3.72E-01	9.40E-11	3.85E-09			1.0E-02	i					1.36E+09	nv
1,2,3-Trichloropropane	0.01	0.5	7.46E-03	7.70E+01	1.54E-01	3.43E-04	1.41E-02	7.0E+00	h	6.0E-03	i			6.0E-03	a	1.36E+09	1.30E+04
Triethylamine	0.01	0.5	3.89E-03	1.07E+02	2.14E-01	1.49E-04	6.11E-03							2.0E-03	i	1.36E+09	2.03E+04
1,2,4-Trimethylbenzene	0.01	0.5	1.05E-01	7.20E+02	1.44E+00	6.16E-03	2.53E-01			5.0E-02	n			1.7E-03	n	1.36E+09	8.38E+03
1,3,5-Trimethylbenzene	0.01	0.5	6.08E-02	6.60E+02	1.32E+00	8.77E-03	3.60E-01			5.0E-02	n			1.7E-03	n	1.36E+09	6.75E+03
1,3,5-Trinitrobenzene	0.10	0.5	5.40E-04	1.04E+02	2.08E-01	3.08E-09	1.26E-07			3.0E-02	i					1.36E+09	nv
Vanadium	0.001	0.026	1.00E-03		6.20E+01					9.0E-03	i					1.36E+09	
Vinyl acetate	0.01	0.5	1.58E-03	5.25E+00	1.05E-02	5.11E-04	2.10E-02			1.0E+00	h			5.7E-02	i	1.36E+09	4.76E+03
Vinyl chloride	0.01	0.5	6.92E-03	1.86E+01	3.72E-02	2.70E-02	1.11E+00	1.4E+00	i	3.0E-03	i	3.1E-02	i	2.9E-02	i	1.36E+09	1.03E+03
Xylene (mixed)	0.01	0.9	5.22E-02	4.10E+02	8.20E-01	7.00E-03	2.87E-01			2.0E-01	i			2.9E-02	i	1.36E+09	6.16E+03
m-Xylene	0.01	0.5	4.69E-02	4.07E+02	8.14E-01	7.34E-03	3.01E-01			2.0E-01	i			2.9E-02	i	1.36E+09	2.38E+03
o-Xylene	0.01	0.5	4.99E-02	3.63E+02	7.26E-01	5.19E-03	2.13E-01			2.0E-01	i			2.9E-02	i	1.36E+09	6.10E+03
p-Xylene	0.01	0.5	4.98E-02	3.89E+02	7.78E-01	7.66E-03	3.14E-01			2.0E-01	i			2.9E-02	i	1.36E+09	5.54E+03
Zinc	0.001	0.2	6.00E-04		6.20E+01	2.45E-02	1.00E+00			3.0E-01	i					1.36E+09	

Please note that toxicity information may have been updated since this table was published, and a more current version of this table may be available on DHWM's website.

** Cadmium- As suggested by IRIS, RfDo=1.0E-03 and Oral Absorbition Factor=0.025 for soil (food) were also used in calculations.

Legend:

a = ATSDR Chronic MRL

i = IRIS

h = HEAST

n = NCEA Provisional value

n*=NCEA RPF*BaP

r = Route Extrapolation

x = Withdrawn value

SFo = Oral Slope Factor

RfDo = Oral Reference Dose

SFi = Inhalation Slope Factor

RfDi = Inhalation Reference Dose

Appendix B

Development of Alternate Metal Standards

As stated earlier in [Section 4.1](#), the Alternate Metal Standards (AMS) may be used to determine if soil is contaminated or remediated. Alternate Metal Standards exist for seven heavy metals; barium, cadmium, chromium, lead, mercury, nickel, and zinc. While the AMSs are listed in [Section 4.1](#), the development of these standards is explained in detail in this appendix.

All soils naturally contain some (usually small) amounts of metals. The concentration of a particular metal typically varies with the type of soil (its geological origin), time and space exposure to that particular metal (from a natural and/or anthropogenic source), capability of soil to retain the metal in its composition, depth of the soil horizon below ground surface, local hydrology, and other related factors. The following AMS are an attempt to statistically summarize this variability of concentrations for some metals naturally occurring (thus attributes “clean” and “native”) in Ohio soils. They are based on a collection of background metal concentrations from various facilities which completed a RCRA closure of their hazardous waste management unit(s), or underwent some other type of remediation activity. They were developed as an alternative approach to the site-specific BRS method, where the remediation standards are determined through a background soil sampling and analysis process conducted at the particular site. Initially, 63 sites located in 35 Ohio counties were considered. Since the objective was to establish remediation goals/standards for the “clean” soils only, a preliminary screening process resulted in elimination of data from 14 sites, due to any of the following reasons:

1. background samples were obtained from fill material and not from clean (native) soils;
2. background samples were obtained in areas that may have been affected by some hazardous waste management activity; or,
3. background samples were taken in an area that may have been contaminated by an industrial or other anthropogenic process (common for an industrial exposure closure scenario).

Data from the remaining 49 sites (representing 32 counties, 3 in central Ohio, 8 in northeast, 8 in northwest, 8 in southeast, and 5 in southwest) served as the basis for determining the AMS. Although data sets were analyzed as if they came from the same population, it should be noted that in reality, soil samples were taken at different locations, from different soils and at different depths, by different sampling methods and equipment. Finally, they were analyzed and interpreted by different laboratories. **For this reason, the AMS given in the following table may not truly represent a particular background, but rather a maximum concentration level which can be regarded as a natural occurrence (i.e., a metal concentration below which soil remediation may not be required).**

Table B-1: List of Alternate Metal Standards (AMS)	
Metal	AMS [mg/kg]
Barium	140.00
Cadmium	1.25
Chromium	22.00
Lead	37.00
Mercury	0.13
Nickel	33.00
Zinc	90.00

The AMS in the above table were derived through a preliminary screening process and subsequent statistical analysis. Procedures used in the statistical analysis are summarized below:

- (1) Outliers were identified as values exceeding the upper cutoff limit (upper quartile + 1.5 x interquartile range), and removed from data sets. The removal generally resulted in bringing a data set closer to normality;
- (2) Concentrations reported as below detection limit (non-detects) were either substituted by one half of a detection limit, or by the lowest value reported for that metal at a particular site (in cases when detection limit was unknown or varied);
- (3) Statistics (such as percentiles, mean value, standard deviation and variance) were calculated for each metal's data set, graphs (such as histogram, distribution curve, box plot and probability plot) were generated to describe and study data distributions, and a normality test was performed to select the most appropriate method (parametric or nonparametric) for AMS determination;
- (4) AMS were determined in accordance with each metal's statistics.

Since none of the data sets were found to be normally distributed, the final determination of AMS was based exclusively on a nonparametric approach. Specifically, an AMS for each metal was established as a lower limit of the 95% confidence interval for the 97.72th percentile. No attempt was made to determine AMS by normalizing data sets, in order to avoid bias commonly associated with back transformations. The following table contains some of the statistics used in the data evaluation process:

Table B-2: Partial Statistics Used in the Data Evaluation Process of Developing the AMS									
Metal	Initial # of Obs.	Final # of Obs.	25% (Q1)	50% (Median)	75% (Q3)	95%	Mean	St.Dev.	Mean +2St.D.
Arsenic	542	511	3.20	5.00	7.70	12.90	5.646	3.493	12.632
Barium	569	539	43.00	60.40	83.50	138.00	66.175	33.607	133.389
Cadmium	623	561	0.25	0.26	0.60	1.25	0.458	0.332	1.122
Chromium	764	704	7.40	11.00	14.25	20.00	11.216	5.039	21.294
Lead	769	711	8.30	12.50	20.00	35.00	15.055	9.686	34.427
Mercury	489	418	0.05	0.05	0.05	0.13	0.058	0.035	0.128
Nickel	478	459	9.20	14.00	20.00	31.00	15.255	8.366	31.987
Zinc	420	389	32.00	42.00	59.00	86.00	45.917	21.833	89.583
<p>Notes:</p> <p>Initial # of Obs. - number of data points (observations) retained for statistical analysis after preliminary screening process (before elimination of outliers);</p> <p>Final # of Obs. - number of data points (observations) actually used to determine AMS (after preliminary screening process <u>and</u> elimination of outliers);</p> <p>xx% - percent of data equal and/or below the shown concentration [mg/kg];</p> <p>St.Dev. - standard deviation [mg/kg];</p>									

Note about arsenic:

Although the data illustrating concentrations of arsenic in various background soils were analyzed, the AMS for arsenic has not been established at the present time. Several factors played into this decision. Arsenic forms oxyanions and a variety of other compounds that depend largely upon the oxidation state of arsenic. The toxicity and cancer causing potential will depend upon the specific compound or ionic form that is stable for a given environment. In addition, the concentrations of total arsenic in background soils is often highly variable in Ohio and, in some instances, can be larger than toxicity-based standards. This heterogeneity makes the designation of a generic standard difficult. For these reasons, a site-specific remediation standard (BRS or risk-based) should be determined for each RCRA closure unit where arsenic is present as a constituent of concern. However, the results of statistical analyses do point out that any concentration of arsenic in a background soil above 13 mg/kg (97.72th percentile of the analyzed data set) may indicate that the sampling area has been affected by a specific source. **In that respect, 13 mg/kg can be considered an upper limit of an arsenic concentration in soil which can be regarded as a “normal occurrence”.** Above this limit, the reviewer should seek an explanation for the elevated concentrations of arsenic and decide whether the soil samples are valid for establishing the BRS.

Table B-3: Comparison of the Mean Values of Metal Concentrations Used to Establish AMS to the Results of Some Other Studies					
Metal	BGND^A	OFS^B	U.S.^C	NE U.S.^D	USGS^E
Barium	66.18	-	-	-	300.00
Cadmium	0.46	0.20	0.27	0.32	1.00
Chromium	11.22	12.00	-	60.30	36.00
Lead	15.06	19.00	12.30	24.80	14.00
Mercury	0.06	-	-	-	0.10
Nickel	15.26	18.00	23.90	23.70	13.00
Zinc	45.92	75.00	56.50	57.50	36.00
Notes: A. Mean values of metal concentrations in Ohio soils located in the vicinity of a HWMU and assumed not to be affected by its activity, or any other anthropogenic source; B. Mean values of metal concentrations in Ohio farm soils; ¹ C. Mean values of metal concentrations in U.S. agricultural soils; ² D. Mean values of metal concentrations in the soils of the Northeast U.S.; ³ E. Geometric mean values of metal concentrations in soils of the northeast U.S. at a depth of 20 cm; ⁴					

Table B-3 is presented for illustrative purposes only. The mean values of metal concentrations in the U.S. soils were compiled from various sources and were not considered by Ohio EPA as the basis for determination of soil remediation standards.

¹ Logan, T.J., and R.H. Miller. (1983) Background Levels of Heavy Metals in Ohio Farm Soils.

² Holmgren, G.G.S., M.W. Meyer, R.L. Cheney, and R.B. Daniels. (1993) "Cadmium, Lead, Zinc, Copper, and Nickel in Agricultural Soils of the United States of America." and Frink C. R. (1996) "A Perspective on Metals in Soils."

³ Combined arithmetic and geometric means from various sources including Frink, C.R. (1996) "A Perspective on Metals in Soils."

⁴ Frink, C R. (1996) "A Perspective on Metals in Soils."

Appendix C

Guidance for Statistical Evaluation of Hazardous Waste Constituent Levels in Soils

As briefly mentioned in [Chapter 4](#), statistics may be used to determine if an area needs to be remediated or has been successfully remediated by comparing confirmation data to background conditions. This appendix describes the statistical comparison process and discusses important items that should be considered throughout the process.

Working with a Limited Number of Samples

Due to practical reasons and constraints, statistical analyses are frequently conducted on a limited number of observations (samples). This limited number of observations represents a statistical sample (not to be confused with a soil sample) extracted from a much larger group of values (called population) in an attempt to estimate statistical parameter(s) (e.g., mean value of metal concentrations), or to conduct a statistical test, while staying within economical and technical limits. If the entire population could be taken into account, a statistical estimate would reflect a “true” value. Any fewer number of observations will probably introduce an error. In other words, how close and how reliably a statistical parameter will represent the truth, or how correct a conclusion drawn from a particular statistical test will be, depends largely on the number of observations that were chosen to represent the population. Determination of a smallest number of observations (smallest sample size) that will still allow a certain satisfactory level of confidence in a statistical evaluation is not quite that simple. The following are some of the reasons:

- Different statistical methods for testing hypotheses or for determination of statistical parameters (mean, variance, quantiles, etc.), require a different number of observations (data points) in order to achieve the desired accuracy and level of confidence (*i.e.*, the kind of methods involved should be known up-front);
- Desired accuracy and confidence level have to be predetermined;
- An assumption about the normality of a data distribution has to be made before the data is actually collected;
- A guess has to be made about the dispersion (variability) of the data.

It is obvious that the above requirements lead to a somewhat arbitrary determination of a smallest acceptable number of observations. To facilitate the initial choice of a statistical sample size for the purpose of establishing a background based remediation standard for soils, Ohio EPA recommends a minimum of 12 (twelve) soil samples to be collected from the appropriate soil type, as described in [Section 3.15, Background and Soil](#) in this document. In statistical terms, these 12 data points allow for determination of a mean value with 95% probability that it will not exceed a true population mean by 50%. In other words, if soil sampling, analysis and the mean value calculations were done repeatedly, many times in the same manner, a chance of making an estimate of the mean value 50% greater than the true mean is only 5%. If, for example, the true mean of a metal concentration in soil is 145 mg/kg, then the estimated mean would be less than 217.5 mg/kg (true mean + 50% of the true mean) 95% of the time. This is correct only under the assumption that the soil samples (not correlated over time and space) were collected through a simple random sampling process, that the results of laboratory analysis (data) are normally distributed, and that the coefficient of variation (the ratio between the standard deviation and the mean of the collected data) is within 95%. For a more detailed explanation, refer to Gilbert, R. O. (1987) *Statistical Methods for Environmental Pollution Monitoring*, Chapter 4.

The above discussion shows that the recommended minimum of 12 (twelve) soil samples offers a somewhat limited accuracy in estimating a true mean value. If a more accurate estimate of the mean concentration of a constituent in a given soil is required, or if any other requirement (statistical method) so dictates, then the necessary number of background and confirmation soil samples has to be increased.

It is also important to mention that all 12 soil samples have to be valid (*i.e.*, usable). To avoid additional sampling in case something goes wrong (lab error, outlier, etc.), it is considered a good practice to collect more than 12 soil samples initially. Various methods on how to determine an appropriate (necessary) number of observations are presented in many statistical textbooks, papers and guidance documents (some of which are referenced at the end of this section).

Instituting a Background Remediation Standard (BRS)

Any closure project that involves remediation of contaminated soil by removal needs a measurable goal for evaluating the success of remediation. For the purpose of knowing how much contamination needs to be removed, this goal can be based on contaminant concentrations in the media prior to the existence of the unit. Such a goal is usually called a Background Remediation Standard (BRS). Under the assumption that the “raw” background data (concentration values as obtained from the physical media samples) are normally distributed, a BRS can be established as the mean value plus two standard deviations of the background data.

So defined, the BRS also represents the 97.72th percentile (or the 0.9772 quantile - since quantiles are percentiles expressed as a fraction rather than percentage) of the *normal* background distribution. In other words, the BRS accounts for the highest value within 97.72% of the whole background population of contaminant concentrations under the normal probability density function (a.k.a. “normal curve”).

It is important to note that if the raw background data are not normally distributed, and if their estimated (sample) mean lies closer to the high-values end of the distribution (a “positively skewed” distribution), then the resulting BRS may not truly represent the defined upper bound of the background contaminant concentrations. Obviously, an incorrect BRS should not be used for either direct or statistical comparison with the confirmation samples. It is equally wrong to accept a BRS established through the process of transforming data to normality, then calculating the BRS based on transformed data, and finally back-transforming the result, with the assumption that it now represents a “true” BRS in its original dimension. Instead of back-transforming the BRS, a correct procedure would be to attempt to use the same type of transformation on both the background and confirmation data and then, providing that normalizing was successful, to perform an appropriate kind of a statistical comparison test (*i.e.*, a t-test, which is explained later in this appendix). If no transformation has been found to normalize both the background and confirmation data, then a distribution-independent, or nonparametric statistical comparison method can be used (*i.e.*, a Wilcoxon Rank-Sum Test). Normality and statistical comparison methods are discussed in more detail later in this appendix.

Checking for Normality

In order to know if a BRS can be established from a raw background data set, and to select an appropriate statistical method (*i.e.*, parametric or nonparametric) for demonstrating that the remaining contaminant concentrations do or do not significantly exceed acceptable levels, the background and confirmation data distributions need to be tested for normality. The demonstration of normality should be made graphically (through probability plots and box plots)

and through either the Shapiro-Wilk test (also known as the *W*-test) or the Kolmogorov-Smirnov test with Lilliefors critical values. An explanation on how to perform the Shapiro-Wilk and Kolmogorov-Smirnov tests can be found in Conover, W. J. (1980) *Practical Nonparametric Statistics* and Gilbert, R. O. (1987) *Statistical Methods for Environmental Pollution Monitoring*. Most statistical software packages also provide a simple way to run the above mentioned tests.

To illustrate how graphical methods help in assessing normality, twelve data points are plotted using a normal probability plot and a box plot (see Figure C-1).

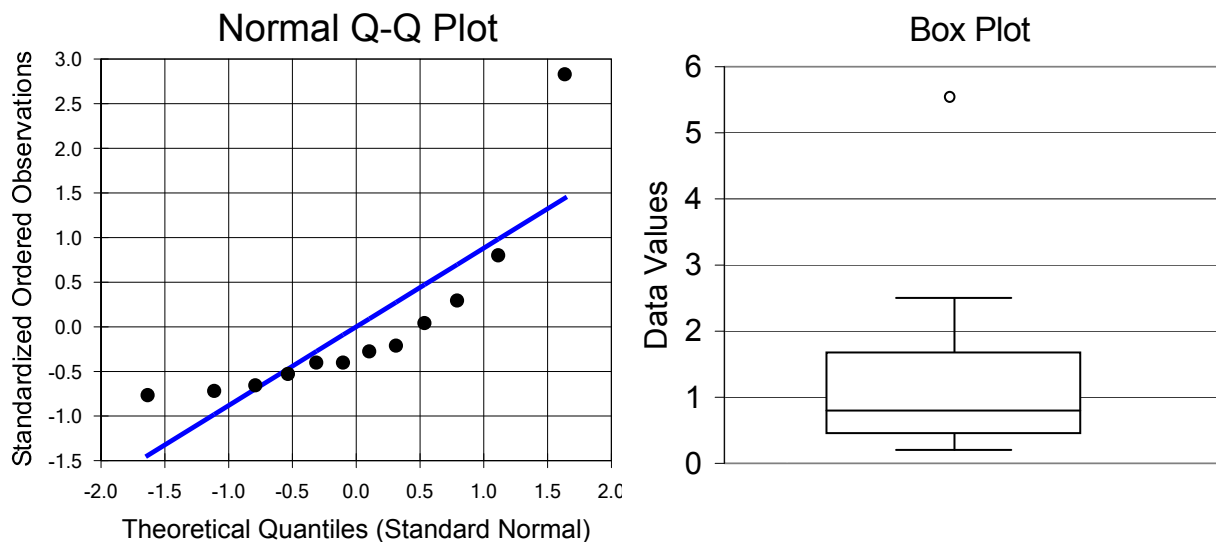


Figure C-1: Probability Plot (left) and Box Plot (right)

These were plotted using the data from Exhibit C-1.

Both graphs in this example indicate that the data distribution may not be normal. In the case of the probability plot, the further the data points are from the straight line defining normality, the more unlikely it is that the data are normally distributed. With the box plot, the less symmetrical the plot, the further the data distribution is from normality.

Transforming Data to Attain Normality

Before performing statistical analysis, an attempt to normalize the data should be made. Logarithmic or power transformations will often make a data set normally distributed. Some computer programs allow for a graphical comparison of several different transformations:

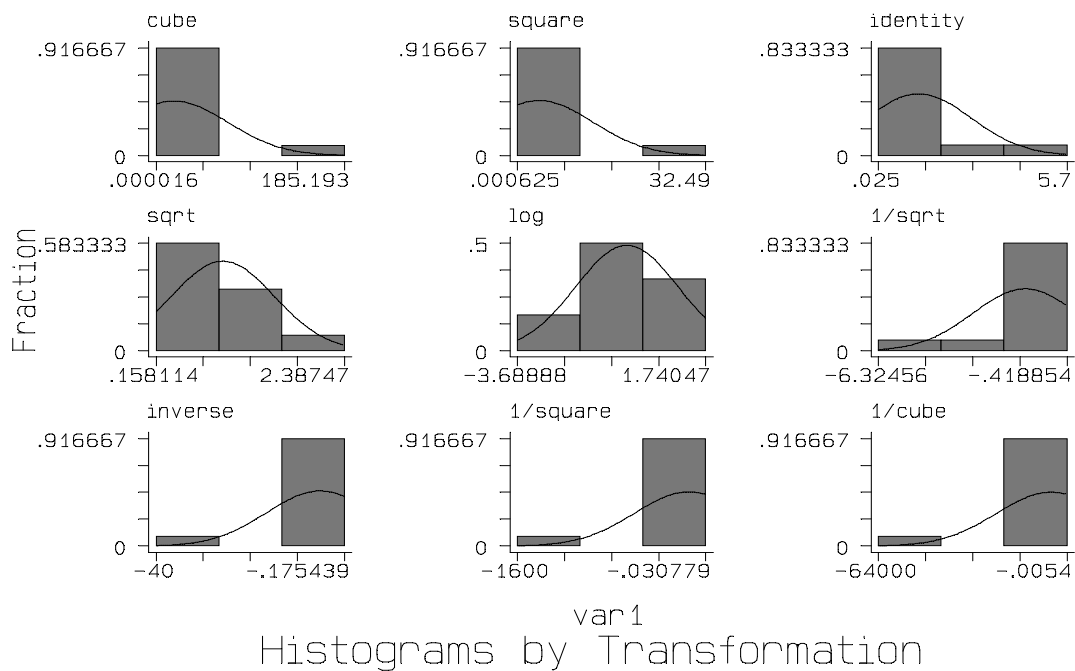


Figure C-2: Histograms by Transformation

In Figure C-2, the histogram in the middle (second in the second row) suggests that a logarithmic transformation may be the best way to normalize the data. After transforming the data, a check with a probability plot and a box plot can be repeated to verify this determination. The graphs in Figure C-3 indicate that the logarithmic transformation did normalize this data.

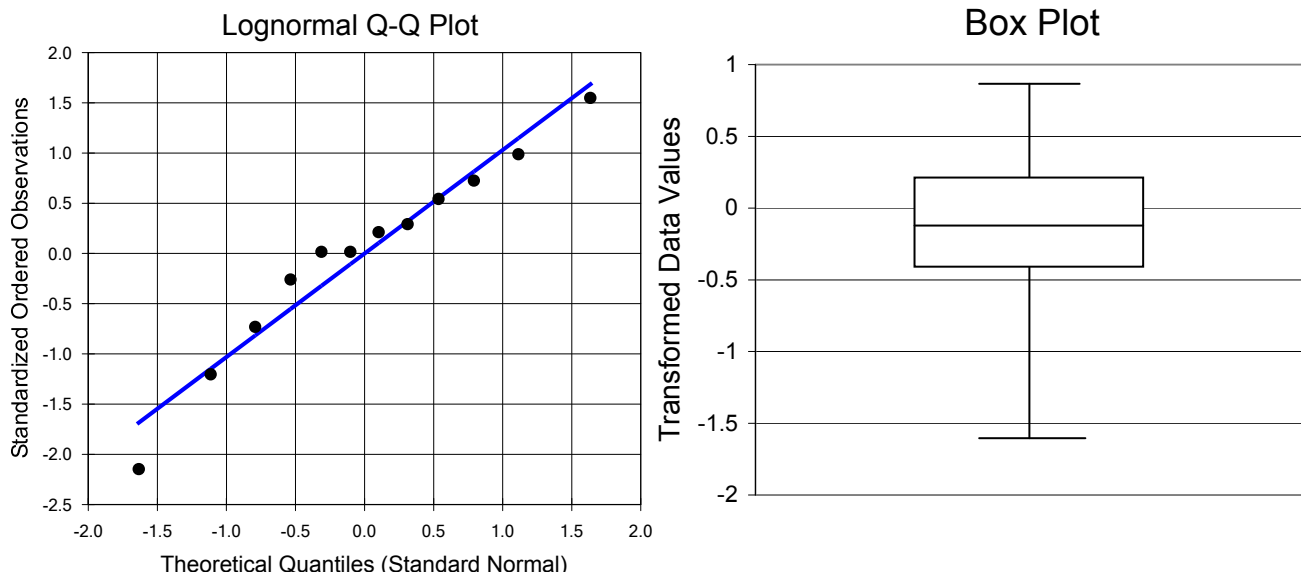


Figure C-3: Probability Plot (left) and Box Plot (right) of the transformed data
 These were plotted using the data from Exhibit C-1.

Outlier Screening Considerations

Availability of pertinent information on the subject of interest is a prerequisite for conducting a statistical analysis. This information is usually contained in the form of a data set generated from a series of observations. Only when these observations are made in accordance with predetermined rules and followed by a careful data screening process, will the conclusions from the statistical analysis be valid. If data do not represent the truth, the results will be more or less irrelevant, no matter how much sophistication was incorporated into the analysis. As will be discussed below, one of the reasons why a statistical analysis may not render a correct result is the presence of “outliers” in a data set.

When comparing a background population to an on-site population to determine whether or not the site is contaminated, the question may arise as to whether a high on-site point value is a statistical anomaly, or it represents a “hot spot.” We define a hot spot as an area of contamination, with constituents of concern attributable to the closing unit, which requires remediation, or a risk evaluation. The type of statistical anomaly we are examining is commonly known as an outlier. By some definitions, an outlier is “an observation which appears to be inconsistent with the remainder of the data set,”¹ or “an observation which deviates so much from other observations as to arouse suspicions that it was generated by a different mechanism.”²

The reviewer should use professional judgment to determine if it is reasonable that the high point value logically could represent contamination attributable to the unit. Look at factors such as the relative locations, potential pathways for migration, and contaminant mix fingerprint. While this provides a good qualitative description of outliers, some formal test may still be required to detect their existence within a data set. Due to a relatively long history of this problem, many methods have been developed and are described in statistical literature.³

The reviewer can also use graphical tools such as box plots and stem and leaf plots, as well as tests such as the sign test and the Wilcoxon rank sum test to evaluate the potential outlier. One such method is the boxplot rule which, in general form, defines the upper and lower fences as shown in Equations C-1 and C-2.

Values falling outside the fences (also called the upper and lower cutoff points) are considered to be the potential outliers. The multiplicative constant, k , is one of the two factors determining the probability of labeling an observation as an outlier (the other factor is the number of observations). The common range for k is between 1.5 and 3.0, where k equals 1.5 for the “standard” boxplot (the method recommended by Ohio EPA for normal distributions).

¹ Barnett, V., and T. Lewis. (1984) *Outliers in Statistical Data*.

² Hawkins, D.M. (1980) *Identification of Outliers*.

³ Iglewicz, B., and D.C. Hoaglin. (1993) *How to Detect and Handle Outliers*.

Equation C-1: Calculation of Upper Fence		
$U = Q_3 + k(Q_3 - Q_1)$		
Equation C-2: Calculation of Lower Fence		
$L = Q_1 - k(Q_3 - Q_1)$		
U	=	Upper Fence
L	=	Lower Fence
Q ₁	=	lower quartile
Q ₃	=	upper quartile
Q ₃ - Q ₁	=	interquartile range
k	=	multiplicative constant

It is important to notice the distinction between the results of the boxplot method when k takes a value on either side of the range from 1.5 to 3.0. When k is set to 1.5, the boxplot may show a relatively high number of observations as outstanding, some of which may not be true outliers. On the other hand, when k equals 3.0, all observations that fall outside the cutoff points can be “safely” considered outliers. A shortcoming, in this case, is that some lesser (but true) outliers may fall inside the fences and remain unflagged. In other words, the “standard” boxplot (k = 1.5) is more likely (approximately nine times - when a normally distributed data set consists of twelve observations) to label an observation as an outlier (albeit possible errors), than a boxplot where k equals 3.0. Hoaglin, D.C. and B. Iglewicz’s (1987) “Fine-Tuning Some Resistant Rules for Outlier Labeling” have provided k values with specified probability of identifying at least one outlier in a normally distributed data set, depending on the number of observations. For example, if a data set consists of twelve observations, and k equals 2.2, the probability of labeling at least one observation as an outlier is 5%. The low probability of labeling an observation as an outlier also indicates that the test is “conservative” and that the labeled observation is indeed very likely an outlier. In cases where no detailed information exists about the origin of the data, the above method can be advantageous by providing a certain predetermined comfort level in screening out anomalous observations. It is important to note that the “standard” boxplot method is considered to be accurate when data are normally distributed. In other cases, it should be used with caution. For the heavily skewed distributions, other methods are available and described in statistical literature.

When screening observations for the purpose of creating a representative data set for determining background based remediation standards, a considerable amount of information on the data generating process is usually available. As required, the collection and analysis of soil samples is assumed to be a process controlled by predetermined sampling methods, analytical procedures and sample handling protocols, where a good understanding of the soil, contaminants and relevant site features provide the basis for the choice of sampling locations. Although the intent of all these requirements is to provide reliable information, it is quite possible that some anomalous observations could be made throughout the process. If these observations are judged exclusively by their numerical properties (through the use of a statistical test), then there is danger that some of them could be removed from the data set, or retained within, without investigating into the causes for inconsistency. Since an outstanding observation may point to some important issue (like possible site wide contamination, inherent variability of soil, sampling problem, lab error, etc.), it is necessary to utilize all available information when deciding whether the observation will be (justifiably) discarded, or retained in the data set. For that reason, as mentioned earlier, Ohio EPA recommends a procedure in

which the “standard” boxplot method is used for labeling potential outliers in a background data set, followed by a thorough investigation to reveal the reasons for any discovered inconsistency.

It is important to note that no datum should be discarded solely on the basis of a statistical test. Indeed, there is always a small chance (the α level of the test) that the test incorrectly declares the suspect datum an outlier. Also, multiple outliers should not be automatically discarded since the presence of two or more outliers may indicate that a different model should be adopted for the frequency distribution of the population. For example, several unusually large measurements may be an indication that the data set should be modeled by a skewed distribution such as the lognormal. There should always be some plausible explanation other than a test result that warrants the exclusion or replacement of outliers. The use of robust methods that have the effect of eliminating or giving less weight to extreme values should also be justified as being appropriate.⁴ The following items related to data validation should also be checked prior to removing an outlier from a data set:

- Investigate the chain of custody thoroughly. Scrutiny of the chain of custody documents may reveal that samples were mixed up, improperly preserved or chilled, or mishandled by field or laboratory personnel.
- Check for errors in transcription, dilution, analytical procedures, etc. If errors are identified and a correct value recovered, then replace the outlier observation with the correct observation.
- If the correct value cannot be recovered from the reports, then delete the value from the data set and document the reason(s) in the report.
- If no error can be determined, confirm it, if possible, by taking an additional sample.

Lastly, when in doubt, err on the side of assuming that the datum is not a Type 1 error (false positive), and truly represents a hot spot.

⁴ Gilbert, R.O. (1987) *Statistical Methods for Environmental Pollution Monitoring*.

Checking for Outliers

Prior to proceeding with a statistical comparison between the background and confirmation data sets, a test for outliers should be conducted. This is especially important for the background data set because unjustifiably high concentrations (*i.e.*, outliers on the high end of the distribution) will cause an unjustifiably elevated BRS. On the other hand, one, or even a few slightly elevated concentrations in a confirmation data set may not necessarily require additional soil remediation - if an appropriate statistical test (such as a t-test) shows that the BRS has not been significantly exceeded. The following equations⁵ are used to determine whether there is statistical evidence that an observation appears extreme and therefore may not fit the distribution of the rest of the data:

Equation C-3: Calculation of Upper Cutoff
Upper cutoff = upper quartile + 1.5 (interquartile range)
Equation C-4: Calculation of Lower Cutoff
<p>Lower cutoff = lower quartile - 1.5 (interquartile range)</p> <p>Upper quartile ($Q_{.75}$ or $Q3$) = an observation in the background data set which divides the data so that 25% of the data are greater than $Q3$ and 75% of the data are less than or equal to $Q3$;</p> <p>Lower quartile ($Q_{.25}$ or $Q1$) = an observation in the background data set which divides the data so that 75% of the data are greater than $Q1$ and 25% of the data are less than or equal to $Q1$; and</p> <p>Interquartile range (IQR) = the difference between the upper quartile and the lower quartile (<i>i.e.</i>, $IQR = Q3 - Q1$).</p>

⁵ Hoaglin, D.C., F. Mosteller, and J.W. Tukey. (1983) *Understanding Robust and Exploratory Data Analysis*.

Exhibit C-1: Determining Outliers - Example for even number of background data

Given the following data set consisting of twelve data points:

1.3 0.8 0.6 0.2 0.1 0.025 0.9 2.5 0.6 0.4 1.7 5.7

The first step is to order the data from least to greatest:

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
0.025	0.1	0.2	0.4	0.6	0.6	0.8	0.9	1.3	1.7	2.5	5.7

For an even number of data points, the quartiles are determined by splitting the ordered data set twice equally (*i.e.*, into fourths). The quartiles are found at the splits and can be adequately estimated by averaging the data points on either side of the split.

Using the above data set, Q1 falls between the 3rd and 4th observation and is therefore calculated as:

$$Q1 = (0.2 + 0.4) / 2 = 0.3$$

Similarly, Q3 falls between the 9th and 10th observation and can be calculated as:

$$Q3 = (1.3 + 1.7) / 2 = 1.5$$

After calculating the quartiles, the next step is to calculate the interquartile range (IQR), or the difference between Q3 and Q1:

$$IQR = Q3 - Q1 = 1.5 - 0.3 = 1.2$$

This can be demonstrated visually as follows:

Q1			Q2 (or median)				Q3				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
0.025	0.1	0.2	0.4	0.6	0.6	0.8	0.9	1.3	1.7	2.5	5.7
0.3			0.7				1.5				
			IQR 1.2								

The final step is to calculate the Upper and Lower cutoffs as defined by the Equations C-3 and C-4 above:

$$\text{Upper cutoff} = 1.5 + 1.5(1.2) = 3.3$$

$$\text{Lower cutoff} = 0.3 - 1.5(1.2) = -1.5$$

(The Lower cutoff = 0, since a negative Lower cutoff does not make sense when data represent constituent concentrations).

In this case, only one observation is not in the range between 0 and 3.3 (*i.e.*, 5.7, or the twelfth observation). Data points not falling between the upper and lower cutoffs should be reviewed to determine whether evidence exists to suggest that these observations are not representative of the background population. The reviewer should direct the facility (entity responsible for conducting closure) to check such data for sampling and laboratory errors, field evidence of waste materials at the sampling locations, and other plausible causes. Where sufficient evidence indicates that an observation does not truly represent concentrations found in background soil, a substitute observation should be provided. If no specific error can be documented, then the observation should be retained in the data set.

Exhibit C-2: Determining Outliers - Example for odd number of background data

For odd numbered data sets, the lower quartile (Q1) can be found by multiplying the number of observations (n) by 0.25, and then rounding the result to the next largest integer. The resulting number indicates the observation which corresponds to Q1.

Similarly, Q3 can be found by multiplying n by 0.75, and rounding to the next larger integer. This number refers to the observation which corresponds to Q3. For example, with the following data set (where n = 13):

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
0.1	0.2	0.4	0.6	0.6	0.8	0.9	1.3	1.7	1.8	2.1	2.5	5.7

For Q1: $0.25 \times 13 = 3.25$; rounded up = 4.
Q1 is the 4th observation or 0.6.

For Q3: $0.75 \times 13 = 9.75$; rounded up = 10.
Q3 is the 10th observation or 1.8.

Q2 (median) is simply the value in the middle - 7th observation or 0.9.

The rest remains the same as in the previous example for even number of data. If there are no outliers, then statistical analysis may proceed. If outliers are found, their origin should be investigated (as previously explained) before proceeding with statistical analysis. If outliers are removed from the raw background data set, then the BRS should be recalculated using the remaining data values and replacement data values, if necessary.

			Q1			Q2			Q3			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
0.1	0.2	0.4	0.6	0.6	0.8	0.9	1.3	1.7	1.8	2.1	2.5	5.7

Equation C-5: Comparison of 95% Upper Confidence Limit to the Background Remediation Standard (BRS) through the t-test

$$\frac{\bar{Y} - \text{BRS}}{S_y / \sqrt{m}} < -t_{m-1, 0.95}$$

Rearranging Equation C-5 will give Equation C-6:

Equation C-6: Comparison of 95% Upper Confidence Limit to the Background Remediation Standard (BRS) through the t-test

$$\bar{Y} + t_{m-1, 0.95} \times (S_y / \sqrt{m}) < \text{BRS}$$

\bar{Y}	-	mean of confirmation data
S_y	-	standard deviation of confirmation data,
m	-	number of confirmation data points (observations), and
$t_{m-1, 0.95}$	-	t- distribution critical value for m-1 degrees of freedom and 95% confidence level

t-test Example

Given normally distributed background and confirmation data sets for barium (Ba), and assuming there are no outliers,

Ba – Background (mg/kg)	Ba – Confirmation (mg/kg)
3.43	15.7
43.37	37.5
44.51	43.7
45.04	44.63
48.29	45.88
50.81	49.5
57.74	55.84
62.36	60.71
64.76	70.26
78.27	80.62
79.4	110.3
110.8	115.24

the mean (μ_b) and standard deviation (S_b) for the background data set are, respectively:

$$\mu_b = 57.398 \text{ and } S_b = 25.946$$

and the BRS can be calculated⁶ as:

$$\text{BRS} = \mu_b + 2 S_b = 57.398 + (2 \times 25.946) = 109.29 \text{ mg/kg.}$$

In order for the soil to be declared remediated for barium, a t-test should show that the 95% upper confidence limit for the mean of confirmation data is smaller than the BRS, this should be done using Equation C-6.

From the confirmation data set:

$$m = 12$$

$$\bar{Y} = 60.823$$

$$df = m-1 = 11$$

$$S_y = 29.236$$

From the table below: $t_{m-1, 0.95} = 1.796$

Table C-1: t Distribution Critical Values for 95% Confidence Level									
df	4	5	6	7	8	9	10	11	12
t crt. val.	2.131846	2.015049	1.943181	1.894578	1.859548	1.833114	1.812462	1.795884	1.782287
df	13	14	15	16	17	18	19	20	21
t crt. val.	1.770932	1.761309	1.753051	1.745884	1.739606	1.734063	1.729131	1.724718	1.720744
df	22	23	24	25	26	27	28	29	30
t crt. val.	1.717144	1.71387	1.710882	1.70814	1.705616	1.703288	1.70113	1.699127	1.69726

Remark: t distribution tables with critical values for other confidence levels and degrees of freedom can be found in various books on statistics.

By entering the values in the t test expression (where the left side represents the 95% upper confidence limit for the mean of the confirmation data, and the right side is the BRS),

Exhibit C-3: Comparison of 95% Upper Confidence Limit to the Background Remediation Standard through the t-test
$\bar{Y} + t_{m-1, 0.95} \times (S_y / \sqrt{m}) < \text{BRS}$ <p>(Equation C-6)</p> $60.823 + 1.796 \times (29.236 / \sqrt{12}) < 109.29$ $75.98 < 109.29$

⁶ See Equation 4-1 in Chapter 4 of this document

Therefore it can be shown that the 95% upper confidence limit for the mean of the confirmation data does not exceed the BRS, and the soil can be declared remediated for barium.

Another way to conduct this test is to calculate a t value using confirmation and background data, and then compare it to an appropriate critical value, i.e.:

<p>Exhibit C-4: Comparison of 95% Upper Confidence Limit to the Background Remediation Standard through the t-test</p> $\frac{\bar{Y} - \text{BRS}}{S_y / \sqrt{m}} < -t_{m-1, 0.95}$ <p>(Equation C-5)</p> $\frac{60.823 - 109.29}{29.236 / \sqrt{12}} < -1.796$ $- 5.743 < -1.796$

It is interesting to note that (in this example) the soil can be declared remediated for barium, in spite of the fact that the two confirmation soil samples exhibit concentrations above the BRS.

Remarks

- (1) It is frequently found that a BRS has been calculated in the log scale and then exponentiated back to the original scale. This procedure is generally not acceptable because the results of operations conducted on means and standard deviations of transformed data may be biased when directly transformed back into the original scale.⁷ However, in some cases, a BRS exclusively calculated in the log scale and then exponentiated back to the original scale can be used for the screening purpose - and only if it does not exceed 97.72nd percentile of the untransformed data set. To finally prove that the soil has been successfully remediated, a t-test should be conducted on the log transformed site and background data.
- (2) Duplicate observations: As part of the quality control process, both field and laboratory samples may have duplicate values reported. Use the arithmetic mean of the results as the input to your site characterization if the relative percent difference is less than 10%.⁸ If the relative percent difference of the duplicate values is more than 10%, consult your supervisor. DHWM has concluded that using two discrete numbers for duplicate samples that have similar values introduces an artificial data point. With small sample sets, this can have a statistical impact that is artificial. On the other hand, duplicates that are significantly different are indicative of a quality control problem and should not be used in the data reduction process without further investigation.
- (3) When non-detects are present, the following statistical methods in Table C-2 are recommended for data comparison.

⁷ Refer to Gilbert, R. O. (1987) *Statistical Methods for Environmental Pollution Monitoring*. Page 149.

⁸ Refer to Ohio EPA's (2003) *Tier I Data Validation Manual* for more information on relative percent difference.

- (4) Another acceptable method for data sets containing less than 50% censored data is to model the non-detects using Monte Carlo simulations. To do this, set the assumptions for each of the censored data points as a uniform distribution from zero to the Estimated Quantitation Limit (EQL) and run a minimum of ten thousand trials. The resulting values may be used directly as inputs to your calculations.
- (5) Besides the specially designed statistical computer programs, general spreadsheet software can also be very useful in assisting closure plan reviewers with statistical reviews. Most spreadsheet applications contain many “built-in” functions for calculating statistical parameters such as the mean, quartiles (or percentiles), variance, standard deviation, etc. However, quartiles (as well as other statistics) calculated by spreadsheet software sometimes may not be the same as if they were determined through the procedures described in this guidance document. The discrepancy is usually caused by the difference in calculation methods.

Table C-2: How to Handle Non-Detects in Statistics	
Percent non-detects (ND)	Recommended Method
ND ≤ 15%	<p>Replace NDs with MDL/2, if appropriate, and proceed with the following analysis:</p> <ul style="list-style-type: none"> - <u>For normally distributed data</u>, use parametric statistics, <i>i.e.</i>, t-test. <p>Note: As an alternative to MDL/2, Cohen’s method may be used (when data are normally distributed) to determine sample mean and variance (<i>i.e.</i>, standard deviation) in order to proceed with a t-test.</p> <ul style="list-style-type: none"> - <u>If data cannot be normalized</u>, use nonparametric statistics such as Wilcoxon Rank-Sum test.
15% < ND ≤ 50%	<ul style="list-style-type: none"> - <u>For normally distributed data</u>, use Cohen’s method to determine sample mean and variance (<i>i.e.</i>, standard deviation) in order to proceed with a t-test. - <u>If data cannot be normalized</u>, use nonparametric statistics such as Wilcoxon Rank-Sum test.
50% < ND ≤ 90%	Use nonparametric methods only, such as Wilcoxon Rank-Sum test.
ND > 90%	Establish BRS = MDL or EQL, if appropriate

Statistical Analyses Step-by-Step

Analyzing the Background Data Set (for the Constituent of Interest)

Step 1: Number of observations

Does the background data set consist of a minimum of 12 (or more) observations derived from 12 (or more) background soil samples (not counting split samples and duplicates)?

NO - Find out the reasons for this deficiency and request additional soil samples in order to obtain a data set with at least 12 observations.

YES - Proceed with Step 2.

Step 2: Number of non-detects (values reported as below the Method Detection Limit (MDL)) Are there any non-detects in the background data set?

NO - Proceed with Step 3.

YES - Check if MDL has been clearly stated and remains the same for all soil samples.

If MDL is not clearly stated (or some other value - like EQL has been used), contact the facility and request the MDL (and any previously unreported values above the MDL) before proceeding with statistical analysis.

If several different values are reported as MDL, request that additional soil samples be analyzed as necessary to obtain a data set (12 observations minimum) based on the same MDL.

If MDL is clearly stated and remains the same for all soil samples, determine the percentage of non-detects.

If the number of non-detects is less than (or about) 15% of the number of observations in the data set, substitute the non-detects with MDL/2 (one half of the Method Detection Limit) and proceed with Step 3.

If the number of non-detects is more than 15% of the number of observations in the data set, proceed in accordance with recommendations given in Table C-2.

Step 3: Check for normality of the background data set distribution

In order to be used in a meaningful calculation of a BRS, the values in a data set have to be normally distributed. To test the normality of a data set, several methods are recommended:

- Shapiro-Wilk (W) test
- Kolmogorov-Smirnov (KS) test with Lilliefors critical values
- Normal Probability plot
- Box and Whiskers plot.

The normality check should at least include the Normal Probability and Box and Whiskers plots, and either the W or KS test.

NORMAL - If the values in the data set are normally distributed, proceed with Step 4.

NOT NORMAL - If the values in the data set are not normally distributed, it may not be possible to calculate a meaningful “single number” as a BRS. In that case, determination on whether the soil has been successfully remediated will have to be based on a statistical comparison of the normalized (transformed) background and confirmation data sets.

Step 4: Test for outliers

Use the following equations (as discussed above in [Checking for Outliers](#)) to determine whether there is statistical evidence that a background observation appears extreme and therefore does not fit the distribution of the rest of the data:

Upper cutoff = upper quartile + 1.5 (interquartile range)

Lower cutoff = lower quartile - 1.5 (interquartile range)

NO OUTLIERS - Proceed with Step 5.

YES OUTLIERS - Resolve the outlier issues (as explained in [Outlier Screening Considerations](#)) and proceed with Step 5.

Remark: If a data set has to be transformed for normality purposes, the test for outliers can be conducted prior to transformation (*i.e.*, on the raw data), bearing in mind that the heavily skewed distributions require extra caution. Sometimes elimination of outliers (and substitution with other valid observations, as necessary) can, by itself, bring a data set to normality.

Step 5: Calculation of BRS from a normally distributed data set

a) Calculate the mean (μ_b) and standard deviation (S_b) for the background data set.

b) Calculate BRS as: $BRS = \mu_b + 2 S_b$

If the BRS was calculated from a raw (untransformed) background data set, then it can be either used for direct comparison with the confirmation concentrations, or in a t-test (where the raw confirmation data also has to be normally distributed).

If direct comparison between the BRS and the raw confirmation data shows that no confirmation concentration exceeds the BRS, **STOP HERE** - the soil has been successfully remediated for this constituent.

If direct comparison shows that one or more confirmation concentrations exceed the BRS, then a thorough evaluation may be conducted to determine if this presents a threat to human health and the environment, whether the elevated concentration(s) should be considered and addressed as “hot spot(s)”, whether and how many additional soil samples need to be collected, if it is appropriate to perform a statistical comparison, should these values be included in the data set when conducting a statistical test, etc. **PROCEED** with analysis of the confirmation data set.

If the BRS was calculated from a transformed (normalized) background data set, then it can only be used for a statistical comparison, where the confirmation data also has to be normalized with the same transformation. **PROCEED** with analysis of the confirmation data set.

Analyzing the Confirmation Data Set (for the Constituent of Interest)

Step 1: Number of observations

Does the confirmation data set consist of at least 12 observations derived from an equal number of confirmation soil samples (not counting split samples and duplicates)?

NO - Find out the reasons for this deficiency and request additional soil samples in order to obtain a data set with a minimum of 12 observations. (In some cases, where only direct comparison with the BRS is employed, a smaller number of confirmation samples may be sufficient.)

YES - Proceed with Step 2.

Step 2: Number of non-detects (values reported as below the Method Detection Limit - MDL). Are there any non-detects in the confirmation data set?

NO - Proceed with Step 3.

YES - Check if MDL has been clearly stated and remains the same for all soil samples.

If MDL is not clearly stated (or some other value - like EQL has been used), contact the facility and request the MDL (and any previously unreported values above the MDL) before proceeding with statistical analysis.

If several different values are reported as MDL, request that additional soil samples be analyzed as necessary to obtain a data set (12 observations minimum) based on the same MDL.

If MDL is clearly stated and remains the same for all soil samples, determine the percentage of non-detects.

If the number of non-detects is less than (or about) 15% of the number of observations in the data set, substitute the non-detects with MDL/2 (one half of the Method Detection Limit) and proceed with Step 3.

If the number of non-detects is more than 15% of the number of observations in the data set, proceed in accordance with recommendations given in Table C-2.

Step 3: Check for normality of the confirmation data set distribution

To test for normality of the confirmation data set, the same methods (previously recommended for the background data set) can be used.

Selecting a Method for Data Comparison and Conducting the Test

PARAMETRIC - In order for the mean of the confirmation data to be compared with the BRS through a t-test (a preferred method), the values in the confirmation data set have to be normally distributed.

If the raw values in the confirmation data set are not normally distributed, then a logarithmic or some other transformation should be performed on both data sets (confirmation and background) in attempt to normalize them. If both data sets can be normalized with the same transformation, then proceed with the t-test.

NONPARAMETRIC - If the attempt to normalize data fails, then a nonparametric statistical method (for instance Wilcoxon Rank Sum test) should be used in order to determine if the soil has been successfully remediated.

References Cited Within this Appendix

Barnett, V. and T. Lewis. (1984) *Outliers in Statistical Data*, 2nd ed. John Wiley & Sons Inc. New York, New York.

Conover, W.J. (1980) *Practical Nonparametric Statistics*, 2nd ed. John Wiley & Sons Inc. New York, New York.

Gilbert, R.O. (1987) *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold. New York, New York.

Hawkins, D.M. (1980) *Identification of Outliers*. New York: Chapman and Hall.

Hoaglin, D.C., F. Mosteller, and J. W. Tukey. (1983) *Understanding Robust and Exploratory Data Analysis*. John Wiley & Sons Inc. New York, New York.

Hoaglin, D.C. and B. Iglewicz. (1987) "Fine-Tuning Some Resistant Rules for Outlier Labeling." *Journal of the American Statistical Association*. 82: 1147-1149.

Iglewicz, B. and D.C. Hoaglin. (1993) *How to Detect and Handle Outliers*. American Society for Quality Control, Statistics Division. Milwaukee, Wisconsin.

Additional References

American Society for Testing and Materials. (1997) *Standard Practice for Dealing with Outlying Observations*. ASTM E178-94. American Society for Testing and Materials. West Conshohocken, Pennsylvania.

Bickel, P.J. and K.A. Doksum. (1977) *Mathematical Statistics: Basic Ideas and Selected Topics*. John Wiley & Sons Inc. New York, New York.

Devore, J. and R. Peck. (1986) *Statistics: The Exploration and Analysis of Data*. West Publishing Company. St. Paul, Minnesota.

Shapiro, S.S. (1990) *How to Test Normality and Other Distributional Assumptions*. American Society for Quality Control, Statistics Division. Milwaukee, Wisconsin.

- Snedecor, G.W. and W.G. Cochran. (1980) *Statistical Methods*, 7th ed. Iowa State University Press. Ames, Iowa.
- U.S. EPA. (1992) *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance*. Office of Solid Waste. Washington, D.C.
- U.S. EPA. (1992) *Statistical Training Course for Ground-Water Monitoring Data Analysis*. EPA/530-R-93-003. Office of Solid Waste. Washington, D.C.
- U.S. EPA. (2002) *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites*. EPA 540-R-01-003. Office of Emergency and Remedial Response. Washington, D.C.
- U.S. EPA. *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Update III (SW-846)*. Office of Solid Waste and Emergency Response. Washington, D.C.
<http://www.epa.gov/epaoswer/hazwaste/test/main.htm>

Appendix D

Grid Spacing Determination

Grid spacing can be determined through different methods, including but not limited to, following the procedures described in this appendix or using a sophisticated computer program, such as Visual Sample Plan (VSP). VSP was developed by the Pacific Northwest National Laboratory and partially supported by U.S. Department of Energy's (DOE's) Environmental Management, U.S. EPA's Offices of Environmental Information and Solid Waste and Emergency Response, and U.S. Department of Defense (DOD). It provides numerical and graphical input/output, statistical analysis, and sampling cost calculations. The program, with instructions and examples, can be downloaded free from <http://vsp.pnl.gov/>.

In addition to using a computer based program, the following procedure has been historically included in previous versions of the CPRG and can also be used to conduct rectangular grid sampling in the horizontal (x-y) plane (*i.e.*, determining the grid intervals and the number of samples needed for a given area).

Step 1: Calculate the weighted average for the potency of carcinogens managed in the unit by assigning a score of 3 to carcinogens with a slope factor greater than $1.6 \text{ (mg/kg-day)}^{-1}$, 2 to carcinogens with a slope factor in the range between equal or less than $1.6 \text{ (mg/kg-day)}^{-1}$ and equal or more than $0.091 \text{ (mg/kg-day)}^{-1}$, and 1 to carcinogens with a slope factor less than $0.091 \text{ (mg/kg-day)}^{-1}$, *i.e.*:

Table D-1: Slope Factor Score	
Slope Factor Range (mg/kg-day)⁻¹	Score
SF > 1.6	3
$1.6 \geq \text{SF} \geq 0.091$	2
SF < 0.091	1
Note: For slope factors see Section 7.3, Toxicity Assessment and Appendix A, Generic Cleanup Numbers.	

Step 2: Calculate the weighted average for the potency of systemic toxicants managed in the unit by assigning a score of 3 to non-carcinogens with a reference dose less than 0.003 mg/kg-day, 2 to non-carcinogens with a reference dose in the range between equal or more than 0.003 mg/kg-day and equal or less than 0.05 mg/kg-day, and 1 to non-carcinogens with a reference dose greater than 0.05 mg/kg-day, *i.e.*:

Table D-2: Reference Dose Score	
Reference Dose Range (mg/kg-day)	Score
RfD < 0.003	3
$0.003 \leq \text{RfD} \leq 0.05$	2
RfD > 0.05	1
Note: For slope factors see Section 7.3, Toxicity Assessment and Appendix A, Generic Cleanup Numbers.	

Step 3: Complete the Risk of Exposure Matrix below and calculate the average Risk of Exposure (ROE) by summing the ROE weight-factor scores (high risk is assigned a weight-factor of 3, moderate a weight-factor of 2, and low a weight-factor of 1) for each criterion in the matrix and dividing by the number of criteria considered. In those cases where a criterion cannot be assessed with confidence, a weight-factor of 3 should be used.

Table D-3: Risk of Exposure (ROE) Matrix				
Criterion	Risk of Exposure Weight-Factor			Score
	Low = 1	Moderate = 2	High = 3	
Access Control	permanent	temporary	none	
Ground Water Depth (ft)	>100	50-100	<50	
Soil Permeability (cm/sec)	<10 ⁻⁷	10 ⁻⁷ -10 ⁻⁵	>10 ⁻⁵	
Unit Design Standard	current	outdated	none	
Adjacent Land Use	industrial	mixed	resident	
Presence of Contaminants	none	possible	confirmed	
Contaminant K _d Value (ml/g) [Weighted Average]	>2	0.5-2	<0.5	
Other				
Average ROE				
Note: Soil: water partition coefficient (K _d) values can be found in Appendix A (Generic Cleanup Numbers). For organics, the K _d values can be calculated using the K _{oc} values (analogous to K _d , except that the adsorbing material is considered to be organic carbon) found in <i>Soil Screening Guidance</i> , and multiplying them by the percent of organic carbon content (f _{oc}) in soil (a default value of 0.002 can be used as an f _{oc}).				

Step 4: By treating each result from Steps 1, 2 and 3 as an individual Sampling Intensity Factor (SIF), complete the Soil Sampling Intensity Matrix below and calculate the composite SIF by summing individual SIF values.

Table D-4: Soil Sampling Intensity Matrix	
Determinant	SIF
Potency of Carcinogens	
Potency of Non-Carcinogens	
Average ROE	
Composite SIF	

Step 5(a): To sample on a consistent basis for a "hot spot" contamination scenario, the size and shape of a characteristic elliptical "hot spot", and an acceptable probability (β) of **not**

finding the “hot spot”, have to be defined a priori. According to the method for determining grid spacing,¹ the size of an assumed elliptical “hot spot” is specified by its semi-long axis (one half of the longer axis = L), and its shape is defined by the ratio of the short axis to the long axis (shape factor = S). By combining this method with the risk associated with the wastes managed in a hazardous waste management unit (calculated as composite SIF in the previous four steps), it is possible to adjust intensity of sampling to the potential environmental threat. In other words, more intense sampling can be required at the units that managed highly toxic and carcinogenic waste, than at the units that managed waste with less adverse characteristics. This is accomplished by assigning lower β (i.e., requiring higher probability of finding a hot spot) and shorter semi-long axis (assuming smaller and harder to find hot spots) to units with a higher composite SIF, and vice versa. The table below presents grid intervals for a square grid pattern, based on three SIF ranges, corresponding β and semi-long axes, and a common shape factor S = 0.80.

Table D-5: Grid Intervals for Soil Sampling in a “Hot Spot” Contamination Scenario				
SIF	Probability of not finding a hot spot ($\beta\%$)	Shape Factor S	Semi-Long Axis (feet)	Grid Interval (feet)
< 4	15	0.80	15	26
4 - 6	10	0.80	10	16
> 6	5	0.80	5	8
Note: Any of these factors may be adjusted in accordance with the site-specific conditions. For example, when sampling in waterways, the shape factor S could be adjusted downward, perhaps to 0.50, to account for more elongated hot spots.				

Step 5(b): To sample on a consistent basis for a **homogeneous contamination scenario**, the Simple Exceedance Rule Method² can be used. This method allows for a statistically based determination of whether a soil remediation goal has been attained at the unit undergoing closure. As with the previously described method for finding hot spots, by linking certain SIF ranges to the method parameters, it is possible to adjust intensity of sampling to the risk associated with the wastes managed in the unit. The method requires predetermination of a proportion of the unit where concentrations of contaminants above the remediation standard may remain undetected (“dirty”), a maximum number of measurements (soil samples) allowed to exceed the remediation standard, and an acceptable false positive rate (i.e., a probability of declaring a successful soil remediation when, in fact, it was not). The table below presents a total number of soil samples that should be taken for each of the three specified SIF ranges in order to stay within the corresponding false positive rate (probability of error). For all SIF ranges, the proportion of the unit which may remain dirty was set to 10 percent, and no measurements were allowed to exceed the remediation standard. Any of these parameters can, of course, be adjusted to the site-specific requirements. A small unit, for instance, may not need as many confirmation samples as the table would indicate, and a large one may require more.

¹ Gilbert, R.O. (1987) *Statistical Methods for Environmental Pollution Monitoring*. Page 121.

² U.S. EPA. (1984) *Characterization of Hazardous Waste Sites: Methods Manual*. Volumes 1 and 2.

Table D-6: Number of Samples for Soil Sampling in a Homogeneous Contamination Scenario		
SIF	False Positive Rate (%)	Number of Samples (n)
< 4	15	15
4 - 6	10	22
> 6	5	29

Once the required number of soil samples has been determined, the evenly spaced (square) grid interval can be obtained by dividing the area of concern, expressed in square feet, by the number of samples and calculating the square root of the quotient, i.e.:

Equation D-1: Calculation of Grid Interval		
$GI = \sqrt{\frac{A}{n}}$		
GI	=	Grid Interval (feet)
A	=	Area of Concern (square feet)
n	=	Number of Samples

The starting point for the grid should be randomly selected and a discrete sample collected at each grid intersection within the area of concern. If excavation is required to remove contaminated soil or to remove the hazardous waste management unit, each excavation face and the floor become a new area of concern that should be gridded and sampled.

Examples of grid spacing calculations, for both the "hot spot" and the homogeneous soil contamination scenarios, are provided below in Examples of the Sampling Grid Calculations.

Examples of the Sampling Grid Calculations

Exhibit D-1: "Hot Spot" Soil Contamination Scenario

ACME Manufacturing, Inc. has a 25' by 40' gravel-based drum storage area behind its maintenance shop. Since 1991, ACME has stored 50 drums of tetrachloroethylene (F001), 25 drums of hexachlorobenzene (F025, F039, K016, U127), and 5 drums of heptachlor (F039, K032, P059).

Step 1: Calculate the weighted average for the potency of the carcinogens.

Equation D-2: Calculation of Weighted Average
$\text{WeightedAverage} = \frac{\sum (\text{no. drums' score})}{\text{total no. of drums}}$

Table D-7: Weighted Average for the Potency of the Carcinogens			
CHEMICAL	POTENCY ¹ (Slope Factor)	"WEIGHT" ² (No. of Drums)	SCORE ³
tetrachloroethylene	5.2E-02	50	1
hexachlorobenzene	1.6E+00	25	2
heptachlor	4.5E+00	5	3
Weighted Average = $\frac{(50 \times 1) + (25 \times 2) + (5 \times 3)}{(50 + 25 + 5)} = 1.44$			
Notes: (1) Carcinogenic potency of a chemical is represented by its Slope Factor [(mg/kg-day) ⁻¹]. Source: Appendix A (Generic Cleanup Numbers), Table A-5 . (2) "Weight" represents the quantity of a chemical. It can be expressed in different units (tons, cubic yards, number of drums, etc.), as long as the units are kept the same for all chemicals. (3) Score is based on a Slope Factor for a particular chemical, as explained earlier in this Appendix, Introduction, Step 1 .			

Step 2: Calculate the weighted average for the potency of the systemic toxicants.

Table D-8: Weighted Average for the Potency of the Systemic Toxicants			
CHEMICAL	POTENCY ¹ (RfD)	"WEIGHT" ² (No. of Drums)	SCORE ²
tetrachloroethylene	1.0E-02	50	2
hexachlorobenzene	8.0E-04	25	3
heptachlor	5.0E-04	5	3
Weighted Average = $\frac{(50 \times 2) + (25 \times 3) + (5 \times 3)}{(50 + 25 + 5)} = 2.37$			
Notes: (1) Toxic potency of a chemical is represented by its Reference Dose (RfD) [mg/kg-day]. Source: Appendix A (Generic Cleanup Numbers), Table A-5 . (2) Score is based on a Reference Dose for a particular chemical, as explained earlier in this Appendix, Introduction, Step 2 .			

Step 3: Complete the Risk of Exposure (ROE) Matrix using the Table from Step 3 in the Introduction to this Appendix. The following facts (criteria) were scored and entered into the matrix:

- I. Storage area is marked with construction tape and unpatrolled. (Score: 3)
- II. Depth to ground water is approximately 25 feet. (Score: 3)
- III. Soil permeability is 5E-06 cm/sec. (Score: 2)

- IV. No environmental controls such as sealed flooring and secondary containment. (Score: 3)
- V. Adjacent land use is 100% industrial. (Score: 1)
- VI. Presence of contaminants is probable because of surface staining. (Score: 2)
- VII. Weighted average of the soil:water partition coefficient (Kd) values for the chemicals of concern is determined in the following table:

Table D-9: Calculation of the Kd Score			
CHEMICAL	Kd¹ (L/kg)	"WEIGHT" (No. of Drums)	Kd x "WEIGHT"
tetrachloroethylene	5.30E-01	50	26.5
hexachlorobenzene	1.60E+02	25	4000
heptachlor	1.91E+01	5	95.5
Weighted Average = $\frac{(26.5 + 4000 + 95.5)}{(50 + 25 + 5)} = 51.525$			
Since 51.525 > 2, Kd score = 1 (Table D-3)			
Note:(1) Source: Appendix A (Generic Cleanup Numbers), Table A-5.			

Table D-10: Risk of Exposure (ROE) Matrix	
Criterion	Score
Access Control	3
Ground Water Depth	3
Soil Permeability	2
Unit Design Standard	3
Adjacent Land Use	1
Presence of Contaminants	2
Kd Score (from the weighted average)	1
Average ROE = $\frac{(3 + 3 + 2 + 3 + 1 + 2 + 1)}{7} = 2.14$	

Step 4: Use the results from Steps 1, 2 and 3 to complete the Soil Sampling Intensity Matrix, and calculate the composite SIF.

Table D-11: Soil Sampling Intensity Matrix	
Determinant	SIF
Potency of Carcinogens	1.44
Potency of Systemic Toxicants	2.37
Average ROE	2.14
Composite SIF	5.95

Step 5(a): Based on the composite SIF, select the grid interval from Table D-5 in this Appendix.

Since the calculated composite SIF (5.95) falls in the 4-6 range, the maximum allowed grid interval is **16 feet**.

Exhibit D-2: Homogeneous Soil Sampling Scenario

To calculate the sampling grid interval for the unit described in the previous example, under the assumption that the contamination is evenly spread throughout the soil, Steps 1 through 4 remain unchanged.

Step 5(b) Based on the composite SIF, select the number of samples from Table D-6.

Since the calculated composite SIF (5.95) falls in the 4-6 range, the minimum required number of samples is 22. Next calculate the square grid interval (GI) by dividing the unit area (25' by 40') by the required number of samples and finding the square root of the quotient.

Calculation of Grid Interval
$GI = \sqrt{\frac{\text{UnitArea}}{\text{NumberofSamples}}}$
$GI = \sqrt{\frac{1000\text{ft}^2}{22\text{ft}}} = 6.74\text{ft} \approx 6.5\text{ft}$

For convenience, the calculated interval can be rounded to a lower number (6.5 feet, for instance).

Remark

The results from the two examples indicate that a smaller grid interval (requiring more samples) is needed for sampling in a “homogeneous scenario,” than when sampling to find a “hot spot.” This seems to contradict the common sense, since the opposite would be expected. In fact, it just shows that either method can be rather heavily biased by the input parameters and various (necessary) assumptions. If, for instance, the area of concern was 5,000 square feet instead of 1,000, the “homogeneous scenario” method would have produced a grid interval of 15 feet -

practically the same result as obtained from the “hot spot” method (16 feet). If, on the other hand, the shape factor S and the semi-long axis were assumed to be 0.5 and 5 feet, respectively, the “hot spot” method would have rendered a grid interval of 6.1 feet, which is very close to the result obtained with the “homogeneous scenario” method in the example (*i.e.*, 6.5 feet). This clearly illustrates the importance of understanding how each method works, as well as the need for careful evaluation of the site-specific information and the assumptions required by each method.

References Cited in this Appendix

Gilbert, R.O. (1987) *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold, New York.

Pacific Northwest National Laboratory. Visual Sample Plan, <http://vsp.pnl.gov/>

U.S. EPA. (1984) *Characterization of Hazardous Waste Sites: Methods Manual*. Volumes 1 and 2. Office of Research and Development. Las Vegas, Nevada.

Additional Reference

Schweitzer, G.E. and J.A. Santolucito (eds.). (1984) *Environmental Sampling for Hazardous Wastes*. ACS Symposium Series No. 267. American Chemical Society. Washington, D.C.

Appendix E

Ground Water Scoring Matrix

The ground water scoring matrix is one tool that may be used as an indicator that soil contamination has not and probably will not reach ground water. However, in addition to using the ground water scoring matrix, multiple lines of evidence are necessary to make this demonstration. As discussed in [Section 3.12, Ground Water Sampling and Analysis](#), this demonstration may be applicable in deciding whether an owner/operator may be released from the closure performance-based ground water sampling and/or whether the ground water risk assessment pathway exclusion as discussed in [Section 7.2](#) is applicable.

The scoring matrix contained in this appendix should not be used if any of the following apply:

- Any underlying ground water zone is known to be contaminated;
- Soil contamination is known to extend to the uppermost saturated zone or to the top of a coarse-grained layer such as sand and gravel;
- Soil contamination is known to extend to within five feet or less of the uppermost saturated zone;
- Secondary pathways to the ground water (piping, fractures, etc.) are present; or
- Constituents of concern are very soluble and do not adhere to soil.

The ground water scoring matrix may not be used to relieve an owner/operator of their responsibility for sampling ground water under a permit condition or OAC Rules 3745-54-90 through 3745-54-100 or OAC Rules 3745-65-90 through 3745-65-94.

TABLE E-1: GROUND WATER SCORING MATRIX / LEACHING EVALUATION SCORING SHEET

I. LAND SURFACE CHARACTERISTICS	<i>low (score 1)</i>	<i>moderate (score 2)</i>	<i>high (score 3)</i>			<i>score</i>	
1. Surface Soil Permeability	< 10-6 cm/s	10-6 to 10-4 cm/s	> 10-4 cm/s				
2. Proximity to Flood Plains	outside 100 yr flood plain	25 to 100 year flood plain	within 25 year flood plain				
3. Terrain Slope	≥ 6%	6 to 2%	≤ 2%				
II. VADOSE ZONE CHARACTERISTICS	Hydraulic Conductivity (cm/sec)	Thickness of Lowest Hydraulic Conductivity Layers (feet)				<i>score</i>	
		≤ 15	15 to 50	50 to 200	> 200		
	1. Thickness and Hydraulic Conductivity (2 factor matrix)	≥ 10-3	<i>score 6</i>	<i>score 6</i>	<i>score 6</i>	<i>score 6</i>	
		< 10-3 to 10-5	<i>score 6</i>	<i>score 6</i>	<i>score 5</i>	<i>score 4</i>	
		< 10-5 to 10-7	<i>score 4</i>	<i>score 4</i>	<i>score 3</i>	<i>score 2</i>	
<10-7		<i>score 3</i>	<i>score 4</i>	<i>score 2</i>	<i>score 2</i>		
2. Feet from Deepest Known Soil Contamination to Uppermost Saturated Zone	<i>low (score 2)</i>	<i>moderate (score 4)</i>	<i>high (score 6)</i>			<i>score</i>	
	> 30 feet	5 to 30 feet	≤ 5 feet				
3. Secondary Characteristics (Directional Flow)	none present	seams or fractures are present but do not appear to act as conduits	significant seams, high density fractures, desiccation cracks, buried utility lines that may act as conduits				
III. GROUND WATER CHARACTERISTICS	<i>low (score 1)</i>	<i>moderate (score 2)</i>	<i>high (score 3)</i>			<i>score</i>	
1. Uppermost Saturated Zone Type	confined	leaky confined	unconfined				
2. Aquifer Type ¹	<i>low (score 1)</i>	<i>high (score 6)</i>					
	other	unconsolidated aquifer yielding >100 gpm, sole source aquifer, or drinking water source water protection area					
IV. CHEMICAL CHARACTERISTICS	<i>low (score 1)</i>	<i>moderate (score 2)</i>	<i>high (score 3)</i>			<i>score</i>	
1. Mobility in Soil							
a. Organic - Koc	> 2000 ml/gm	150 to 2000 ml/gm	< 150 ml/gm				
b. Metals ²	Al, Cr, Tl, Th, Sn	Ba, Be, Co, Cu, Pb, Mn, Ni, P	As, B, Br, Cd, F, I, Mg, Hg, Mo, Ra, Sb, Se, Ag, U, V, Zn				
2. Persistence	Refer to Table E-2	Refer to Table E-3	Refer to Table E-4				
3. Specific Gravity	<i>low (score 1)</i>		<i>high (score 3)</i>			<i>score</i>	
	<1		>1				

¹ If there is evidence of sloppy maintenance or a large number of identifiable WMUs at the site, or if it is in close proximity to an outstanding resource surface water that may be interconnected w/ground water or near a salt dome, underground mine, cave or other geologically unstable area, add a point for each of these factors.

² For Cr, Ni, Pb, Co, and Cu, increase mobility factor value by one if there is evidence of an acidic leachate (pH < 3) OR the metals are present in solution in liquid hazardous substances at the site (e.g., plating wastes). Decrease by one the assigned mobility value for a metal in alkaline areas (pH > 8), if it can be determined that the metal is present in solid form. Don't assign a value <1. (Note: This doesn't apply to Se and As, which are more mobile under alkaline conditions.)

Table E-2: Low - Nonpersistent Compounds	Table E-3: Moderate - Persistent to Somewhat Persistent Compounds		Table E-4: High - Highly Persistent Compounds	
acetaldehyde acetic acid acetone acetophenone benzoic acid di-isobutyl carbinol docosane eicosane ethanol ethylamine hexadecane methanol methyl benzoate 3-methyl butanol methyl ethyl ketone 2-methylpropanol octadecane pentadecane pentaol propanol propylamine tetradecane n-tridecane n-undecane	acenaphthylene acetylene dichloride atrazine (diethyl) atrazine barbital behenic acid, methyl ester benzene benzene sulfonic acid borneol bromobenzene camphor e-caprolacam carbon disulfide chlorobenzene 1,2-bis-chloroethoxy ethane b-chloroethyl methyl ether chloromethyl ether chloromethyl ethyl ether 3-chloropyridine o-cresol decane n-decane di-t-butyl-p-benzoquinone 1,2-dichloroethane dichloroethyl ether dihydrocarvone 1,2-dimethoxy benzene 1,3-dimethyl naphthalene 1,4-dimethyl phenol dimethyl sulfoxide 2,4-dinitrotoluene dioctyl adipate ethyl benzene 2-ethyl-n-hexane cis-2-ethyl-4-methyl-1,3-dioxolane trans-2-ethyl-4-methyl-1,3-dioxolane o-ethyltoluene	guaiacol 2-hydroxyadiponitrile idene isoborneol isodecane isophorone isopropenyl-r-isopropyl benzene isoprophyl benzene limonene methane 2-methoxy biphenyl methyl biphenyl methyl chloride methyl ester of lignoceric acid 2-methyl-5-ethyl-pyridine methyl naphthanlene methyl palmitate methyl phenyl carbinol methyl stearate methylene chloride methylindene naphthalene nitroanisole nitrobenzene nonane octane octyl chloride pentane phenyl benzoate phthalic anhydride propylbenzene 1-terpineol toluene 1,1,2-trichloroethylene trimethyl-trioxo-hexahydro-triazine isomer vinyl benzene xylene	aldrin antimony compounds arsenic compounds barium compounds benzopyrene benzothiazole benzothiophene benzyl butyl phthalate beryllium compounds bromochlorobenzene bromodichloromethane bromoform bromoform butanol bromophenyl phytyl ether cadmium carbon tetrachloride chlordane chlormochloromethane chloroform chlorohydroxy benzephenone bis-chloroisopropyl ether m-chloronitrobenzene chromium compounds DDE DDT dibromobenzene dibromodichloroethane dibutyl phthalate 1,4-dichlorobenzene dichlorodifluoroethane dieldrin diethyl phthalate di(2-ethylhexyl)phthalate	dihexyl phthalate di-isobutyl phthalate dimethyl phthalate 4,6-dinitro-2-aminophenol dipropyl phthalate endirin heptachlor heptachlor epoxide 1,2,3,4,5,7,7- heptachlorobornene hexachlorobenzene hexachloro-1,3-butadiene hexachlorocyclohexane hexachloroethane lead compounds mercury compounds methyl benzothiazole nickel compounds pentachlorobiphenyl pentachlorophenol selenium compounds silver compounds 1,1,3,3-tetrachloroacetone tetrachloroethane tetrachlorophenyl thallium compounds thiomethylbenzothiaole trichlorbenzene trichlorobiphenyl 1,1,2-trichloroethane trichlorofluormethane 2,4,6-trichlorophenol triphenyl phosphate

I. LAND SURFACE CHARACTERISTICS

1. Surface Soil Permeability

Soil permeability is a measure of the tendency of a liquid (usually water) to permeate the soil or an indicator of the potential for precipitation to lead to runoff. Lower surface permeabilities are associated with greater runoff and a smaller chance that any surface contamination will filter down to the ground water. Higher exponents indicate lower permeability and lower risk. The presence of any engineered containment structures and/or site controls (e.g., fencing, paving, etc.) that modify surface permeability should not be considered in evaluating this factor. Surface permeability should be estimated from field or laboratory determinations.

2. Proximity to Flood Plains

Flooding potential is a measure of the potential for surface contaminants to be transported by flood waters both horizontally and vertically to the ground water. Flooding potential is measured by the frequency (observed or estimated) of inundation due to stream flooding, high lake levels, or other causes. Facility engineering offices or the U.S. Army Corps of Engineers should be contacted to obtain flood plain maps or engineering reports that provide the information needed to evaluate this factor. County or state agencies responsible for planning, zoning, or flood plain management may also be able to supply relevant information. For flood insurance maps, contact the Federal Emergency Management Agency in Baltimore, Maryland at 1-800-333-1363.

3. Terrain Slope

To assign a score for terrain slope, the slope should be determined from a topographic map. The slope between the site and the nearest downgradient body of surface water (if it is within reasonable distance from the unit) is then used to determine the value. Surface water may be defined as perennial streams and impounded waters, including wetlands. If more than one surface water body is present, utilize the one for which the shortest distance can be calculated. If a surface water body is on site and downhill from the source of contamination, record the highest values. The higher the slope, the greater the runoff, the less chance for surface contamination to permeate to the ground water.

The slope of the terrain between the site and nearest downgradient body of surface water is determined by the following steps:

1. Determine the pathway by which runoff will flow from the site to surface water (*i.e.*, downhill, perpendicular to topographic contours).
2. Measure the distance along the flowpath, and assign this value to X (e.g., X = 800 feet).
3. Subtract the surface water elevation from the site elevation, and assign this value to Y (e.g., Y = 50: 900 - 850 = 50 feet).

4. Calculate the slope using the formula below:

$$\text{Slope (\%)} = Y/X * 100: 50/800 * 100 = 6.25\%$$

II. VADOSE ZONE CHARACTERISTICS

1. Thickness and Hydraulic Conductivity

Evaluation of whether ground water will be affected by the unit/site may be based on the thickness of the least permeable continuous unit in the interval between the lowest point of known contamination and the top of the first saturated zone. Only consider continuous layers that are at least five (5) feet in thickness.

Hydraulic conductivity is a measure of the ease with which water may move through the subsurface and is expressed in units of length per time.

If site-specific values for hydraulic conductivity are not available, then the following default values for hydraulic conductivity can be assigned based on regional information.

Table E-5: Default Hydraulic Conductivity Values	
Description	Hydraulic Conductivity (cm/sec)
Unfractured clay, shales, claystone, mudstone, clay, silty clay, low permeable tills	$\leq 10^{-7}$
Clayey silt, moderate permeable till, silty shale, unfractured siltstone-sandstone-limestone	$> 10^{-7}$ to 10^{-5}
Sandy silt, silty sand, permeable till, clayey sand, cemented sandstone, fracture geologic material, coal, peat	$> 10^{-5}$ to 10^{-3}
Well sorted sand, sand and gravel, highly fractured rock, poorly lithified sandstone, karst limestone	$\geq 10^{-3}$

Assign a value from Table E-1 based on the thickness and hydraulic conductivity of the most impermeable continuous unit(s) in the interval between the lowest point of known contamination to the top of the uppermost saturated zone. If contiguous layers are within the same hydraulic conductivity range categories in Table E-1, then the entire thickness for those layers can be used. If contiguous layers are combined that are in different hydraulic conductivity range categories, then the total thickness can be used if the greatest hydraulic conductivity value is assigned.

If the depth to the uppermost saturated zone is less than ten (10) feet, then the value for this score is maximized.

2. Feet from Deepest Known Soil Contamination to Uppermost Saturated Zone

The depth shall be measured from the deepest point of known contamination to the uppermost saturated zone. For facilities that may not be required by rule/regulation to conduct site-specific ground water investigations (e.g., hazardous waste storage pad), the depth criteria can be estimated from regional information. This information is best obtained from reviewing individual well logs in the area of the facility. Well logs are on file at Ohio Department of Natural Resources. Reviewing site-specific investigations that were conducted in close proximity to the facility is also beneficial. State water level information can be reviewed in conjunction with geologic description, the length of casing, and well depth to determine the appropriate depth to the saturated zone.

If contaminated soil extends to the bedrock and if the potentiometric surface of the uppermost saturated zone is within the bedrock, then well logs within one-half mile of the unit should be evaluated to determine if it is possible to calculate the feet from the deepest known contamination (the bedrock surface) to the uppermost zone. In some areas of Ohio with large surface elevation variations, it may be difficult or impossible to calculate this distance. In such cases, the score should be maximized to be conservative.

3. Secondary Characteristics

The potential for discrete features in the unsaturated zone (both unconsolidated and consolidated deposits) to act as a conduit to the water table should be assessed qualitatively, considering the presence, character, and density of faults, fractures, joints, subsidence fissures, solution channels, significant sand seams and other similar features that might act as conduits for contaminant travel through the unsaturated zone. If anthropogenic excavations occur within the saturated zone, then the value for this score is maximized.

III. GROUND WATER CHARACTERISTICS

1. Uppermost Saturated Zone Type

The type of saturated zone will affect the susceptibility of the zone to site-specific contaminant releases. The saturated zone may be either unconfined (water table aquifers), confined, or leaking. An unconfined zone is one where ground water possesses a free surface open to the atmosphere. Recharge to the saturated zone is from downward seepage through the unsaturated zone, lateral flow, or upward seepage from underlying strata. A confined saturated zone is under pressure by overlying subsurface materials. Recharge to confined zones occurs in recharge areas, where the strata crops out (*i.e.*, becomes unconfined) or by slow downward leakage through a confining layer (*i.e.*, leaking aquifer).

Unconfined saturated zones are typically more susceptible to contamination. Because they are unconfined, the vadose zone materials are usually fairly permeable also. The presence of a semi-confined saturated zone suggests the presence of a partially confining, lower permeability layer that could inhibit the movement of contaminants. It is important to note that discontinuities (secondary characteristics) often occur in these partially confining layers, including fractures, significant sand seams, or thinning or absence of a clay bed in some areas providing a "window" of leakage across the semi-confining unit.

The seasonal high water table needs to be taken into consideration as part of the saturated zone.

2. Aquifer Type

While a high likelihood of extensive current and/or potential ground water use does not by itself indicate that there is high potential for contamination to reach the uppermost saturated zone, it does indicate that a degree of conservatism is needed in the evaluation. Conditions warranting a higher score include location of the facility over a drinking water source water protection area, a Sole Source aquifer, or a 100 gpm unconsolidated aquifer. Information on Sole Source Aquifers and drinking water source water protection areas may be obtained from Ohio EPA, Division of Drinking and Ground Waters.

IV. CHEMICAL CHARACTERISTICS

1. Mobility in Soil

Mobility is a measure of the tendency of a substance to migrate through soil to the ground water. The constituent which is most mobile in the soil should be used.

2. Persistence

Persistence of each hazardous substance is evaluated on its biodegradability. The score for the persistence of metals is always maximized. The constituent which is most persistent in the soil should be used.

3. Specific Gravity

The K_{oc} addressed in the mobility factor does not take into account whether the constituent is a floater or a sinker (Dense Non-Aqueous Phase Liquid). A more thorough ground water investigation should be required if the specific gravity is >1 .

V. DETERMINING WHETHER TO INCLUDE A GROUND WATER INVESTIGATION

Table E-6: Determining if a Ground Water Investigation Should be Performed	
Should a ground water investigation be performed as part of closure?	Total Point Range
Total Possible Points	45
Definitely	30-44
Possibly	0-29

Soil Leaching Flowchart can be used to determine if a ground water protection standard needs to be established.

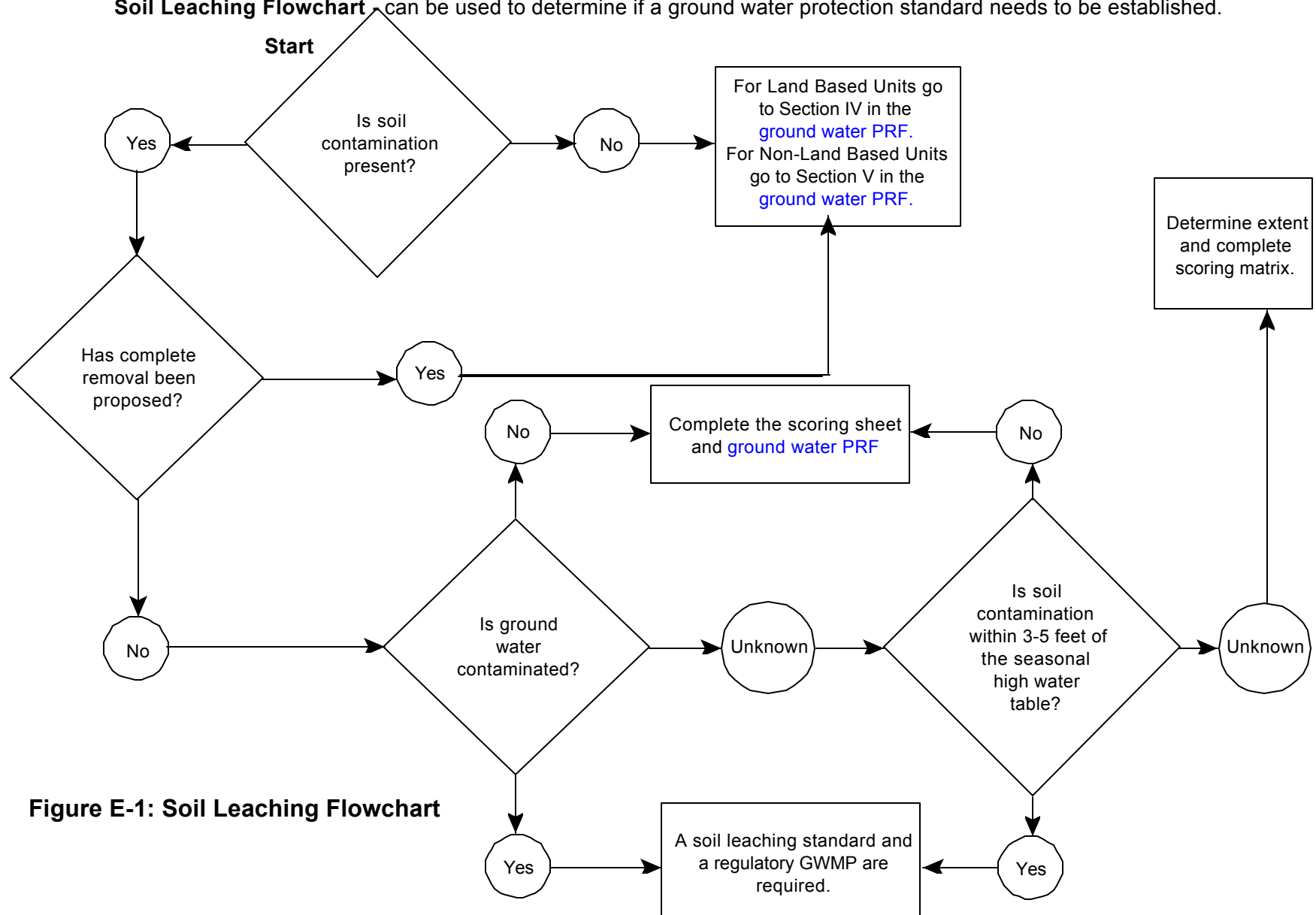


Figure E-1: Soil Leaching Flowchart

Land Based Units FlowChart - can be used to determine what type of ground water monitoring plan should be established

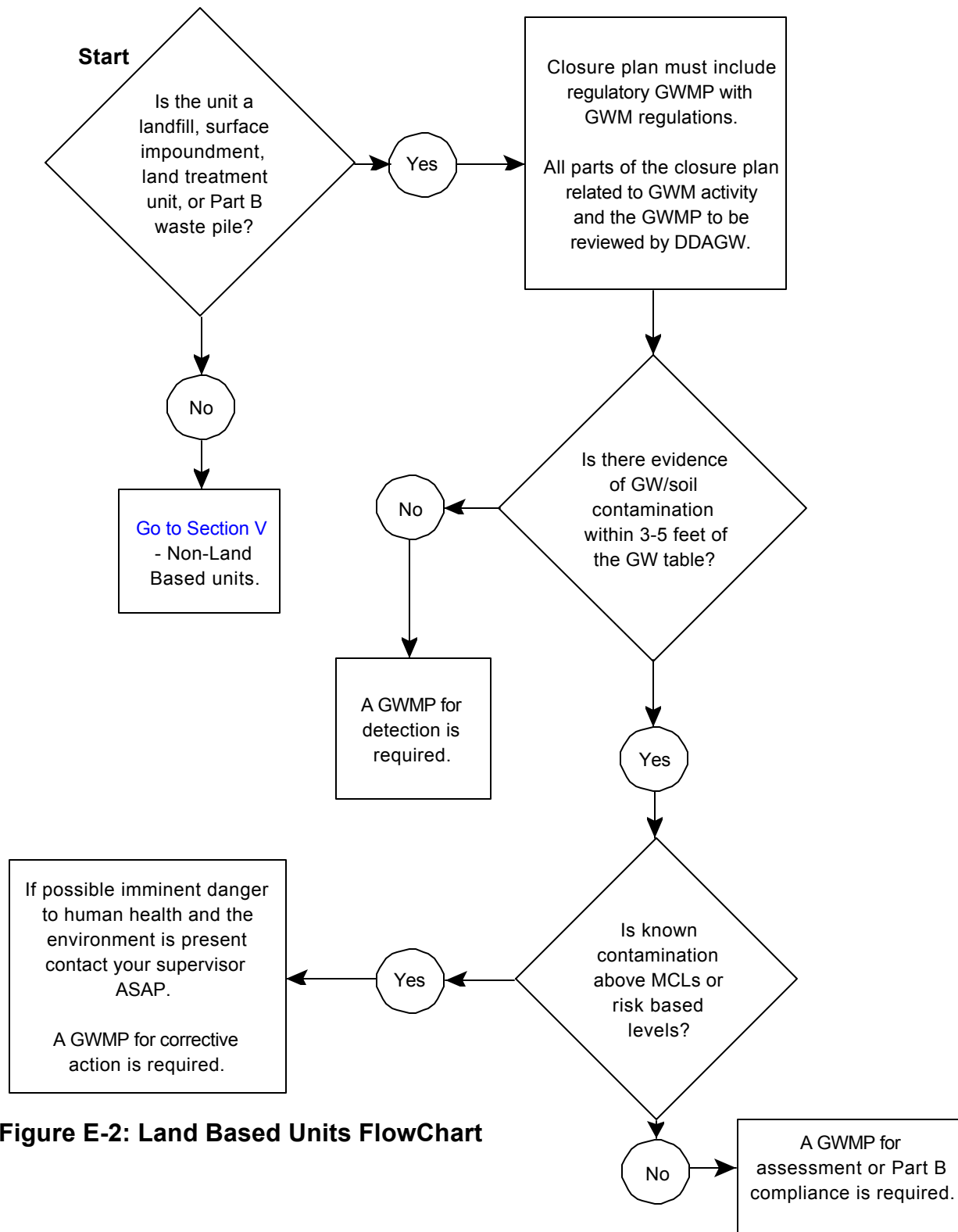


Figure E-2: Land Based Units FlowChart

Non- Land Based Units Flowchart - can be used to determine what type of ground water monitoring plan should be established

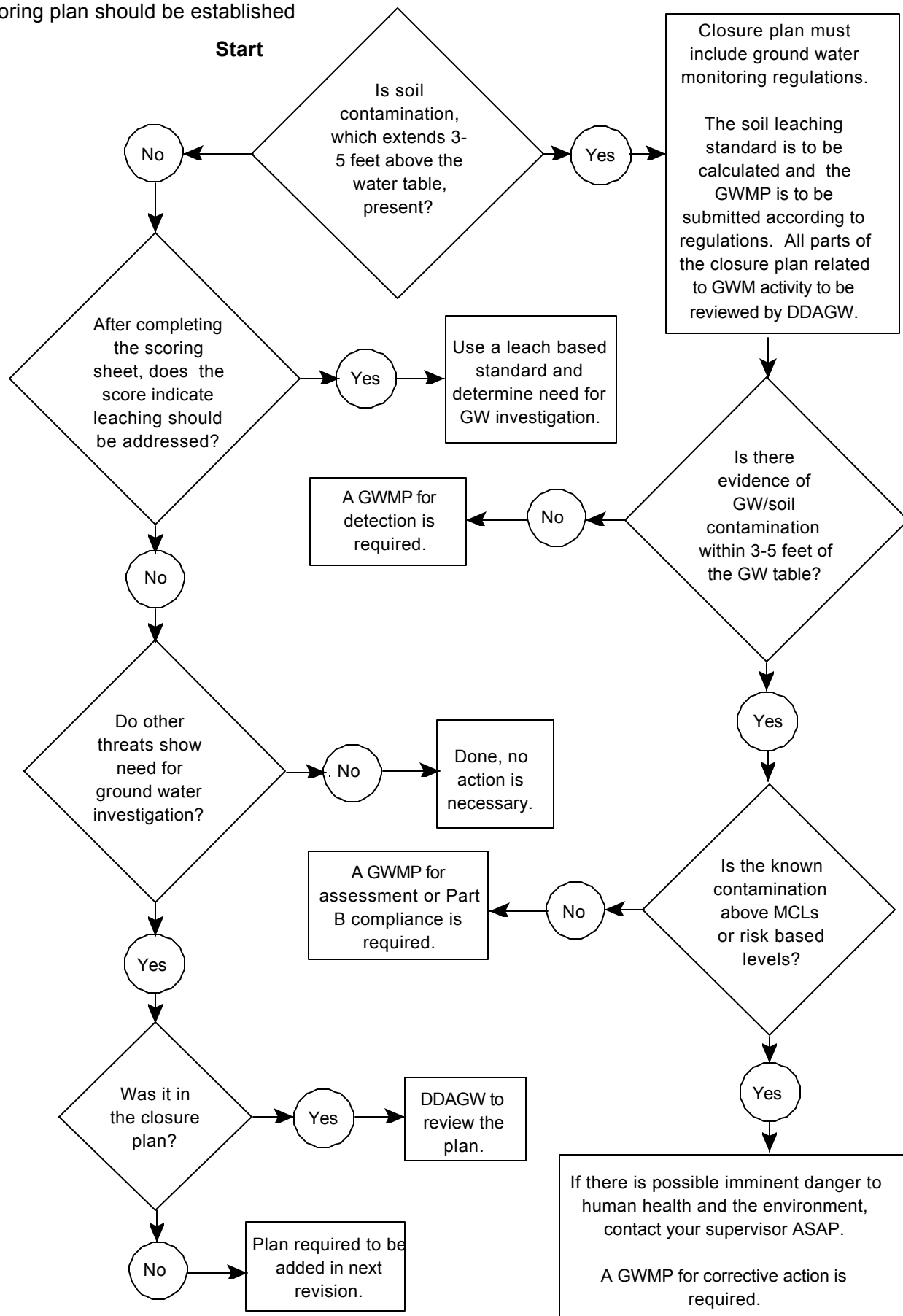


Figure E-3: Non- Land Based Units Flowchart

Appendix F

Mobile Laboratory Guidance

DHWM has seen an increase in the amount of requests to use mobile laboratories for RCRA closure projects. Mobile laboratories are often desirable because they can supply analytical data more quickly than a conventional, fixed laboratory. As such, mobile laboratories can be useful for delineating the extent of contamination and for screening purposes. While DHWM has never objected to the use of mobile laboratories for screening purposes, these requests are beginning to focus on the use of mobile laboratories as substitutes for analyses traditionally performed at fixed laboratories, such as data used for risk assessment, ground water sampling data, and confirmation sampling of soils.

The use of mobile laboratories for these more critical types of analyses may be problematic. Quality Assurance/Quality Control (QA/QC) checks for accuracy and precision are generally performed at fixed laboratories at a frequency of at least 10% of the samples or once per batch. Unfortunately, the specific frequency used by mobile laboratories and fixed laboratories can vary. In addition, mobile laboratory storage, sample log-in, preservation and chain of custody recordkeeping may also differ considerably from fixed laboratories. For example, volatile samples are often not stored properly and kept at 4°C, which can compromise the integrity of the results. Also, mobile laboratories may not be able to analyze for every constituent of concern, or provide every QC protocol that is stipulated by an analytical method. Plus, due to problems arising in the field, analyses and procedures performed in mobile laboratories may not mirror what is stated in their Quality Assurance Project Plan (QAPjP).

In order for a mobile laboratory to be deemed acceptable for the analysis of sensitive analytical data such as that used in a risk assessment, it should be able to make all QA/QC demonstrations and sample handling procedures that are required of a fixed laboratory. However, some projects will require only minimal QA/QC information. For example, field measurements of pH and conductivity have little quality assurance data associated with these analyses. Therefore, the reviewer must evaluate the necessary QA/QC components that are required to meet a project's Data Quality Objectives (DQOs). When considering whether a mobile laboratory is appropriate for use in a remediation project, the reviewer should, at a minimum, consider the following:

- 1. Technical Holding Times** - Technical holding times are the elapsed times from sample collection to preparation, extraction or analysis. Technical holding times achievable by a mobile laboratory should ideally correspond to those of a fixed laboratory, especially for certain sensitive analyses such as SW-846 Method 5035. In some cases, samples which are analyzed by mobile laboratories are unpreserved under the assumption they will be analyzed immediately. If samples are not analyzed immediately (a common occurrence), then data for these samples should be rejected. Therefore, sample receipt, sample preservation, sample preparation, and sample analysis dates and times should be recorded and kept on file for data validation. Refer to Ohio EPA's [Data Validation Tier I Plan Review Form, Table I](#) for more information on this subject.
- 2. Calibrations** - In order to meet the highest level of DQOs, initial and continuing calibration should be performed as specified in the analytical method (See *SW-846*, Chapter 8). For other DQO levels, at least three standards and a laboratory blank should be performed. Minimum levels of acceptance criteria for the initial and continuing calibration should be specified by the mobile laboratory in its QAPjP. Calibration for all constituents of concern should be performed on a daily basis, as well as whenever problems are noted in the continuing calibration check standards.

3. **Field Visits** - The DO contact should visit the mobile laboratory during field work. They should evaluate how samples are stored, preserved and staged prior to analysis. Bench sheets should be reviewed for consistency and whether necessary information is being properly recorded. Central Office's laboratory coordinator may be contacted if questions arise.
4. **Reports Submitted** - The reviewer should expect to see the same type of reports (chain of custody, cover letter or case narrative, sample receipt form, etc.) as they would receive from a fixed laboratory, with the same level of detail.
5. **Personnel** - The mobile laboratory should be able to provide credentials for all personnel involved in the analysis of samples associated with this project, as well as credentials for any substitute personnel who may need to fill in for the analyst.
6. **Electricity** - Analytical instruments need a consistent source of power so that stable analytical results can be achieved. The laboratory should demonstrate that they have a reliable power source and, possibly, a back-up power supply. Portable generators are not always able to supply sufficient power and can contribute to sample contamination in the case of gasoline-powered generators. If possible, power supplies should be hard wired into a dedicated power line.
7. **Temperature Stability** - Internal temperatures of mobile laboratories are subject to greater fluctuation than fixed laboratories. Elevated temperatures, such as those in the summer, can influence sample results. The mobile laboratory should be moderated appropriately with air conditioning and adequate ventilation. The laboratory should maintain a log that demonstrates the stability of temperature in the laboratory environment. In addition, laboratory instruments will occasionally have recommended operating temperature ranges. If this is encountered, those specifications should be met.
8. **Sample Handling Procedures** - Even if analyses for dissimilar compounds (*i.e.*, inorganics and organics) are performed in separate trailers, they will still be exposed to more opportunities for contamination than in a fixed laboratory. Chemical extractions may also be performed closer to samples and blanks than in a fixed laboratory, possibly introducing laboratory contamination. The mobile laboratory should have procedures for addressing this situation. Ventilation will also play a role in this area. It may be advisable to analyze ambient air blanks to assess cross contamination. In addition, cooler temperatures should be logged periodically to demonstrate the adequacy of the laboratories sample storage facilities.
9. **Other** - The following QA/QC samples, criteria for acceptance and sample frequency should be discussed in a mobile laboratory's QAPjP. Specific DQO requirements for a project should be incorporated into the sampling and analysis plans.
 - a. **Surrogate Compound Recovery** - Surrogates are spiked compounds of known composition which are added to samples and blanks to assess matrix interference.

- b. **Matrix Spike/Matrix Spike Duplicates** - are performed to assess method precision for Volatile Organic Compounds (VOC) and Semi-Volatile Organic Compounds (SVOC) and metal analysis.
- c. **Blanks** - These may take the form of either method, laboratory, or field blanks, depending on where contamination (or its absence) is to be demonstrated. The goal with any blank is to demonstrate that contamination has not been introduced into the analysis at some point.
- d. **Laboratory Control Sample (LCS)** - Laboratory control samples are clean material of like matrix as the samples of interest which have been spiked with a known amount of target analytes. LCSs are used to evaluate whether the analytical instruments are capable of analyzing samples with appropriate sensitivity.
- e. **Split/Confirmatory Samples** - It is common practice to include some independent assurance of the mobile laboratory's accuracy. Ohio EPA recommends confirmation of at least 10% of field analyses by fixed laboratory analysis based on U.S. EPA's (1992) *Guidance for Data Useability in Risk Assessment (Part A)*. The Relative Percent Difference (RPD) between the fixed and mobile laboratories should not exceed 40% (20% on either side of the concentration).
- f. **Performance Evaluation Samples (PE)** - Performance Evaluation samples may also be used to assess accuracy. These samples are obtained from an independent source for selected constituents of concern, **by matrix**, and shipped to the mobile laboratory. The specific constituents and concentrations are not provided to the mobile laboratory. The mobile laboratory then performs their analysis and sends the results to the PE provider. The PE provider will then tell the mobile laboratory if their values are within acceptable concentrations. Adjustments can be made as necessary.

Should the mobile laboratory not be able to demonstrate that they are able to meet the requirements specified by the analytical method to the reviewer's satisfaction, results obtained from the laboratory **may not** be used for confirmation sampling, ground water sample analysis, or risk assessment. The laboratory may still be used for delineation and screening.

Mobile laboratories have become increasingly more sophisticated in recent years. DHWM feels that if a laboratory is able to demonstrate they have an adequate QA/QC program, data from that laboratory can be used for any purpose, regardless of whether it is fixed or mobile. However, our experience thus far has indicated that mobile laboratories warrant heightened scrutiny. While many claim to be able to duplicate the quality and procedures of fixed laboratories, this is often not the case in practice. Vigorous QA checks before agreeing to use of a mobile laboratory, as well as site visits to observe laboratory operations during field work, are necessary.

Appendix G

Final Covers for Hazardous Waste Surface Impoundments, Waste Piles, and Landfills¹

Introduction

The purpose of this appendix is to provide guidance on final cover design solutions suitable for various waste in place (*i.e.*, landfill type) closure scenarios. This appendix includes a discussion of essential final cover design requirements for surface impoundments, waste piles and landfills. The discussion is based on an examination of the applicable Ohio rules as well as DHWM's recommendations and views on how the requirements of the rules can be met. These concepts may also be extended to final covers required for containment buildings, tanks or container storage areas that cannot meet the closure by removal or decontamination standards due to the inability to remove contaminated subsoil. Lastly these concepts may also be applicable to sites with RCRA corrective action obligations. This appendix concludes with some examples of accepted final cover designs.

More specifically, the next section of this appendix, titled Background, consists of an overview of the applicable rules and the role that final covers play in the ground water protection strategy. The Technical Performance Standards section describes the technical performance standards of a final cover and Ohio EPA's recommended design solution. This is followed by sections describing considerations of alternative design solutions and critical design elements of a final cover. The final section of this guidance provides examples of approved final covers.

This appendix is intended to convey the general guidelines for evaluating a proposed final cover design and is not to serve as a detailed instructional manual. Refer to the References section at the end of this appendix for additional sources of information.

Background

A determination of appropriate (or acceptable) final cover (or cap) designs for closure must be based upon the regulatory standard. There are two types of closure requirements in the rules: (1) general requirements, which are contained in OAC Rules 3745-55-11 and 3745-66-11, and (2) specific technical performance requirements, which are included with the unit specific requirements for surface impoundments, waste piles and landfills.

Under the general closure performance standard (OAC Rules 3745-55-11 and 3745-66-11), the owner/operator must close the facility in a manner that:

- A) Minimizes the need for further maintenance;
- B) Controls, minimizes or eliminates, to the extent necessary to prevent threats to human health and the environment, post-closure migration of hazardous waste, hazardous constituents, leachate, contaminated run-off, or hazardous waste decomposition products to the ground or surface waters or to the atmosphere; and
- C) Complies with the applicable closure requirements of the unit specific rules.

In addition to the general closure performance standard, U.S. EPA was required by RCRA to, among other things, issue standards applicable to owner/operators of hazardous waste land disposal facilities. In July of 1982, U.S. EPA promulgated such regulations specifying

¹ When a waste in place closure plan is submitted, the reviewer should contact their supervisor and appropriate ERAS member to help with the review.

requirements for closure of surface impoundments and waste piles. In order to assure that those land disposal standards were protective of human health and the environment, U.S. EPA developed the regulations based upon a strategy which focused on and addressed potential adverse effects on ground water².

The fundamental goal of the regulations (as stated in the preamble to the rule) is to minimize the potential for migration into the environment of the hazardous component of the waste placed in the land disposal unit. This goal is achieved by creating regulatory requirements directed towards liquids management at the unit and establishing, through the rules, a comprehensive ground water monitoring and response program. The ground water protection strategy works by combining efforts to both minimize leachate generation and migration into the subsurface along with a ground water monitoring and response program to remove leachate from the ground water if it is detected.

The regulations developed were, to a large degree, technical performance standards. Such standards establish an engineering objective and allow the owner/operator to develop a design or set of practices to achieve the objective. In other words, the level of environmental protection remains constant. The regulating agency, however, is required to draw a balance so that the final cover approved and implemented fits the site conditions.

Specifically, the technical performance standards for waste in place closures of surface impoundments, waste piles, and landfills were promulgated by U.S. EPA in July of 1982³. In April of 1985, U.S. EPA amended the interim status rule for closure of landfills to conform to the final standards (except for post-closure ground water monitoring). In March 1987, U.S. EPA made similar changes to the interim status rule for closure of surface impoundments making it conform to many of the final or permitted facility requirements.

Closure of Surface Impoundments (OAC Rules 3745-56-28 and 3745-67-28)

Currently, Ohio rules allow owner/operators of surface impoundments, at the time of closure, to choose between removing hazardous waste and waste residue (and terminating responsibility for the unit) or leaving the wastes in place. If the latter option is selected, the owner/operator must also eliminate free liquids, stabilize the wastes sufficiently to support a final cover, place a final cover on top of the waste, and conduct post-closure monitoring and maintenance including continued ground water monitoring. Consistent with the ground water protection strategy, the final cover must be designed and constructed to provide long term minimization of the migration of liquids into the closed surface impoundment. In fact, after closure, the protective final cover is the primary element of the liquids management strategy. A well designed and carefully maintained final cover can be quite effective in reducing the volume of liquids entering a unit and therefore can substantially reduce the potential for leachate generation at the unit for long periods of time. In addition, where a bottom liner is present, the cover must be at least as impermeable as the bottom liner in order to avoid the build-up of liquids in the closed surface impoundment. In a waste in place closure, free liquids must be eliminated and the remaining waste must be stabilized to a bearing capacity to support the final cover. This will prevent differential settlement which can create cracks or depressions in the final cover, increasing infiltration. The final cover must also be designed to minimize erosion as well as to accommodate any settlement.

² Federal Register: July 26, 1982 (47 FR 32283)

³ Federal Register: July 26, 1982 (47 FR 32274)

Closure of Waste Piles (OAC Rules 3745-56-58 and 3745-67-58)

In the case of waste piles, all waste residues, contaminated subsoils, and equipment must be removed or decontaminated at closure. However, if the owner/operator, after removing or decontaminating all waste residue and making all reasonable efforts to remove or decontaminate contaminated components, subsoils, structures and equipment, finds that not all contaminated soils can be practicably removed or decontaminated, then the pile is considered a disposal unit. The unit must then be closed in accordance with the closure requirements for landfills, including post-closure care. The preamble of the 1982 Federal Register⁴ suggests that a “reasonable effort” to remove all contaminated subsoils includes removal of all waste and waste residue in the unit, all contaminated liners and equipment, and at least some subsoil. The landfill closure standard contained in OAC Rules 3745-57-10 and 3745-68-10 is very similar to the technical standards for final covers of surface impoundments in terms of the ground water protection strategy.

Closure of Landfills (OAC Rule 3745-57-10 and 3745-68-10)

At closure, the owner/operator must cover the landfill or cell with a final cover that is designed and constructed to meet the technical performance standards listed in OAC Rules 3745-57-10 (A)(1) through 3745-57-10(A)(5) and 3745-68-10(A)(1) through 3745-57-10(A)(5).

The Issue

As discussed in the Background section above, the technical performance standards contained in the Ohio closure rules for final covers are virtually identical to the U.S. EPA rules. The federal rules are generic in nature and are intended to meet the statutory requirement (Section 3004 of RCRA) to promulgate national standards that may be necessary to protect human health and the environment. The rules allow the owner/operator to propose a design or set of practices to achieve the regulatory objective. Using the technical performance standards as a foundation, Ohio EPA through issuance of a closure plan approval establishes site-specific closure requirements with which the owner/operator must comply. Because such a determination is performed on a case-by-case basis, this appendix includes the requirements of Ohio EPA's recommended final cover design and also provides examples of approved designs that vary from the Agency's recommended design.

Technical Performance Standards

Regulatory Performance Requirements

From the previous regulatory discussions, it follows that final covers must be designed and constructed to:

- Provide long-term minimization of the migration of liquids through the closed impoundment;
- Function with minimum maintenance;
- Promote drainage and minimize erosion or abrasion of the final cover;
- Accommodate settlement and subsidence so that the integrity of the final cover is maintained; and
- Have a permeability less than or equal to the permeability of any bottom liner system present.

⁴

Federal Register: July 26, 1982 (47 FR 32324)
Closure Plan Review Guidance 2009
Final Cover Guidance, Page G-3

Ohio EPA's Recommended Design Solution

Based upon various federal guidelines⁵ and Ohio EPA's experience with closures, Ohio EPA's recommended design for a RCRA final cover that complies with the above technical performance standards includes:

- First low permeability layer - a two-foot thick layer of recompact clay with a maximum permeability of 1E-07 cm/sec;
- Second low permeability layer - a flexible membrane liner (40 mil minimum thickness, usually High-Density Polyethylene (HDPE), or more if needed for successful welding);
- Drainage layer - at least a 12 inch thick soil drainage layer with a minimum permeability of 1E-02 cm/sec, or an equivalent geosynthetic drainage layer; and
- Protection layer - at least an 18 inch thick soil vegetative/frost protection layer.

Note: 18 inches of the soil protection layer combined with 12 inches of the soil drainage layer provides a total of 30 inches of soil frost protection. Some areas of Ohio (Ashtabula, Cuyahoga, Erie, Fulton, Geauga, Lake, Lorain, Lucas, Ottawa, and Williams counties) recommend 36 inches of soil for frost protection.

If a geosynthetic drainage layer (geonet) is used, the soil vegetative/frost protection layer should be at least 30 inches or 36 inches thick, as recommended.

Alternative Design Solutions

The above recommended design may be appropriate in many instances, especially for closures of landfills, waste piles and surface impoundments. However, sometimes there are reasonable constraints which make this design impractical or impossible to construct. In such a case, the following additional factors which may affect the design need to be considered:

- Spatial setting - For example, consider if it is a relatively small area to be covered (about 0.5 acre or less (*i.e.*, 150 feet by 150 feet)), a particular prohibitive location (*e.g.*, between two factory buildings, inside a building, or on a portion of roadway), or a pending corrective action which encompasses the unit.
- Hydrogeological setting - Consider the geological attributes, as well as identification of aquifers and saturated zones.
- Future land use of the site - Future use may require a particular design, which should not compromise necessary features of the final cover or pose a threat to humans or to the environment. The closure plan should provide information about how the unit and the site will be used. Both current and future land use at the site and the unit should not jeopardize the integrity of the final cover design.
- Concentration, mobility, toxicity and persistence of waste or waste constituents - Consider site-specific information on constituents contained in materials that are proposed to remain at the site after closure.

⁵

U.S. EPA. (1989) *Seminar Publication: Requirements for Hazardous Waste Landfill Design, Construction, and Closure*, U.S. EPA. (1991) *Seminar Publications: Design and Construction of RCRA/CERCLA Final Covers*, and U.S. EPA. (1993) *Engineering Bulletin: Landfill Covers*.

Reasons justifying an alternative solution for the final cover should be clearly stated, *i.e.*, why construction of the Ohio EPA recommended design is impractical (or impossible).

Critical Design Elements

The following elements are critical to the design of the final cover. In developing a proposed solution, all of these elements should be considered. Then, based upon the site-specific factors, the cover design should be developed and evaluated.

Size

In general, the final cover should completely cover the waste and/or contaminated soils. It should also extend several feet beyond the horizontal extent of contamination (2 to 3 feet minimum, or more if delineation is not clear) in full thickness and with all designed features. In cases where the final cover should extend to a structure, an appropriate interface should be designed.

Structural Integrity

The final cover should have sufficient strength to resist slope failures and any other kind of structural damage. General assistance with issues of structural strength and slope stability is available from the appropriate ERAS member. Specific assistance with issues on slope stability (such as reviewing data and factor of safety calculations) is available through Ohio EPA's Geotechnical Resource Group (GeoRG).

Final Cover Surface

The surface of the final cover should be able to handle atmospheric impact (heat, rain, wind, snow, frost, etc.) and to support all expected loads without sustaining damage.

While for "conventional" final covers the surface is usually grass, for "alternative" final covers, it may consist of any material (such as concrete, asphalt, etc.) that will best serve the purpose of an alternative solution. It should, in any case, be weather resistant and easy to maintain and repair.

The surface should be designed and constructed with sufficient slopes to ensure the efficient removal of precipitation and erosion protection. In situations where "impermeable" final covers (described in detail later in this appendix as Type 1 covers) are warranted, it is recommended that the surface of the final cover have a minimum slope of 5 percent. Runon, runoff, and erosion protection become progressively less critical with "low permeability" (Type 2 covers) and "protective" final covers (Type 3 covers).

Protection Layer

The purpose of the protection layer is to protect the underlying drainage and low-permeability layers from the frost/thaw process and from any physical damage resulting from the loads imposed on the surface layer. The protection layer may be constructed of any clean soil material which will satisfy this purpose. It should have sufficient thickness to provide protection based on the anticipated frost depth and the type of material used in the construction of the underlying layers. It should be constructed in a manner which does not permit settlement to occur.

Drainage Layer

The purpose of the drainage layer is to drain the water percolated from the top protective media and to keep it from collecting on the liner. Ohio EPA makes the following recommendations for the design and construction of the drainage layer:

- Minimum slope of 1 percent;
- Minimum hydraulic conductivity of $1\text{E-}02$ cm/sec for a drainage layer constructed from granular materials with a minimum thickness of 1 foot;
- Minimum hydraulic transmissivity of $3\text{E-}05$ m^2/sec for a drainage layer constructed from synthetic drainage materials;
- The drainage layer should have a free exit flow to a purposefully designed ditch, sewer, or other structure capable of handling maximum expected flow without unintended discharge;
- The drainage layer's outlets should have the means to prevent any sort of soil, trash, or animals from entering into the pipes. In addition, they should be accessible for a periodic inspection and maintenance.

Note: The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional model of water movement across, into, through and out of landfills. The program was developed to conduct a water balance analysis of landfill and cover systems. The model provides a means of estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection and liner leakage that may be expected to result from operation of various landfill designs.

The primary purpose of the HELP model is to assist in the comparison of design alternatives as judged by their water balances. Since all models have limitations, test pads should be constructed to verify that the materials and methods of construction will meet the proposed design criteria.

Low-Permeability Layer(s)

The purpose of the low-permeability layers is to minimize the infiltration of leachate into the subsurface soils below, thus eliminating the potential for ground water contamination. The final cover design may include one or more low-permeability layers. A low-permeability layer can be constructed of either synthetic materials or natural soil. However final cover designs employing both, a geomembrane and a recompacted soil layer, provide more protection and are hydraulically more effective than either type of layer alone.

Synthetic (geosynthetic) Low-Permeability Layer

A synthetic (geosynthetic) low-permeability layer can be constructed from a single flexible membrane liner (FML), also known as a geomembrane, a single geosynthetic clay liner (GCL), or a combination of both. The synthetic materials should be able to withstand any predictable mechanical, chemical, and thermal stress, during the construction period and during the anticipated long-term use. They should be installed according to their manufacturers' recommended QA/QC procedures.

One advantage of geosynthetic low-permeability layers (liners) is that their quality parameters (surface uniformity, thickness, tensile properties, seam strength, etc.)

can be monitored during the fabrication process. However, despite the fact that the liners fabricated from plastic materials are practically impermeable, their protective effectiveness largely depends on installation quality. Besides good seaming, it is important to free the underlying surface of all potentially damaging objects, abrupt changes in grade, standing water, excessive moisture, or mud. Installation on frozen surfaces and on slopes steeper than 3:1 is not recommended because of potential stability problems. The same recommendations apply to installing GCLs, which do not have the plastic component attached.

Literature containing detailed information on design, construction and QA/QC procedures for the geosynthetic components of final covers can be found in the References section at the end of this appendix.

Soil Low-Permeability Layer

A soil low-permeability layer is constructed by recompacting the natural soil to a required specification. The recompacted soil barrier layer should:

- Be at least twenty-four (24) inches thick after compaction, have a maximum permeability of $1\text{E-}07$ cm/sec, and extend at least twenty-four (24) inches beyond the lateral limit of waste placement;
- Be constructed in accordance with the approved construction specifications derived from the test pad;
- Be constructed on a prepared surface that should:
- Be free of debris, foreign material, and deleterious material;
- Be able to bear the weight of the entire cover system and its construction without causing or allowing a failure of the cover system to occur through settling;
- Be tested for moisture content and density at least five (5) times per acre per lift. If the nuclear methods, or any other rapid methods are used, at least one (1) conventional test for water content (ASTM D-2216) should be performed for every ten (10) rapid water content tests, and at least one (1) conventional test for density (ASTM D-1556 or ASTM D-2167) should be performed for every twenty (20) rapid density tests.

Test Pad Requirements

A test pad should be built prior to construction of any recompacted clay layer in order to verify that the materials and method of compaction will achieve the desired results (e.g., low in-field hydraulic conductivity). The minimum design requirements of a test pad include:

- Be designed such that the proposed tests are appropriate and their results valid;
- Be constructed to establish the construction details which are necessary to obtain sufficient compaction to satisfy the permeability requirement. These construction details include such items as soil properties, lift thickness, moisture content necessary to achieve the

desired compaction, the type, weight, and number of passes of construction equipment, etc.;

- Be constructed and tested prior to construction of the final cover system's recompacted soil barrier layer. The test pad should be constructed on a surface which is equivalent in nature to the surface upon which the final cover system's recompacted soil barrier layer will be constructed. If the test pad is constructed within the area of waste placement, it should be completely removed prior to construction of the final cover system;
- Be reconstructed and retested whenever there is a significant change in soil material properties or any other significant change in the construction details or construction specifications;
- Have a minimum width three times the width of the compaction equipment. Be of sufficient length for the compaction equipment to reach proper operating speeds across the test area. The length shall not be less than two times the length of the compaction equipment including power equipment and any attachments;
- Be constructed using a roller with fully penetrating feet (such as a sheepfoot roller) and loose lifts eight inches thick or less to achieve uniform compaction. Prior to placement of a new lift, the surface of the previously compacted lift should be scarified to a depth of at least two inches. The zone of scarification should be counted in the loose lift thickness for the new layer of soil. Each lift should have a maximum permeability of $1\text{E-}07$ cm/sec;
- Be constructed of a soil with a maximum clod size of three inches or half the compacted lift thickness, whichever is less;
- Be constructed of a soil:
- With one hundred percent of the particles having a maximum dimension not greater than two inches;
- With not more than ten percent of the particles, by weight, having dimension greater than 0.75 inches;
- Be compacted to at least ninety-five percent (95%) of the maximum "Standard Proctor Density" using ASTM D-698, or at least ninety percent (90%) of the maximum "Modified Proctor Density" using ASTM D-1557;
- Be compacted at a moisture content at or wet of optimum (not to exceed four percent (4%) wet of optimum);
- Not be comprised of any type of waste material;
- Be comprised of at least four lifts. Each lift should have a maximum compacted thickness of no greater than six inches. Minimum compacted thickness of the test pad should be no less than twenty-

four inches. Additional lifts may be required dependent upon the field permeability testing method utilized;

- Be tested for field permeability. Following the completion of test pad construction, field permeability should be determined utilizing a method acceptable to the Ohio EPA (e.g., a Sealed Double Ring Infiltrometer - ASTM D-5093, or the Two-Stage Borehole Test - Boutwell Test - ASTM D-6391);
- Be tested at least three times total (i.e., one sample collected from each third of the test pad's length) for undisturbed sample permeability (ASTM D-1587, ASTM D-4220, and ASTM D-5084);
- Be tested during construction for moisture content and density at least three times per lift. If the nuclear methods, or any other rapid methods are used, at least one conventional confirmation test (ASTM D-2216 for water content and ASTM D-1556 or ASTM D-2167 for density) should be performed for every ten rapid tests;
- Be reconstructed as many times as necessary to meet the 1E-07 cm/sec maximum permeability requirement.

Test Pad and Recompacted Soil Barrier Layer Testing Requirements

The appropriate DO of Ohio EPA should be notified at least seven days prior to test pad construction and field permeability testing. Prior to construction of the final cover system's recompact soil barrier layer, the test pad construction specifications and testing results should be submitted to Ohio EPA's CO and the appropriate DO for review and acceptance. During construction of the test pad or the recompact soil barrier layer, the following items should be addressed.

- Following placement of each loose lift (just before compaction), the soil material to be utilized in construction of both the test pad and the final cover system's recompact soil barrier layer should be sampled and tested for the following parameters:
 - (i) Soil particle size (ASTM D-1140 and ASTM D-422);
 - (ii) Liquid and plastic limits (ASTM D-4318);
 - (iii) Compaction curve (ASTM D-698 or ASTM D-1557);
 - (iv) Recompacted permeability at construction specifications (ASTM D-5084, maximum effective confining stress not to exceed 35 kPa);

Note: For the soil material used to construct the test pad, at least two (2) tests (per test pad) should be performed for all four (4) parameters. However for the soil material used to construct the recompact soil barrier layer of the final cover system, parameters (i) and (ii) should be tested at least once for every thousand (1,000) cubic yards, parameter (iii) should be tested at least once for every five-thousand (5,000) cubic yards, and

parameter (iv) should be tested at least once for every ten-thousand (10,000) cubic yards.

- **Construction oversight should be provided continuously.**
- All penetrations into the lifts of compacted soil comprising either the test pad or the final cover system's recompacted soil barrier layer should be repaired by backfilling with **powdered** bentonite in loose lift thicknesses not exceeding two inches. The bentonite should be compacted into each penetration until full.
- All testing locations on either the test pad or the final cover system's recompacted soil barrier layer which fail to meet the required specification(s) should be recorded and investigated. Any area(s) with a verified failure should be reconstructed to meet the required specification(s). Reconstructed areas should be retested in an appropriate manner and at an appropriate frequency.
- The number of passes made by the compaction equipment during construction of the final cover system's recompacted soil barrier layer should be verified by at least one observation per acre per lift.
- For all construction and testing details not specified here, U.S. EPA's (1993) *Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities* should be followed.

These above requirements may be modified, with approval from Ohio EPA, to accommodate a particular solution for the final cover.

Examples of Approved Final Covers

Type 1 - Impermeable Final Covers

The design should include two separate low-permeability layers (at least one of which should be a geomembrane strong enough to allow overlap welding without developing cracks or holes - a minimum 40-mil HDPE, or equivalent), a drainage layer, a protection layer, and a surface layer. A Type 1 cover could be used to cover an outside area containing contaminated media, where contamination could reach ground water if the media is subjected to water percolation.

Example

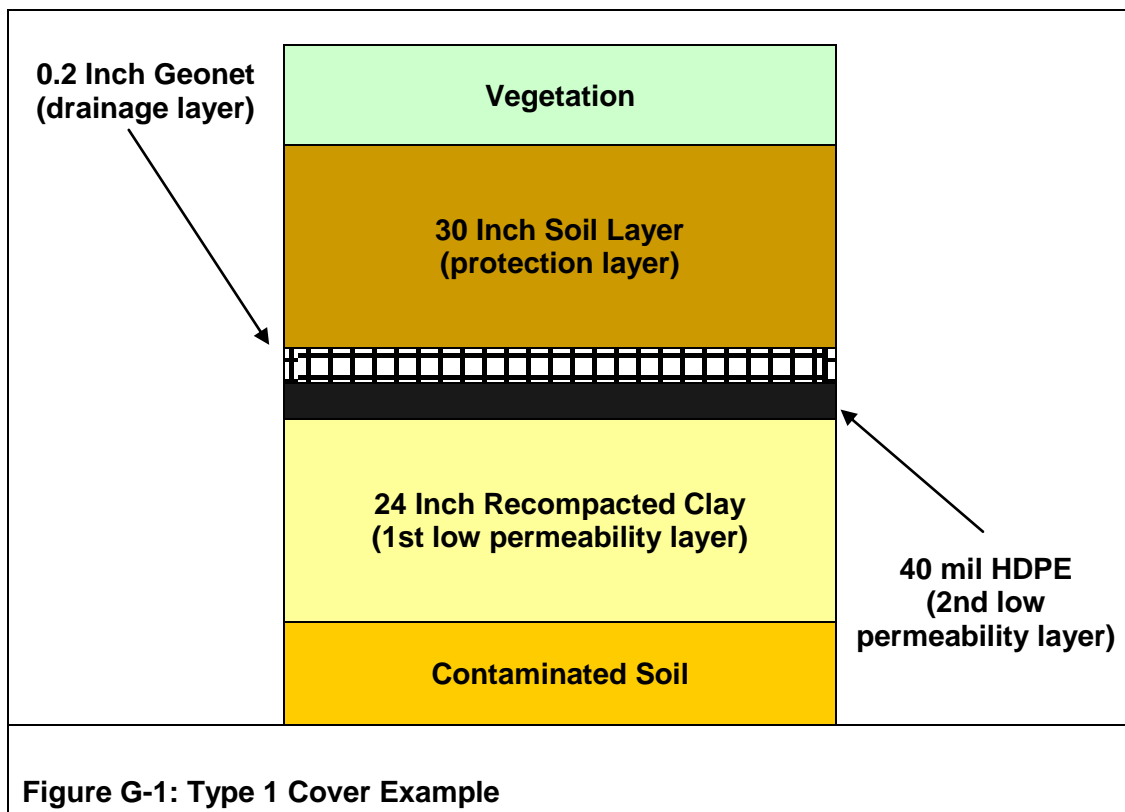
Eljer Plumbingware, Inc., Salem, Ohio - Foundry Sand Waste Pile

The final cover was needed to cover the waste pile and an outside area containing contaminated media, where contamination could reach ground water if the waste and media are subjected to water percolation. It is important to note that this was a waste in place closure with no bottom liner or leachate collection system.

This suggested that a final cover consisting of the Ohio EPA recommended design (*i.e.*, the design incorporating two low-permeability layers, a drainage layer, and a protection layer) would adequately address the regulatory performance requirements.

The selected final cover consisted of the following design elements:

- Size - The final cover completely covers the contaminated soils and then extends to 2 feet beyond the horizontal extent of contamination - in full thickness and with all design elements.
- Protection layer - A 30 inch thick frost protection/vegetative soil layer was placed on the drainage layer.
- Drainage layer - A 0.2 inch thick synthetic drainage layer (geonet) with a non-woven geosynthetic fabric bonded to both sides was placed on the second low-permeability layer. The synthetic drainage material had a minimum permeability of $1\text{E-}02$ cm/sec and a minimum slope of 1%.
- Second low-permeability layer - A 40 mil thick textured HDPE geomembrane was placed on the first low-permeability layer.
- First low permeability layer - A 24 inch thick recompacted clay layer with a maximum permeability of $1\text{E-}07$ cm/s was placed over the contaminated soil. Natural soil was recompacted to specifications approved by Ohio EPA.



Type 2 - Low Permeability Final Covers

The design should include at least one low permeability layer, a drainage layer, a protection layer, and a surface layer. A Type 2 cover could be used to cover an outside area of contamination, where contaminants are less mobile, and the chances of contamination spreading to an aquifer are minimal.

Example

Cowan Lake State Park, Ohio - Wood Treating Plant

The final cover was needed to close (cover) an outside area with contaminated soil. The contamination originated from spilled fluids containing hazardous chemical compounds (mainly fuel oil and pentachlorophenol) used at the former wood treating plant. The ground water investigation indicated that the chances of contamination spreading to the relatively deep aquifer were minimal. This suggested that a final cover, consisting of a single low-permeability layer, a drainage layer, a protection layer, and a surface layer, would adequately address the regulatory performance requirements.

The intended future use of a portion of the site is as a machine/vehicle service area and the presence of several buildings in the area imposed specific final cover design requirements. These included the need to have a pavement surface, the need to design a surface layer with shallow slopes to drain precipitation because of available surface elevations, and the need to construct the interfaces with existing and new buildings.

The selected final cover consisted of the following design elements:

- Size - The final cover completely covers the horizontal extent of contaminated soil - in full thickness and with all design elements. In this case, the final cover extended to a structure and an appropriate interface was designed.
- Surface - A 4 inch thick asphalt layer with a maximum permeability of 1E-07 cm/sec was placed on the protection layer.
- Protection layer - An aggregate base (varied thickness) with an asphalt aggregate base (minimum thickness of 8 inches) on top was placed on the drainage layer.

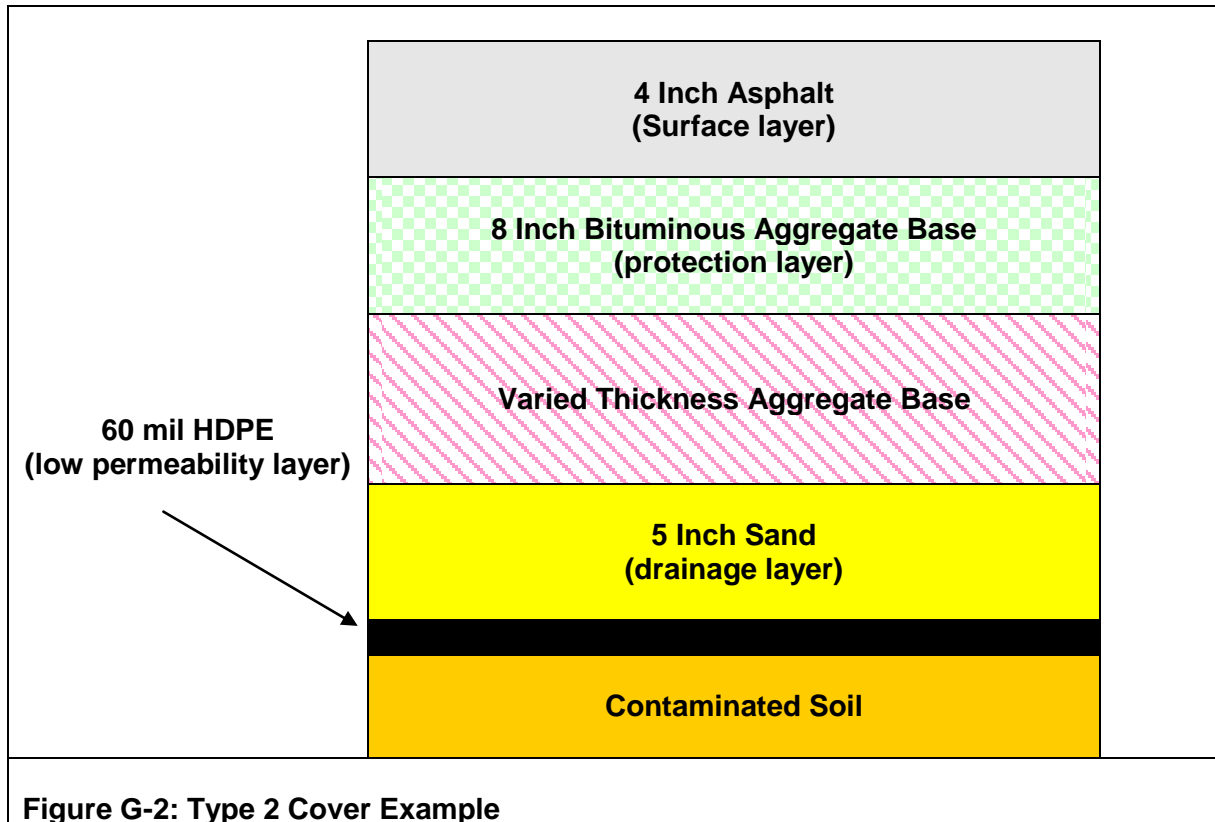
Note: Typically, when a final cover has an impermeable barrier layer constructed from clay, a soil protection layer should be between 30 and 36 inches thick (depending on the geographic location) to protect the clay and the drainage layer from a damaging freeze-thaw process. This requirement was modified because a geomembrane was used instead of the clay and less water was expected to permeate to the drainage layer due to the installation of a low permeability asphalt layer.

- Drainage layer - A sand layer (minimum thickness of 5 inches) was placed on the low-permeability layer.

Note: Typically, the minimum thickness of a granular material drainage layer constructed under a soil protection layer should not be less than 12

inches. In this case, the drainage layer was constructed under an asphalt-aggregate protection layer which is expected to permeate less water than a soil protection layer.

- Low-permeability layer - A 60 mil thick HDPE geomembrane with a geotextile protective layer on top was placed over the contaminated soil.



Type 3 - Protective Final Covers

The design should include a permanent and durable barrier which separates contaminated media from the space in use. A Type 3 cover could be used to cover a contaminated area (inside a building or outside) where the contamination does not pose a significant environmental threat.

Example A

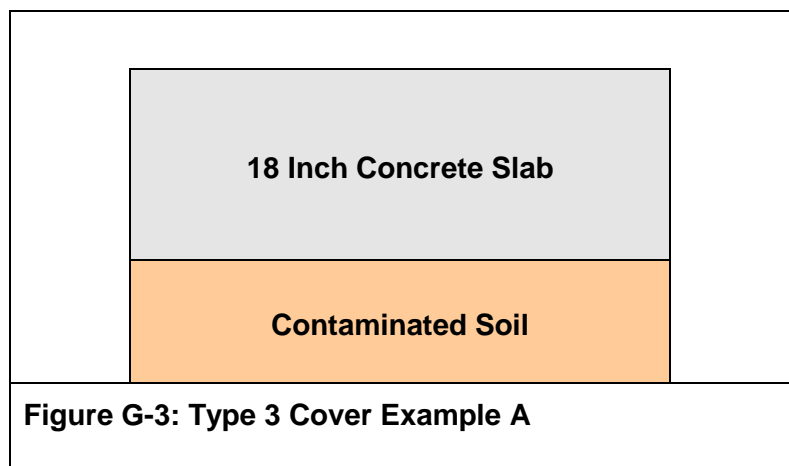
Cold Metal Products Company, Youngstown, Ohio - Drum Storage Area

The final cover was needed to cover a hot spot (a chromium contaminated area) that was left in place under an 18 inch thick reinforced concrete slab. The area was located inside a multi-story factory building. The contamination did not pose an environmental threat. This suggested that a final cover consisting of a permanent and durable barrier, which separates contaminated media from the space in use, would adequately address the regulatory performance requirements. It is important to note that this was not a waste in place closure and that the area will be further addressed during RCRA Corrective Action.

The existing 18 inch thick reinforced concrete slab itself (which is a permanent and durable barrier that separates the contaminated media from the space in use) was considered a final cover which satisfies the regulatory performance standards.

The selected final cover consisted of the following design elements:

- Size - The final cover completely covers the contaminated area.
- Surface - An 18 inch thick concrete slab.



Example B

Water Tower Square (formerly known as Sherwin Williams), North Olmsted, Ohio - Drum Storage Area

The final cover was needed to cover the former D001/F005 solvent container storage area, provide space for some useful purpose (a parking lot), and protect the media underneath from any additional contamination due to this usage.

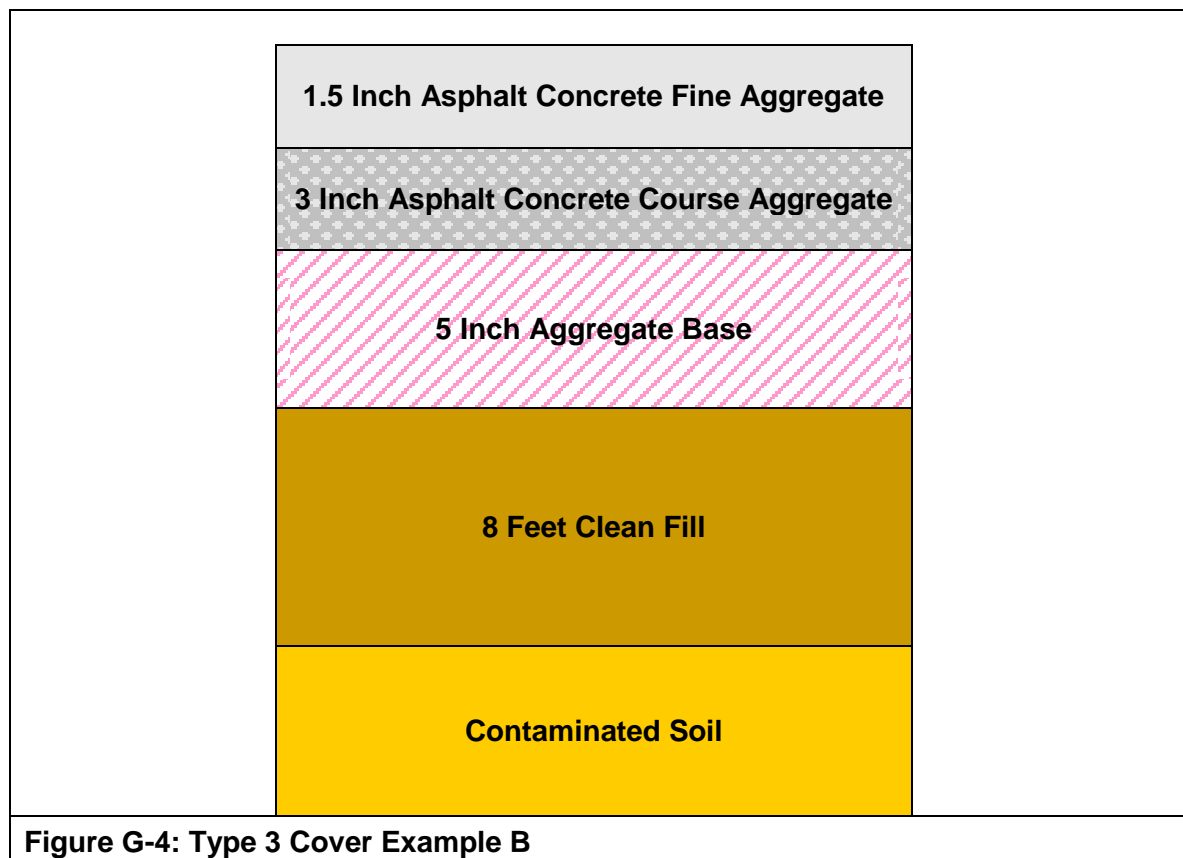
All contaminated media under the container storage area had been removed and was replaced with 8 feet thick clean backfill soil. However, the ground water remained contaminated. The ground water is not being used for any purpose. The area was located outside, in the center of the hazardous waste facility. Therefore, the contamination did not pose any environmental threat.

This suggested that a final cover consisting of a permanent and durable barrier, which separates contaminated media from the space in use, would adequately address the regulatory performance requirements. It is important to note that this was not a waste in place closure and this area will be further addressed during RCRA Corrective Action.

A composite asphalt layer consisting of a 5 inch thick aggregate base, under a 3 inch thick asphalt concrete with coarse aggregate layer, under a 1.5 inch thick asphalt concrete with fine aggregate layer, was considered a final cover which satisfies the regulatory performance standards.

The selected final cover consisted of the following design elements:

- Size - The final cover completely covers the container storage area.
- Surface - A 9.5 inch composite asphalt layer consisting of a 5 inch thick ODOT-304 aggregate base, under a 3 inch thick asphalt-concrete layer with ODOT-402 (coarse) aggregate, under a 1.5 inch thick asphalt-concrete layer with ODOT-304 (fine) aggregate.



References Cited in this Appendix

- American Society for Testing and Materials. (1998) *Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*. D2216-98.
- American Society for Testing and Materials. (1999) *Standard Test Method for Field Measurement of Hydraulic Conductivity Limits of Porous Materials Using Two Stages of Infiltration from a Borehole*. D6391-99.
- American Society for Testing and Materials. (2000) *Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter*. D5084-00e1.
- American Society for Testing and Materials. (2000) *Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes*. D1587-00.
- American Society for Testing and Materials. (2000) *Standard Practices for Preserving and Transporting Soil Samples*. D4220-95(2000).
- American Society for Testing and Materials. (2000) *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ (600 kN-m/m³))*. D698-00a.
- American Society for Testing and Materials. (2000) *Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method*. D1556-00.
- American Society for Testing and Materials. (2000) *Standard Test Methods for Amount of Material in Soils Finer Than the No. 200 (75-um) Sieve*. D1140-00.
- American Society for Testing and Materials. (2000) *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*. D4318-00.
- American Society for Testing and Materials. (2001) *Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method*. D2167-94(2001).
- American Society for Testing and Materials. (2002) *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2,700 kN-m/m³))*. D1557-02.
- American Society for Testing and Materials. (2002) *Standard Test Method for Particle-Size Analysis of Soils*. D422-63 (2002).
- American Society for Testing and Materials. (2002) *Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring*. D5093-02.
- U.S. EPA. (1989) *Seminar Publication: Requirements for Hazardous Waste Landfill Design, Construction, and Closure*. EPA/625/4-89/022. Office of Research and Development. Cincinnati, OH.
- U.S. EPA. (1991) *Seminar Publications: Design and Construction of RCRA/CERCLA Final Covers*. EPA/625/4-91/025. Office of Research and Development. Washington, D.C.

- U.S. EPA. (1993) *Engineering Bulletin: Landfill Covers*. EPA/540/S-93/500. Office of Emergency and Remedial Response. Washington, D.C.
- U.S. EPA. (1993) *Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities*. EPA/600/R-93/182. Risk Reduction Engineering Laboratory. Cincinnati, OH.
- U.S. EPA. (1994) *The Hydrologic Evaluation of Landfill Performance (HELP) Model*. EPA/600/R-94/168a. Office of Research and Development. Washington, D.C.

Additional References

- Daniel, D.E., et al. (1993) *Geotechnical Practice for Waste Disposal*. Chapman & Hall. London, UK.
- Ingold, T.S., R.J. Bathurst, and J.P. Giroud. (2000) *Geosynthetics International: Special Issue on Liquid Collection Systems*. Volume 7, Nos. 4-6. Industrial Fabrics Association International. Roseville, MN.
- Koerner, J.R., Te-Yang Soong, and R.M. Koerner. (1998) *A Survey of Solid Waste Landfill Liner and Cover Regulations: Part I - USA Status*. GRI Report #21. Geosynthetic Research Institute. Folsom, PA.
- U.S. EPA. (1988) *Guide to Technical Resources for the Design of Land Disposal Facilities*. EPA/625/6-88/018. Risk Reduction Engineering Laboratory. Cincinnati, OH.
- U.S. EPA. (1991) *Technical Guidance Document: Inspection Techniques for the Fabrication of Geomembrane Field Seams*. EPA/530/SW-91/051. Cincinnati, OH.
- U.S. EPA. (1992) *Technical Guidance Document: Construction Quality Management for Remedial Action and Remedial Design Waste Containment Systems*. EPA/540/R-92/073. Office of Solid Waste and Emergency Response. Washington, D.C.

Appendix H

Soil Permeability Data Evaluation

Introduction

The final cover system (“cap”) and the bottom liner system (“liner”) are the two essential protective systems used at waste disposal units and other sites where contaminated media has been contained. The design of these systems and the quality of their construction directly impacts the effectiveness of isolating hazardous waste constituents from the environment. These systems for waste isolation function in tandem. The function of the cap is to obstruct atmospheric water from entering into, and consequently percolating through the waste, while the liner prevents leachate (any liquid that has come into contact with the waste) from migrating below the unit.

Construction and design aspects of a waste isolation system may vary. However, a commonly used structural component of these systems is a separator layer constructed from mineralogically and structurally suitable natural clay (or clay-rich soils, predominantly those characterized as inorganic, plastic, and fine grained). This layer is usually referred to as a “compacted clay liner” (CCL), or a “re-compacted” clay liner or layer (like in rules OAC 3745-27-08(B)(1)(c)(i) and OAC 3745-57-03(c) - for example), based on the fact that the soil is first excavated from its original deposit and then placed at a desired location in a controlled manner, i.e., “re -compacted”. Obviously, a CCLs key requirement is to have the high resistance to transmission of liquids (water, leachate). In other words, a CCL must exhibit a “low permeability” characteristic. This characteristic is expressed as a liquid’s rate of propagation through the liner or soil. As a generally accepted standard in industry, and also prescribed by the current rules (such as: OAC 3745-57-03, for instance), the maximum permeability for a CCL is 1×10^{-7} cm/sec. To ensure that this requirement can be (has been) met, it is necessary to conduct some standard permeability tests, before, during, and (sometimes) after construction. Several test methods are available for both, laboratory and field applications. This guidance provides a means to interpret results from the two commonly used permeability tests, i.e., ASTM D 5084 - 03 (a lab method utilizing the “Flexible-Wall Permeameter”) and ASTM D 6391 - 99(2004) (a field method based on Boutwell’s “Two-Stage Borehole Permeameter”). Details on how to prepare and conduct these two tests can be found in ASTM standards, textbooks and various technical papers (see references listed below). There are also several U.S. EPA and Ohio EPA guidance documents which explain how to select and test the soil for constructing CCLs (see documents referenced at the end of this appendix). See the guidance documents referenced at the end of this appendix. For overall information, the following two documents offer a good starting point:

- Technical Guidance Document EPA/600/R-93/182, September 1993, “Quality Assurance and Quality Control for Waste Containment Facilities”
- “Design, Construction, and Evaluation of Clay Liners for Waste Management Facilities”, EPA/530/SW-86/007F, November 1988

Other permeability tests (such as: “sealed double ring infiltrometer”, “air-entry permeameters”, “porous probes”, etc.) are less frequently used and will not be discussed here. However, much of the following information is applicable to any type of a soil permeability test that is used for construction purposes.

Factors which influence the engineering quality of soils (*mineralogy, type of soil, grain shape and size, water content, density, etc.*)

Since the silt loams are a predominant type of soil in Ohio, mineralogy (mineral composition) is typically not a big question. Where mineralogy becomes important, is when expanding clays (such as bentonite) are used, or when the native clays are augmented with fly ash. For engineering purposes, the soil type is really the key. Clay soils may range significantly in physical properties. Furthermore, in glaciated regions, sub-soils may have very different physical properties than top soils. So, location within the soil column may also become a significant factor.

A soil's ability to have the necessary engineering properties for constructing a compacted liner (or a final cover), is partly determined by its grain-size distribution and its mineral composition. In order to understand why this is so, one must examine the "substance" of soil. In general, every soil consists of three "phases":

- solid particles (solids),
- air trapped in voids, and
- water trapped in voids.

The ratio (usually expressed as either a percentage or a decimal) between phases, for a given soil, greatly influences its ability to "hold" or transmit water. Research over the last century has shown that soils with smaller-sized particles have a greater amount of void space (porosity) and also have a greater water holding capacity. However, the ability of finer grained soils to transmit water (i.e. a soil's permeability) is decreased. This is because finer grained soils have less interconnection between pores and therefore cannot transmit water as readily as coarser grained soils.

Having determined that there is a relationship between the particle- (or grain-) size and the ability of a soil to transmit water exists, this relationship needs to be defined in order for it to be useful. Soils typically do not have a single grain-size, but instead, a range or distribution of sizes that can vary from gravel-sized to clay-sized particles. Typical grain-size measurements are shown in the following table, H-1.

Table H-1: Typical Particle Sizes	
Particle	Size (mm)
Very Coarse Sand	2.00-1.00
Coarse Sand	1.00-0.50
Medium Sand	0.50-0.25
Fine Sand	0.25-0.10
Very Fine Sand	0.10-0.05
Silt	0.05-0.002
Clay	below 0.002

The distribution of grain sizes is used by soil scientists to define a soil's texture. Soil texture is determined by the relative amounts of sand-, silt- and clay-sized particles. A coarse soil has a relatively large amount of sand or gravel. A soil dominated by clay-sized particles is generally described as fine. The grain-size distribution of a soil can be easily defined by laboratory tests.

These tests are relatively simple. In general, dried soils are passed through a series of sieves, each with a smaller size of openings. These sieves correspond to the different sand-size particle range. The finer soil material will pass through all the sieves. This material is then gathered and allowed to settle in a column of water, where the amount of silt and clay-size materials is determined. For further information see the American Society of Testing and Materials standard D 422 (1999). Typically, the results of grain-size distribution test will resemble the graph in the following figure, H-1.

This diagram represents a cumulative grain-size curve, where each size fraction (i.e. that amount of sample retained in a given sieve) is expressed as a percentage. A complete grain-size curve would therefore give the amount (in percent) of sand-sized, silt-sized and clay-sized particles in a sample. This curve is cumulative, so the amounts of all size fractions add up to 100%. The graph is expressed in a log scale. It has demarcations in both sieve size and in millimeters (x axes). It also expresses the percent of soil material that either passes through each sieve size or is retained on a sieve (y axes). A great deal of information can be gained from grain-size analyses. Reading this graph, a reviewer may tell whether the soil being tested is relatively uniform in size or is well graded (i.e. displays a range of sizes) in particle size. This can be observed because soils predominately composed of one particle size will have very steep or vertical slopes in a cumulative grain-size curve while well graded soils will have shallow slopes. Soil scientists and engineers have developed measures of soil grading based upon certain grain sizes and the amount of material passing through a sieve. The sieve numbers 4, 10, 40, and 200 (top of the chart) are used to express the amount of material that passes these size sieves expressed as a percentage of the sample's weight. Data for the percent passing sieves are used to classify the soil in the engineering classifications. The lower right corner of this graph shows some of these measures. The measure, D₁₀, is known as the *effective particle size*. This designates the particle diameter at which only 10 percent of the particles in a soil sample are of smaller diameter. This diameter of particles is important because it has been found that particles of this size control many of the physical properties of a soil. This is because they fill the void spaces around the larger soil particles. More information can be found on grain-size analyses from ASTM D 422. It should also be noted that soil characteristics are influenced by the depth distribution of grain-size for the soil as well as its mode of deposition, stress history, density, and other features and that these measures are only estimates of a soils physical properties.

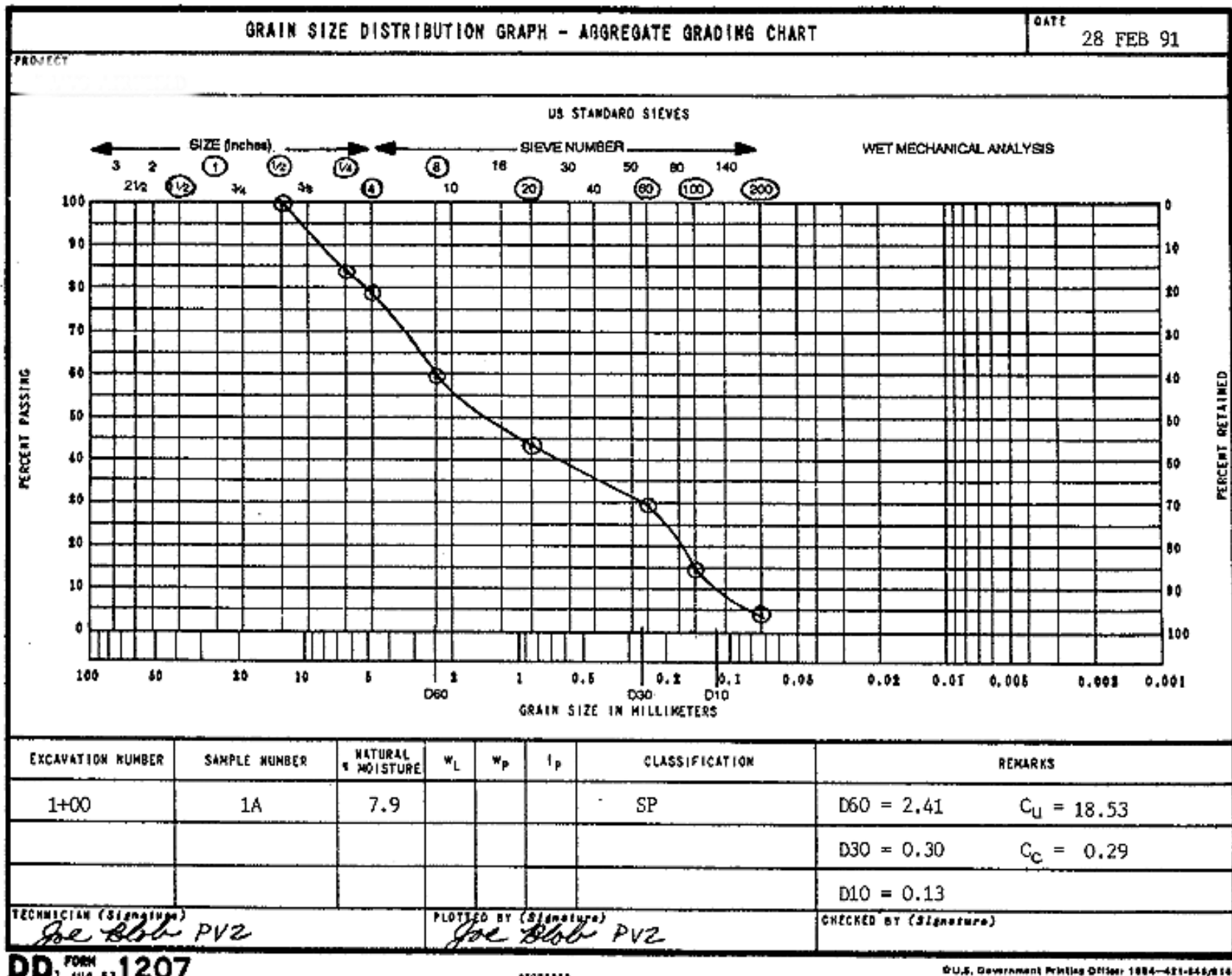


Figure H-1: Example of a Grain-Size Distribution Test

The sand, silt and clay percentages are also useful because we can use these measures to classify soils into general categories. Each soil type will have similar properties including compaction and cohesiveness, but more importantly for our discussion hydraulic conductivity, water holding capacity and permeability will also be similar. One such classification system, the United States Department of Agriculture's soil classification triangle, is shown below in Figure H-2.

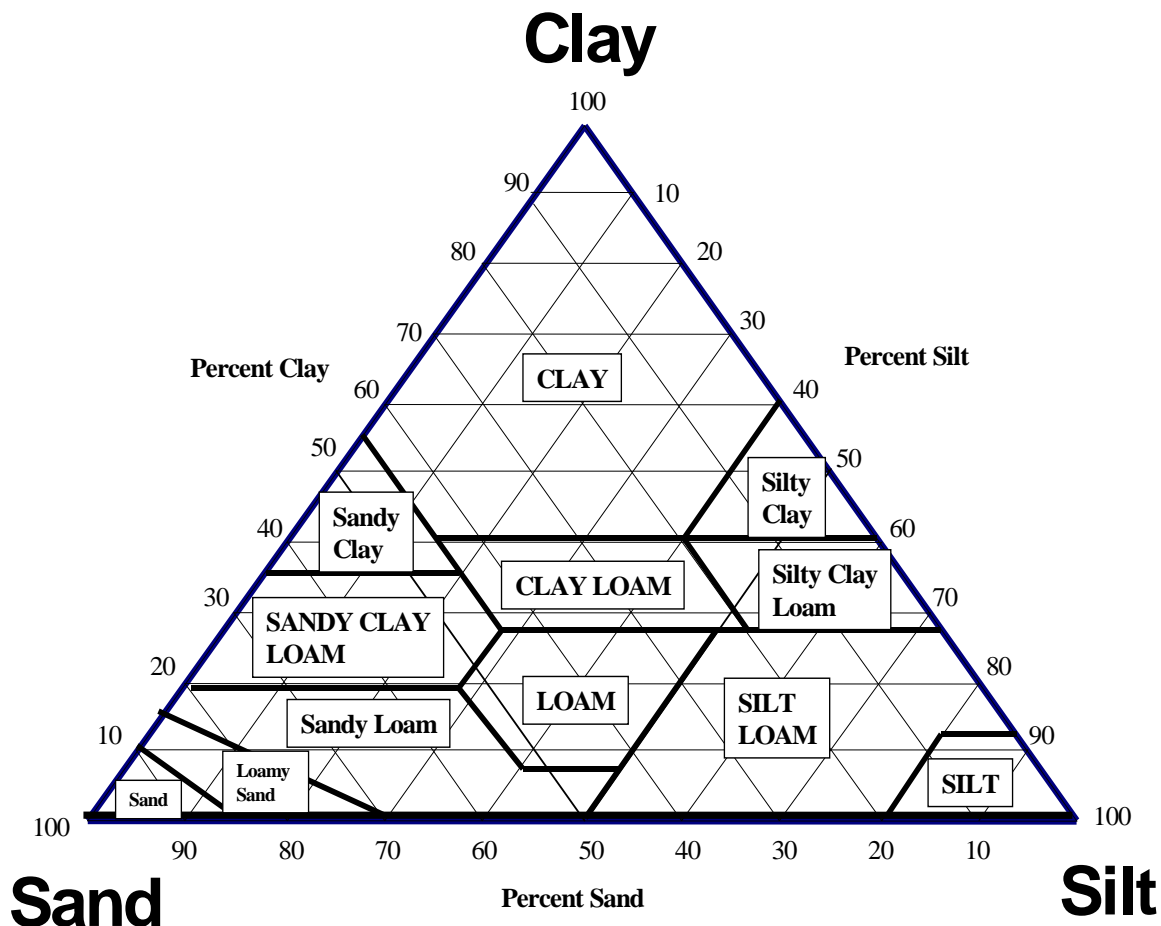


Figure H-2: Soil Properties on the United States Department of Agriculture's Soil Classification Triangle

Therefore, using the information from a grain-size analysis, an engineer can determine what type of soil is present at a site and also its approximate engineering properties. In general, clay- and silt-rich soils are mostly used to construct liner systems, or other engineered soil layers. These types of soils are plastic, cohesive and compactible. To a large degree, these properties are result of a soil's clay content. Physical and chemical activities of a soil are related to the kind and amount of clay minerals. Clay particles may have thousands of times more surface area per gram than silt particles and nearly a million times more surface area than very coarse sand particles. Thus, clay particles are the most chemically and physically active part of soil. Clay mineralogy and clay percentage have a strong influence on engineering properties and the behavior of soil material when it is used as construction or foundation material. A soil's plasticity is one such measure of the clay content of a soil. The plasticity index (PI) will tend to increase as the clay content increases (for a given moisture content). Soils that have a high plasticity index have a wide range of moisture content in which the soil performs as a plastic material. Highly and moderately plastic clays have large PI values. A field method to determine a soil's

plasticity index is found in ASTM D 2487. In general, the range of soils that display significant plasticity is shown in the following table, H-2.

Table H-2: Soil Types and Plasticity		
Soil Type	Plasticity	Plasticity Index
Clayey Silt	slight	1 to 5
Silty Clay	high	20 to 40
Clay	very high	40 plus

In order for a soil to be used for a liner, it must have certain characteristics that make it appropriate for use.

The plasticity of a soil is a general requirement for engineering because, in general, the higher a soil's plasticity, the easier it will be to be compacted without fracturing. The compaction (void reduction) process places soil particles closer together, decreasing the openings and making it harder for water to flow through. Compaction only reduces the volume of air-filled voids (changes macro structure), but does not generate enough pressure to squeeze-out pore water. (Some pore water may be additionally squeezed-out when, for instance, the clay bottom liner is loaded with waste.)

Assessing Plasticity of Clay Soil in the Field:

One practical field test, based on "plasticity" characteristic of clay-like materials, can provide an instant (albeit, rough) estimate of soil's permeability.

The test is performed by taking a pinch of clay and rolling it easily between the palms of both hands in a circular motion. If it readily forms into a ball, the clay has reached (or maybe exceeded) its "plastic limit". At this point, the material is also somewhere close to its "optimal" moisture content and a density peak (as defined by the Proctor moisture/density curve). Since the permeability is directly related to the density and moisture content, this also corresponds to the beginning of a low permeability range (1×10^{-6} to 1×10^{-9} cm/sec) for most clays.

Although this test is convenient, quick and easy to perform, it should only be used as a screening tool, and by no means considered a substitute for any ASTM test. Furthermore, while this test usually works for clay soils, it may not necessarily be applicable to all loams.

A word of caution: Rolling soil extensively between hands will dehydrate it and the effect could be misleading.

The conductivity of water through a soil is also decreased with increasing clay content. The following table, H-3, illustrates the range in hydraulic conductivities for typical soils.

Table H-3: Range of Hydraulic Conductivities in Soils	
Media Type Soil Type	Saturated Hydraulic Conductivity, K_s (cm/s)
Gravel	3.0E-2 to 3.0E-0
Coarse Sand	9.0E-5 to 6.0E-1
Medium Sand	9.0E-5 to 5.0E-2
Fine Sand	2.0E-5 to 2.0E-2
Loamy Sand	4.1E-3
Sandy Loam	1.2E-3
Loam	2.9E-4
Silt, Loess	1.0E-7 to 2.0E-3
Silt Loam	1.2E-4
Till	1.0E-10 to 2.0E-4
Clay	1.0E-9 to 4.7E-7
Sandy Clay Loam	3.6E-4
Silty Clay Loam	1.9E-5
Clay Loam	7.2E-5
Sandy Clay	3.3E-5
Silty Clay	5.6E-6
Unweathered marine clay	8.0E-11 to 2.0E-7
<i>Note: Above data is from Table A.6, "Vadose Zone Modeling in RCRA Closure", DHWM Guidance Document, January 7, 2005.</i>	

To explain the flow-impeding role of clay in soil materials, one can use flow through pipes as an analogy. Narrow diameter pipes will be more restrictive to the flow of water (under the same pressure) than a single large diameter pipe, having the same cross-sectional area as all narrow ones put together. This is basically due to frictional forces, such as capillarity, that tend to impede the flow of water in small diameter pipes. Figure H-3 illustrates this concept. As shown, the flow through a single large pipe is greater than the flow through all the narrow pipes combined. Soils are much more complex than pipes, but the same principle holds true. Flow through soil, as measured by hydraulic conductivity, is affected by the degree of saturation, capillary forces, connection between voids, mineralogical structure, and soil texture.

Therefore, the reason that clay-rich soils have such low hydraulic conductivities is because there is less connection between the pores and a greater resistance to flow through the narrow passages.

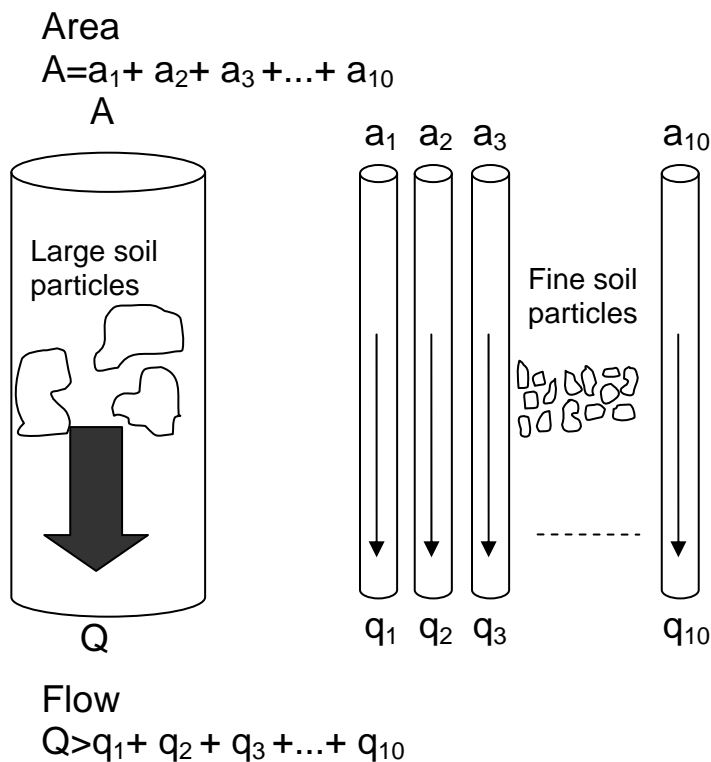


Figure H-3: Demonstration of Difference of Flow in Large and Small Diameter Pipes

Testing frequencies

Typically, laboratory permeability tests are done once in advance, to determine if borrow soils are suitable for liner construction. The field permeability tests are performed later on a test pad, where the compaction parameters (liner construction specifications) will be established. Usually, a minimum of five Boutwell permeameters are installed on a finished test pad, and these five (plus one temperature adjustment gauge - TAG) are considered to represent a single testing event. In addition, for control purposes, several Shelby tube samples are extracted from the test pad and submitted to a laboratory for permeability and moisture-density tests.

A new test pad has to be constructed and the tests need to be repeated whenever a soil with different characteristic(s) is going to be used - as determined by either Construction Quality Control (CQC) or Construction Quality Assurance (CQA) personnel. This is also true in case of a construction parameter change (for example: a change in weight of a compactor, use of a different type of roller, etc.).

Other related tests, such as those for obtaining Atterberg limits, Proctor curves, soil moisture, bulk density and specific gravity, should be performed at instances and frequencies recommended in guidance documents.^{1,2}

¹ U.S. EPA, Technical Guidance Document EPA/600/R-93/182, September 1993, "Quality Assurance and Quality Control for Waste Containment Facilities". The "Acceptable Zone" can be found in chapter 2, Figures 2.5, 2.6, and 2.7. Field test information is in Chapter 2, Table 2.10.

² U.S. EPA, Seminar Publication EPA/625/4-91/025, May 1991, "Design and Construction of RCRA/CERCLA Final Covers"

It should also be noted that the amount of geotechnical variability can be significant throughout field plots. The affect this has on permeability test results can only be assessed after all data is gathered. To facilitate this assessment, it is recommended that the test report includes the following information:

1. The rationale/method used to determine necessary number of samples and sampling locations, and the factors which prompted additional testing (if any);
2. The perceived precision and accuracy of the field results;
3. The standards and reporting requirements that were used for collection of samples; and
4. The copies of field notes with sampling locations, descriptions of soil strata, atmospheric conditions, and any other ancillary test data.

Graphical presentation of soil's characteristics

When interpreting results of a permeability test, it is helpful to visualize the relationship between various geotechnical characteristics of the tested material. One particular diagram, based on soil's moisture (or, molding water) content - dry density (or, dry unit weight) axes, is probably the most frequently used graphical interpretation of major construction (compaction) parameters, i.e., those that are responsible for the required characteristics (permeability and/or shear strength) of the re-compacted soil.³ This is likely due to a convenience of simultaneously showing a relationship between moisture content-density and compaction effort (through a family of "proctor curves"), followed by the degree of saturation curves and a "best fit line of optimums"⁴ (BFLO). Finally, if both, the shear strength and permeability must be monitored throughout the construction process, an "Acceptable Zone" (a.k.a., "acceptance window")³ can be constructed.

Figure H-4 shows all of these curves displayed at the same time. While such a complex presentation is hardly ever used in practice, being able to plot any particular, or any chosen combination of these relationships on a single drawing, makes it a very convenient tool for tracking compliance with any required compacted soil characteristic(s). This task can be accomplished by conducting periodic³ field tests for moisture content and density of the compacted soil, and then plotting the values on the diagram to see if they fall within acceptable zone, or (usually) between 85% and 100% saturation, or beyond the line of optimums (BFLO). These three (most frequently used) criteria are illustrated on Figures H-5, H-6 and H-7. In any case, it is assumed that the graphs, which are based on the test pad and/or laboratory data, correlate well with the actual construction parameters. When the required permeability and/or shear strength (both related to dry density and moisture content) have been determined to lie above the line of optimums (or within acceptable zone), the subsequent moisture content and density measurements, taken from the constructed liner and plotted on the same graph, can serve as good indicators of compliance. In some cases, where permeability testing is not required, but the low permeability is still desirable (as with some alternate final covers), the use of BFLO alone may be acceptable.

³ Technical Guidance Document EPA/600/R-93/182, September 1993, "Quality Assurance and Quality Control for Waste Containment Facilities"

⁴ Ohio EPA (DSIWM), "Use of Best Fit Line of Optimums (BFLO) for Recompacked Soil Liner Construction", Guidance Document #0665, June 1, 2005

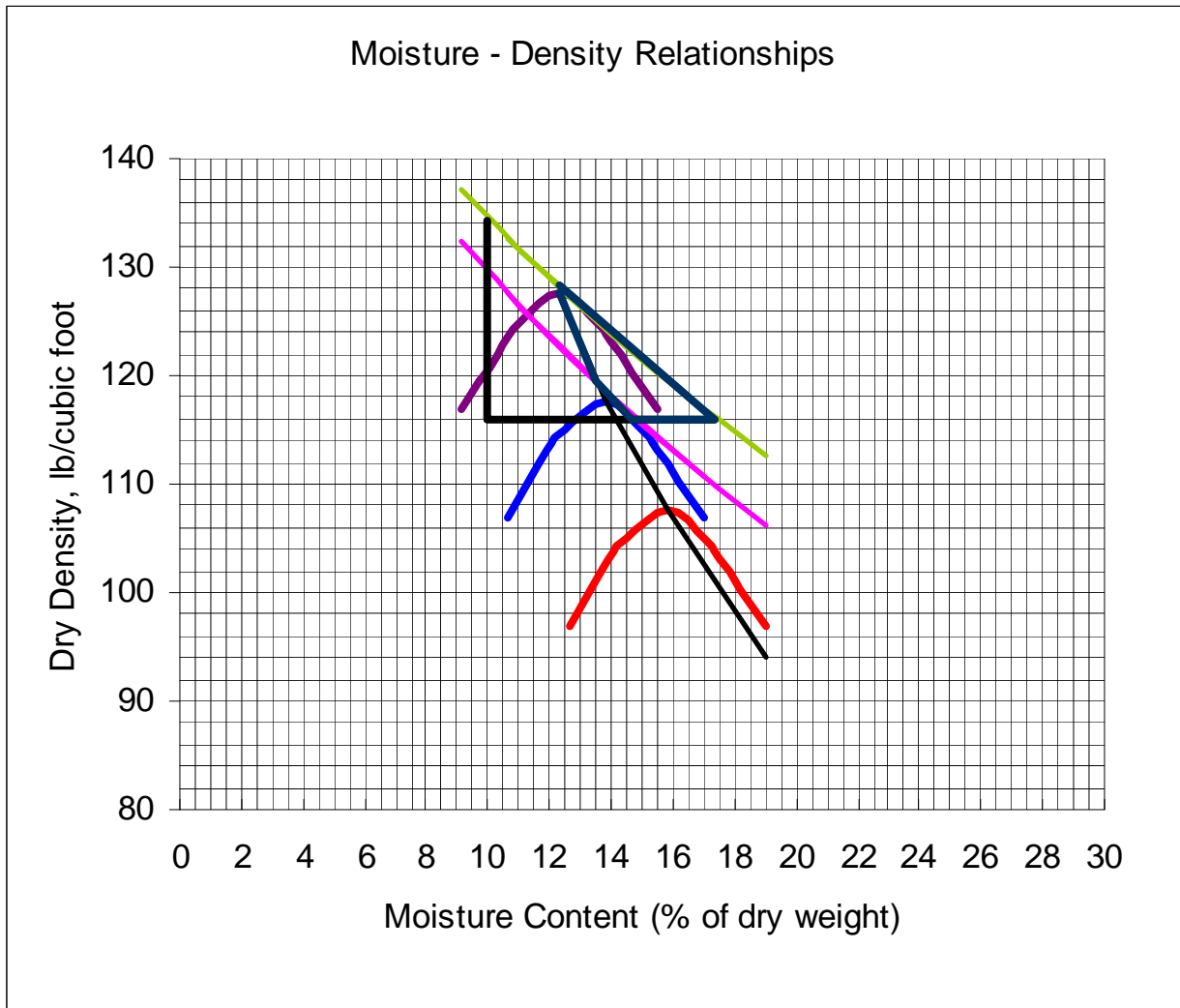


Figure H-4: Moisture-Density Relationships - Moisture-density curves, line of optimums, density and moisture cutoff lines, 85% and 100% degree of saturation lines

The two slanted lines on Figure H-5 represent 85% degree of saturation (lower line) and 100% degree of saturation (upper line). Acceptable results (regarding permeability) from moisture-density confirmation testing are expected to fall between these two lines. Shear strength is usually not a concern in this case.

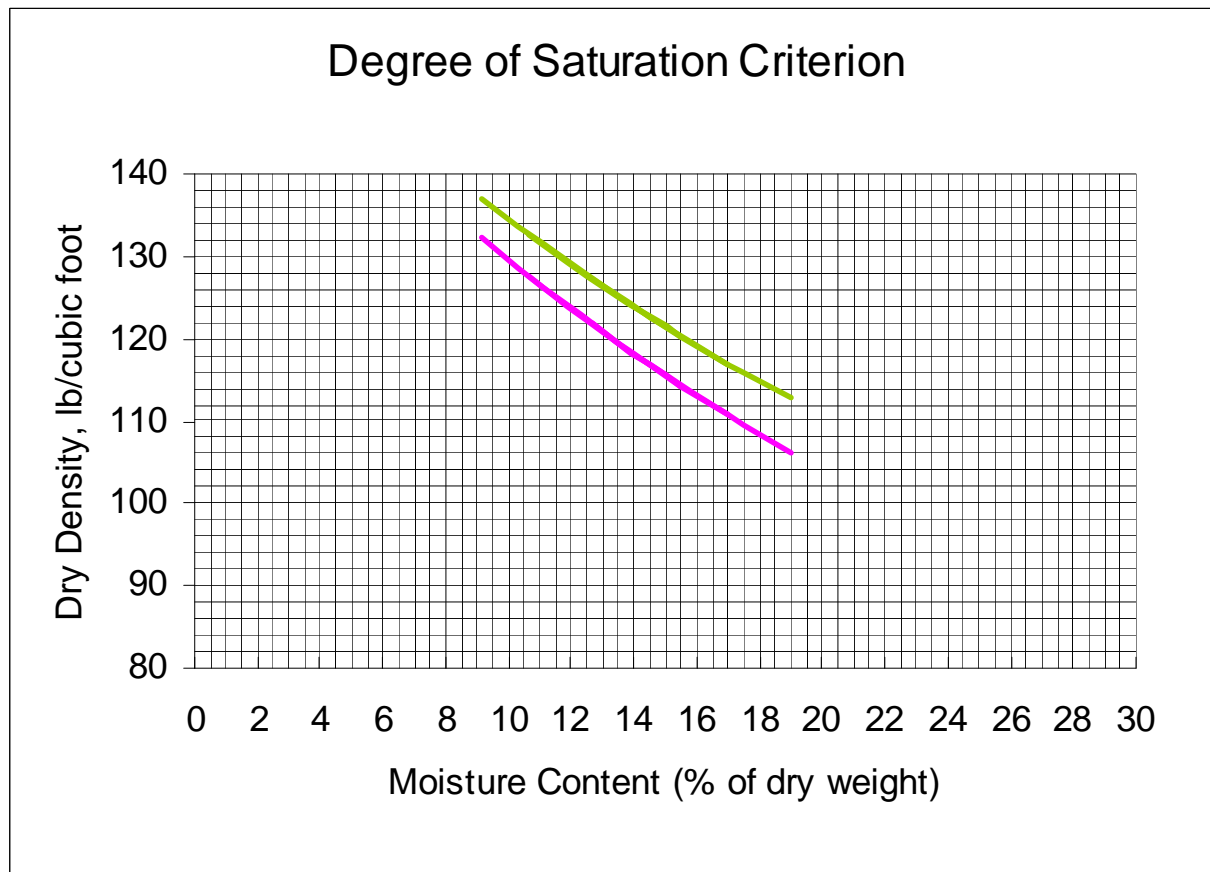


Figure H-5: Degree of Saturation Lines Lower line is the 85% degree of saturation Upper line is the 100% degree of saturation

The line on Figure H-6 connects “optimum moisture content” points on three proctor curves (generated with different compaction efforts). Acceptable results (regarding permeability) from moisture-density confirmation testing are expected to fall to the right of this line. Neither the upper limit of moisture content, nor the minimum shear strength are strictly prescribed in this graph.

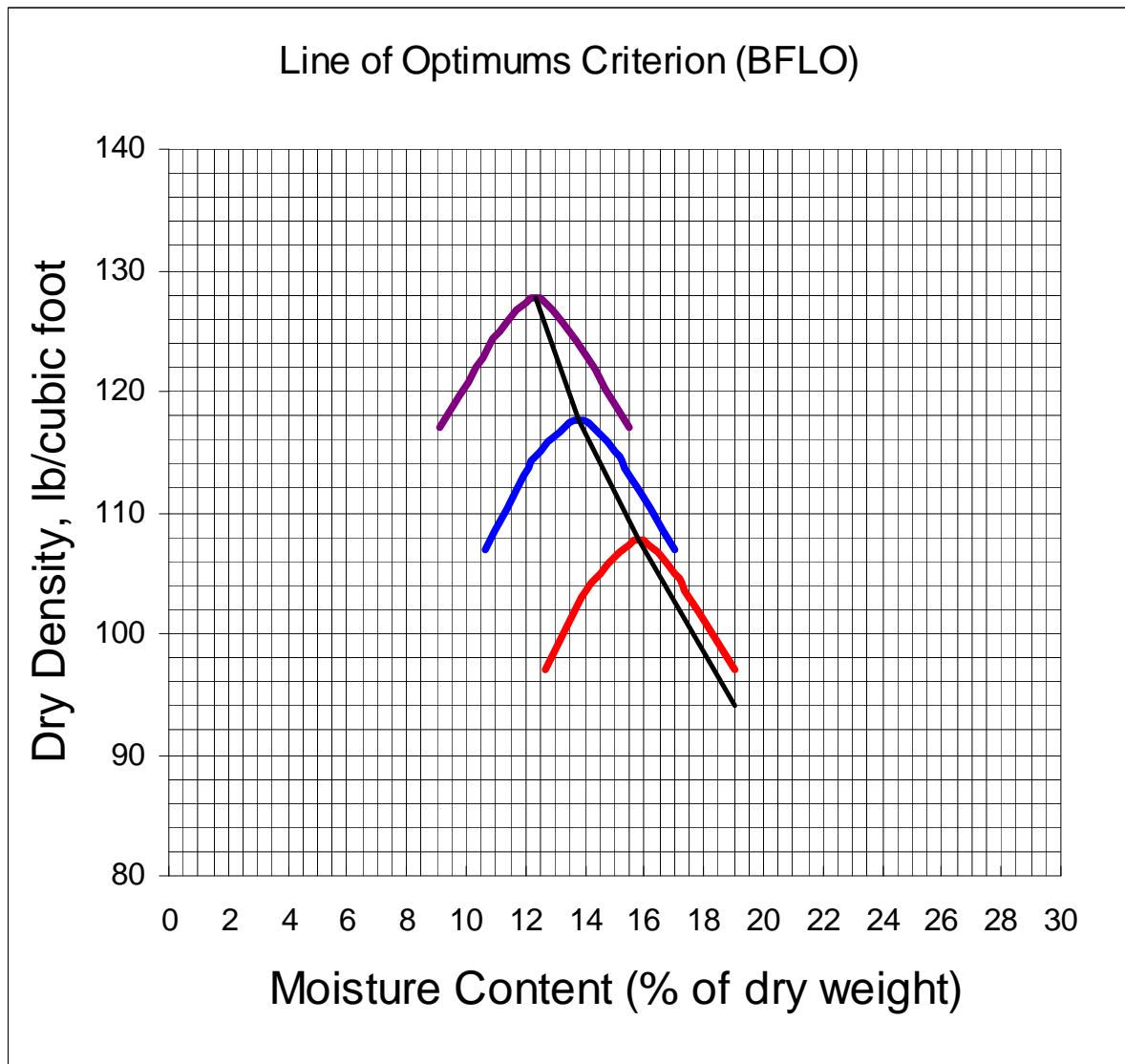


Figure H-6: Line of Optimums Criterion - Line intersects the curves at their point of optimum moisture content

The acceptable zone (window) area on Figure H-7 is determined by the 100% degree of saturation line (the upper slanted line), the 85% degree of saturation line, a portion of the line of optimums (the steeper of the two lower slanted lines), and the minimum acceptable dry density (the horizontal line). It is assumed that the results from the field moisture-density confirmation testing, that plot within this window, will satisfy the re-compacted soil layer's permeability and strength requirements. This is probably one of the best graphical means to monitor the quality of soil compaction.

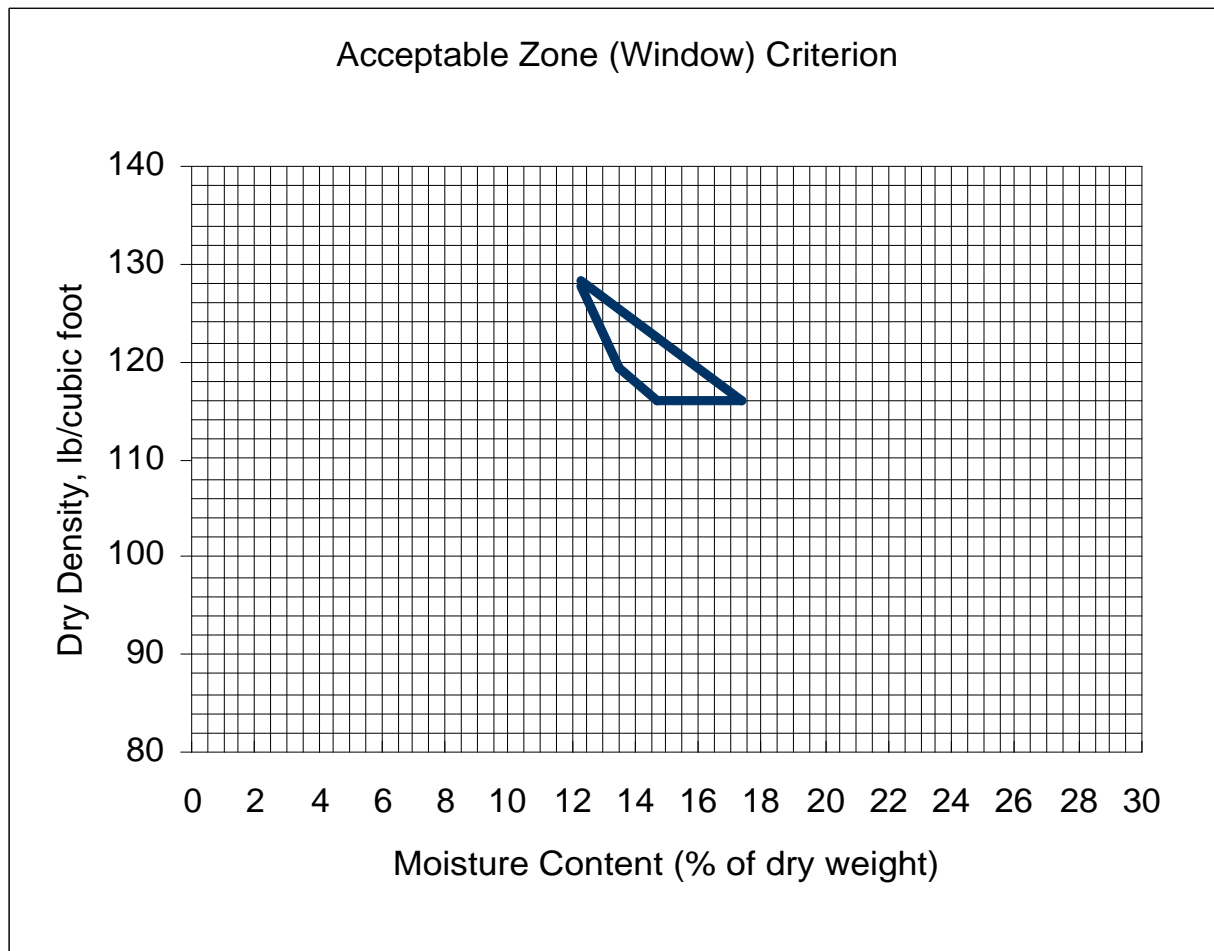


Figure H-7: Acceptable Zone Criterion

Laboratory and field test results and data evaluation

While permeability tests generally provide reliable results, accuracy of a test may be greatly influenced by the condition of the equipment and the sample quality, as well as by the experience, dedication and knowledge of the person who performs the test. Since these factors are not provided in the lab or field report, some other "indicators" may be used to check the "performance" quality of the test. Here are some common indicators:

- **permeating fluid pressures** (applicable to a lab flexible wall permeameter test, only);
- **degree of saturation** (applicable to any permeability test);
- **bulk density comparison** (applicable to any permeability test);
- **duration of the test** (differs with the kind of test);
- **permeability curve** (works for both field and laboratory tests); and
- **vertical vs horizontal permeability comparison** (for the Boutwell test, exclusively).

The following sections give some insight in how to use these parameters:

a) Checking “back pressure” and “confining pressure” in the lab test

A permeability measurement relies on accuracy of fluid pressures imposed on the sample at different stages of the test. There are pressures applied during the sample saturation process (before the actual permeability measurement), and a variable or constant (depending on method) hydraulic head applied during the measurement. So-called “back pressure” is the pressure under which the permeating fluid is introduced into the sample to accomplish saturation. “confining pressure” is applied outside the flexible wall to keep it from separating from the sample. It is recommended that it does not exceed 5 psi. Naturally, confining pressure must be always higher than the back pressure. Confining pressure, back pressure, hydraulic gradient and head are all detailed in ASTM D 5084 standard. Precise control of these pressures, in accordance with the standard recommendations, is essential for obtaining an accurate permeability test result. If any one of them is either lower or higher than needed, the sample will be affected in some manner, and the results will likely be wrong.

b) Degree of saturation

This is, perhaps, the best and easiest way to estimate effectiveness of soil compaction in relation to expected permeability. Please note that the proctor “optimum” compaction point at the top of the curve, obtained at a certain water content and dry density (dry unit weight), does not automatically translate into achievement of the lowest possible coefficient of permeability in soil. In fact, it denotes the beginning of the desirable low permeability range. It has been demonstrated in practice, that a degree of saturation which falls in the range between 85% and 100%, generally corresponds to permeability below 1×10^{-7} cm/sec in compacted clay liners. The Equation H-1 below⁵ defines water content which is necessary to accomplish complete saturation (i.e., 100% degree of saturation) for the given dry bulk density of compacted soil γ_d and specific gravity G_s (typically 2.6 - 2.8) for the soil materials.

Equation H-1: Water Content at 100% Saturation

$$w_{sat} = [(62.4 / \gamma_d) - (1 / G_s)] \times 100$$

By substituting value 100 (%) with a variable name (such as DS, for example), a degree of saturation can be calculated for any given dry density, water content and specific gravity.

Equation H-2: Degree of Saturation (DS)

$$DS = w_{sat} / [(62.4 / \gamma_d) - (1 / G_s)]$$

⁵

Equation and values of specific gravity G_s from: U.S. EPA, Technical Guidance Document EPA/600/R-93/182, September 1993, “Quality Assurance and Quality Control for Waste Containment Facilities”

For analytical purposes, this formula can be easily programmed into a calculator or a spreadsheet. Anything that computes as more than 105% is probably wrong (because 100% is a theoretical maximum saturation, and an exceedance of +5% can be considered an acceptable error). Anything less than 85% will probably not satisfy the permeability requirement. In either case, permeability calculations, related soil tests and acquired data should be thoroughly examined for the causes of discrepancy.

c) Bulk density

Bulk density can also be used as a means to assess soil permeability. This is based on the fact that permeability decreases with the decrease of void space, i.e., with increase in bulk density. In essence, as the degree of compaction increases, the bulk density will approach the particle density. Therefore, the ratio of the before compaction bulk density (not to be confused with dry bulk density) to the after compaction bulk density should approach about 0.5. Anything above 0.4 could be considered appropriate. (Before and after compaction specific gravity can also be used for comparison.)

d) Test Duration

Permeability tests can last between several hours and several days. Because the test duration depends on a type and characteristics of soil material, as well as on the kind of the test being performed, it is more appropriate to watch for discrepancies in test duration between soil related samples, than to try to establish some arbitrary times based on test similarity. In general, if some tests are performed on the same type of soil, but take more or less time to complete, there could be a potential problem. If a test, for example, is terminated after a (comparatively) short period, this could indicate a “bad” sample, a premature sample failure, or an operator’s error. In any case the result should be reviewed with special caution.

e) Permeability Curve

A permeability curve can be generated by plotting permeability data versus elapsed time during the test. Typically, permeability values will be higher at the beginning of the test (due to the initial saturation and suction process (this latter is more pronounced in field tests) in the soil at the bottom of the test borehole (or the test chamber - in case of a lab test), reach some peak value, and then start decreasing, finally stabilizing at a certain value. The reviewer should recognize that other kinds of data behavior may indicate a problem with the test. For instance, if initial water loss (high permeability) is intensive and continual, it may indicate any one of the following problems: poor compaction, cavitation at the borehole bottom, weak bonding between the lifts, inappropriate soil, poor test setup, etc. If an explanation cannot be determined, questionable tests results should be rejected.

f) Vertical vs Horizontal Permeability Comparison

This indicator is typically used for checking Boutwell’s two stage borehole test. The test itself consists of two parts or “stages”. Stage 1 renders “vertical” permeability (the wetting front is assumed to propagate perpendicularly to the plane of compaction), and stage 2 measures “horizontal” permeability (the wetting front moves along compaction planes). The horizontal permeability is expected always to be higher than vertical. The ratio between these two can reveal the quality of bonding between the lifts in a liner. If horizontal permeability

is more than 4 times higher than vertical, the bonds are probably weak and the liquid is finding its way between the lifts.

Exhibit H-1: Example: Reviewing Soil Test Results from Lab Testing

Figure H-8 shows an example of a lab test results sheet. The method used was ASTM D 5084 - 03, also known as the Falling Head, Method C Test.

Figure H-8 shows a well designed test “data-and-results” sheet. The only missing information is the specific gravity of clay, but, as stated before, it can be approximated between 2.6 and 2.8. The temperature-corrected permeability results are within expected range for the compacted clay material (usually between 1×10^{-7} and 1×10^{-9} cm/sec for laboratory tests).

The best way to review this type of permeability test results is to have ASTM D 5084 - 03 available, and to compare its requirements to the given values in the sheet. For instance (using example from figure H-8) the following can be determined:

- The difference (confining pressure) between the chamber (cell) pressure and back pressure is 4 psi, and this value is within the recommended range of 1 to 5 psi;
- The start and end temperatures are within commonly used range of 15 - 30°C;
- *B* parameter (coefficient) indicates adequate (100 = full) sample saturation;
- The formula used to calculate hydraulic conductivity (*k*) is correct;

Hydraulic gradient ($I = h/L$) indicates somewhat accelerated test (this could warrant additional review by the appropriate CO ERAS member); etc.

Job Number: _____	Data: 7/16/2004 to 7/21/2004	Maximum Dry Density: 122.80 pcf
Project Name: _____	Boring: TP-7C	Optimum Moisture Content: 11.80%
Project Location: _____	Sample: _____	% Compaction: 97.13%
Tested By: _____	Depth: 7.50'	Optimum +/-: 2.19%
Remarks: _____		Natural: _____
Material: Sandy Lean Clay CL		Remolded: X

<u>Sample:</u>		<u>Test Conditions:</u>		<u>Moisture Content:</u>		Before Test	After Test
Initial Length:	2.6000in = 6.604 cm	Chamber Pressure:	62 psi	Pan No. =		C	C
Final Ave Length (L):	2.6000in = 6.604 cm	Back Pressure:	58 psi	Wet Wt+ Pan =	589.90		594.49
Diameter:	2.8450 in = 7.23 cm	Confining Pressure:	4 psi	Dry W. + Pan=	517.48		517.48
Area (A):	6.357 sq in = 41.01 sq cm	Temp @ Start:	22.7 °C	Wt of Pan =	0.00		0.00
Volume (V):	16.528 cu in = 270.85 cu cm	Temp @ End:	23.6 °C	Wt of Dry Soil =	517.48		517.48
Wet Wt.:	589.90 grams	Ave Temp:	23.2 °C	Wt of Water =	72.42		77.01
Unit Wet Wt.:	135.97 pcf	B Parameter:	100	% Moisture =	13.99		14.88
Unit Dry Wt.:	119.28 pcf						

Pipette Pressure During Test:

Top Pipette: 58 psi = 4079.6 cm

Bottom Pipette: 60 psi = 4220.3 cm

Pipette:

Area (a): 0.3435 sq in = 0.8725 sq cm

Calculations:

$$k = \frac{a \times L}{2 \times A \times \Delta t} \ln \left(\frac{h_1}{h_2} \right)$$

Where:

k = Hydraulic Conductivity Δt = Time Interval ($t_2 - t_1$)

a = Pipette Cross-Sectional Area h_1 = Head Loss Across Permeameter/Specimen at t_1

L = Length of Sample h_2 = Head Loss Across Permeameter/Specimen at t_2

A = Sample Cross-Sectional Area ln = Natural Logarithm (Base e = 2.71828)

Date	Time Readings	Time Interval Δt Seconds	Bottom Pipette cc	Hydraulic Head Headwater H_1 cm	Top Pipette cc	Hydarulic Head Tailwater H_2 cm	Head Loss $h = H_1 - H_2$ cm	$\ln(h_1 - h_2)$	Temp Corr Permeability k cm/sec
7/20/2004	3:15 PM	0.00	0.90	4287.26	31.40	4111.62	175.64	-	-
7/21/2004	8:32 AM	62,220	6.60	4280.72	25.70	4118.15	162.57	0.07731	8.099E-08
7/21/2004	10:36 AM	7,440	7.40	4279.81	25.00	4118.96	160.85	0.01063	9.314E-08
7/21/2004	12:20 PM	6,240	8.20	4278.89	24.20	4119.87	159.02	0.01147	1.198E-07
7/21/2004	3:11 PM	10,260	9.20	4277.74	23.10	4121.13	156.61	0.01525	9.690E-08
7/21/2004	4:17 PM	3,960	9.50	4277.40	22.70	4121.59	155.81	0.00514	8.454E-08

Time Weighted Average, k [cm/sec] = 8.664E-08

Figure H-8: Example of Lab Test Results

Exhibit H-2: Example: Reviewing Soil Test Results from Field Testing

Figure H-9 is an example of field test results using the ASTM D 6391 - 99 method. This is also known as the Boutwell test.

Figure H-9 is a summary of the Boutwell test results for the three series of tests (SIL, SIC and LFC), each consisting of five permeameters. Full evaluation of these results requires understanding of the test method and performing some relatively elaborate calculations. For doing this, essential recommended references are ASTM D 6391 - 99 and Dr. Boutwell's technical paper.⁶ However, some preliminary screening can be done to identify questionable results, as noted in the "Comment" column in Figure H-9. For instance:

- Possible bottom hole smear (or some other problem) with Stage 2 of the test is apparent. This is indicated by the ratio $K2/K1 < 0.4$ (criterion established by Dr. Boutwell). In this case, using only Stage 1 result ($K1$) to calculate k_v (vertical permeability) is recommended (Stage 2 is considered unreliable.);
- Possible poor bonding between lifts (poor lift joint) is noted in all cases where the ratio $K2/K1$ was above 4 (per Dr. Boutwell's recommendation). (Additional review by the appropriate CO ERAS member is recommended in cases like this.);
- The liner fails the 1×10^{-7} cm/sec requirement; and
- A "bad" hole due to leakage (usually caused by unsuccessful permeameter installation) is declared based on the missing test results. (Such instance may warrant additional review by the appropriate CO ERAS member.)

⁶

Boutwell, G. P., March 12, 1992, "The STEI Two-Stage Borehole Field Permeability Test", Presented to: "Containment Liner Technology and Subtitle D" Seminar, Geotechnical Committee, Houston Branch, ASCE, Houston, Texas. Ratio of $K2/K1 < 0.4$ found on page 21.

Test No.	Sp. Gravity	Dry Density	Moist. Cont.	K1	K2	Kv	Kh	K2/K1	Kh/Kv	Sr	Comment
		(pcf)	(percent)	(cm/s)	(cm/s)	(cm/s)	(cm/s)			%	
SIL-12A	2.70	106.70	20.50	4.50E-06	4.50E-08	8.00E-08	1.80E-07	0.01	2.25	95.59	St. 2 smear, use Kv=3.05E-06 ¹
SIL-12B	2.70	108.10	20.00	7.90E-09	3.40E-09	1.10E-08	5.40E-09	0.43	0.49	96.68	O.K.
SIL-28A	2.70	107.70	20.70	6.50E-09	4.10E-09	3.10E-09	1.40E-08	0.63	4.52	99.04	O.K.
SIL-28B	2.70	106.80	20.10	5.70E-09	4.70E-09	3.80E-09	8.60E-09	0.82	2.26	93.97	O.K.
SIL-42A	2.70	105.50	20.40	6.40E-09	4.10E-09	3.20E-09	1.40E-08	0.64	4.38	92.27	O.K.
SIL-42B	2.70	107.00	20.00	7.40E-08	8.00E-08	5.30E-08	1.10E-07	1.08	2.08	93.98	O.K.
SIC-1	2.70	98.60	20.80	4.00E-06	2.20E-06	4.40E-06	3.60E-06	0.55	0.82	79.24	Permeability above 1.00E-07
SIC-2	2.70	107.60	18.20	3.40E-08	3.00E-07	1.00E-09	1.30E-06	8.82	1300.00	86.85	Poor lift joint ²
SIC-3	2.70	108.80	18.40	6.90E-08	1.60E-06	6.10E-10	9.20E-06	23.19	15081.97	90.57	Poor lift joint ²
SIC-4	2.70	108.20	18.90	1.10E-07	5.50E-08	9.80E-08	1.20E-07	0.50	1.22	91.60	O.K.
SIC-5	2.70	103.10	19.70								No results due to leakage
LFC-1	2.70	95.90	21.00	7.60E-08	1.10E-06	1.20E-09	5.50E-06	14.47	4583.33	74.92	Poor lift joint ²
LFC-2	2.70	96.50	24.00	7.70E-07	2.40E-06	9.10E-08	7.40E-06	3.12	81.32	86.87	O.K.
LFC-3	2.70	98.80	22.80	4.60E-08	1.80E-06	2.20E-10	1.10E-05	39.13	50000.00	87.29	Poor lift joint ²
LFC-4	2.70	101.10	22.30	2.50E-08	1.20E-07	1.70E-09	4.50E-07	4.80	264.71	90.34	Poor lift joint ²
LFC-5	2.70	99.70	19.80	4.80E-08	3.10E-08	2.40E-08	1.00E-07	0.65	4.17	77.49	O.K.
Notes:						The comments are based on the following:					
	SIL = Surface impoundment liner						1. Dr. Boutwell, "The STEI Two-Stage Borehole Field Permeability Test", 1992, p. 21 (When K2/K1<0.4 use Stage 1 only approach, i.e. a problem exists with State 2)				
	SIC = Surface impoundment cover										
	LFC = Phase III landfill cover										
	K1 = Stage 1 apparent permeability (vertical)										
	K2 = State 2 apparent permeability (horizontal)						2. Ohio EPA DSIWM Guidance, November 7, 1994 (proper lift bonding when K2/K1<4)				
	Kv = "True" vertical permeability (calculated)										
	Kh = "True" horizontal permeability (horizaontal)										
	Sr = Degree of saturation at compaction										

Figure H-9: Example of Field Test Results

Determination of compliance (with caution when using statistics)

Whenever statistics are derived from a small number of values (in this case, from just a few permeability tests), they unavoidably include a large margin of error. In most cases, a decision which would be based on such statistics alone, would not be reliable. For that reason, when dealing with a small number of permeability tests, every test result must be below the compliance and/or regulatory threshold. In case of failure, all components of the failed test must be thoroughly examined. These components are: sampling location and the way the samples were collected, sample preparation, compliance of the test parameters and procedures with the ASTM standard requirements, implementation of QA/QC, interpretation of the results, etc. The number of necessary subsequent tests (always more than one) should then be determined based on the findings.

Conclusions

This CPRG appendix was written with a purpose of assisting closure plan reviewer in screening, interpreting and evaluating soil permeability test results - only. It is weighted toward the practical rather than theoretical approach. It has not been intended to be a substitute for the soil mechanics textbooks, research papers, guidance documents, and the rules. Complete knowledge and understanding of the soil mechanics and associated testing procedures is not expected from the reviewer. In case a questionable permeability test result has been discovered, the reviewer is encouraged to forward his/her concerns to the appropriate CO ERAS member for a detailed investigation.

References:

- U.S. EPA, Technical Guidance Document EPA/600/R-93/182, September 1993, "Quality Assurance and Quality Control for Waste Containment Facilities"
- U.S. EPA, "Design, Construction, and Evaluation of Clay Liners for Waste Management Facilities", EPA/530/SW-86/007F, November 1988
- Ohio EPA (DSIWM), "Use of Best Fit Line of Optimums (BFLO) for Recompacted Soil Liner Construction", Guidance Document #0665, June 1, 2005
- U.S. EPA, Seminar Publication EPA/625/4-91/025, May 1991, "Design and Construction of RCRA/CERCLA Final Covers"
- Boutwell, G. P., March 12, 1992, "The STEI Two-Stage Borehole Field Permeability Test", Presented to: "Containment Liner Technology and Subtitle D" Seminar, Geotechnical Committee, Houston Branch, ASCE, Houston, Texas.
- Das, B. M., 1998, "Principles of Geotechnical Engineering, 3rd ed., PWS Publishing Company, Boston.
- Boutwell, G.P., "Soil Compaction for Earthwork Contractors", Monograph available from author, POB 83710, Baton Rouge, LA.