BRITISH COLUMBIA | Ministry of Environment

TECHNICAL GUIDANCE ON CONTAMINATED SITES

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Using Monitored Natural Attenuation and Enhanced Attenuation for Groundwater Remediation

This document provides guidance on the use of monitored natural attenuation (MNA) and enhanced attenuation (EA) for the remediation of contaminated groundwater in B.C.

Definitions

Acronyms and terms used in this guidance are defined in the ministry's Procedure 8, "Definitions and Acronyms for Contaminated Sites":

- Act
- Approval in Principle
- Certificate of Compliance
- enhanced attenuation
- independent remediation
- natural attenuation
- monitored natural attenuation
- performance verification plan
- Regulation
- remediation concentration goal
- site-specific risk-based concentration

Monitored natural attenuation

MNA is a passive approach to remediation that monitors natural attenuation processes which reduce the levels of contaminants and bring contaminated environmental media into compliance with the remediation standards of the Contaminated Sites Regulation (the Regulation).

Natural attenuation

Natural attenuation refers to a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil, sediment or groundwater.

The effectiveness of natural attenuation is determined by the rate of contaminant loading versus the rate of contaminant attenuation. When natural attenuation is not effective within a reasonable time frame, enhanced attenuation may be a viable alternative remedial strategy.

Enhanced attenuation

Enhanced attenuation refers to any type of intervention used to sustainably increase the magnitude of remediation occurring by natural attenuation. EA includes both chemical and biological enhancement techniques.

Chemical enhancement

Supplementing the hydrogeological system with additional electron acceptors and donors can enhance and maintain biological degradation processes by:

- Increasing the availability of electron acceptors (e.g., dissolved oxygen, nitrate, and sulphate) to facilitate the breakdown of substances amenable to aerobically mediated degradation (e.g., petroleum hydrocarbons), or
- Increasing the availability of electron donors (e.g., hydrogen, carbohydrates, fatty acids) to facilitate the breakdown of substances amenable to anaerobically mediated degradation (e.g., chlorinated organics).

Biological enhancement

Bioaugmentation can be used to supplement the natural biological capacity and longevity within the source-plume system by:

- Adding nutrients (e.g., nitrogen, phosphorus, trace minerals, and vitamins) to stimulate the naturally occurring bacteria/microorganisms, and
- Adding species of microorganisms that are not naturally present in the hydrogeological system, but are necessary to facilitate biodegradation.

Relation of MNA and EA to active contaminant management

Groundwater contamination is often remediated by source removal followed by physical remediation using for example, a pump and treat system. Such an approach can be energy intensive and does not always meet remedial objectives cost effectively or within a reasonable time frame. MNA and EA are both lower-energy remedial alternatives which offer a number of important features.

EA can be used as a bridge between aggressive remediation actions and MNA. EA expands remediation opportunities, and potentially offers less disruption to land owners and the environment, more energy efficiency, and lower costs than traditional active remediation technologies.

Selecting MNA or EA for remediation

EA and MNA are most appropriate when used in conjunction with other remediation measures (e.g., hydraulic control, groundwater extraction, reactive barriers) or as a follow up to active remediation measures (e.g., groundwater contamination source removal and control) that have already been implemented. Reliance on MNA without source removal and control as the sole remedial technique is appropriate at few contaminated sites.

Basic prerequisites for MNA and EA

MNA and EA should be carried out only if following conditions are met:

a) they are performed in the context of a risk assessment that indicates no unacceptable risks to human health or the environment;
b) groundwater contamination sources will be remediated or contained and controlled;
c) the contaminant plume is stable (on the source parcel) or shrinking (on the affected parcels);
d) a long term performance monitoring and validation program can be and will be put in place;
e) the use of MNA or EA will result in the remediation concentration goals being met within 20 years; and
f) a detailed contingency plan that includes clearly defined implementation trigger(s) is in place.

Additional prerequisites for EA

In addition to the basic prerequisites above, to be considered acceptable, the application of EA should:

- increase the rate of attenuation; and
- have sufficient longevity to ensure remediation concentration goals will be met, with minimal enhancement applications.

Choosing EA instead of MNA

If the rate of natural attenuation is insufficient to meet the remediation standards in a reasonable timeframe, EA may sufficiently increase the attenuation capacity of the hydrogeological system. A decision flowchart for the use of MNA alone or together with EA for groundwater remediation is shown in Appendix 1.

Monitoring the progress of MNA and EA

The progress of groundwater remediation under MNA and EA should be closely monitored to ensure that:

- attenuation occurs at an acceptable rate to meet the applicable remediation concentration goals,
- attenuation mechanism(s) remain effective over time and capable of supporting continued acceptable attenuation rates, and
- there are no unacceptable risks to human health and the environment from contamination.

Monitoring and application of the risk-based remediation standards

If MNA or EA is used to remediate a parcel, the remediation should be performed in the context of a risk assessment based on an evaluation of current exposure pathways. However, potential future exposure pathways must be considered if, under Protocol 21, "Water Use Determination," groundwater use has been established for drinking, irrigation or livestock water uses. In general, for these situations the applicable standards in Schedule 6 and 10 of the Regulation apply.

Typically the progress of MNA and EA would be evaluated by measuring contaminant concentrations rather than by measuring changes in the risks posed by individual substances. Environmental consultants should evaluate the progress of MNA or EA by comparing groundwater concentrations to the remediation concentration goals, which include site-specific risk-based concentrations.

> **Site-specific risk-based concentrations**
> These concentrations are one of several types of remediation concentration goals. They are derived by calculating concentrations of substances based on site-specific information used in risk assessments that represent a risk equivalent to the risk-based standard for a substance. If the concentration of the substance is less than that calculated concentration, the risk-based remediation standard for that substance would be met.

Supplemental guidance for MNA and EA

The directive "Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites," adopted by the U.S. Environmental Protection Agency in 1999, provides guidance which has the fundamental concepts and key components for the use of MNA at contaminated sites. Its general guiding principles may be applied to the remediation of groundwater by MNA in B.C. regardless of the characteristics of the contamination.

In addition, one or more of the references (including updated versions) provided in Appendix 2 should be used throughout the planning and implementation of an MNA or EA program, as appropriate for the substance(s) at a given site. Additional resources, computer applications and links are provided in Appendix 3.

> **Need to use current supplemental guidance**
> The documents referenced in Appendix 2 are considered current as of the date of this guidance; however, these publications may be superseded as advancements are made in the science surrounding MNA and EA. The ministry expects those using MNA and EA to ensure that advances in the state of the science and practice surrounding MNA and EA are considered and incorporated into all MNA and EA based remedial programs, to the degree practicable.

Dealing with conflicting guidance

If guidance in the documents in Appendix 2 conflicts with the requirements of this document or other ministry requirements and guidance, the ministry provisions should take precedence, bearing in mind that the technical methodologies of those documents could be used to meet ministry guidance or requirements.

Use of alternate methods

Alternate methods that are not part of the standard guidance referenced in Appendix 2 may be used if they provide an equal or higher standard of care, if a detailed rationale is provided supporting the proposed approach, and if relevant scientific literature regarding the change in method or procedure has been submitted to and approved by the Director before commencing remediation. Such deviations from standard practices should be documented in reports produced for the site.

Justification to use MNA or EA required

Both MNA and EA require careful design, documentation, monitoring, and contingency plans in the event the system fails to perform as anticipated. Those using MNA or EA should be prepared to provide the ministry with:

- strong arguments indicating that MNA or EA can meet remedial goals in 20 years (using, for example, historic trends, predictive modelling, geochemical arguments, and other lines of evidence);
- performance verification plans (including indicators, well coverage, monitoring frequency, and reporting requirements); and
- contingency plans.

How MNA and EA fit with B.C.'s legal requirements for remediation

The definition of "remediation" under the *Environmental Management Act* (the Act) includes "monitoring, verification and confirmation of whether the remediation complies with applicable standards and requirements imposed by a director." Thus MNA and EA may only be performed under the provisions of the Act dealing with remediation, including an Approval in Principle, Certificate of Compliance and independent remediation.

Choosing an appropriate remedial strategy

Protocol 5, "Groundwater Remediation Requirements for Protecting Drinking, Irrigation and Livestock Water Uses" outlines the approach to using remediation strategies like MNA and EA to remediate groundwater. It requires that groundwater located at downgradient affected parcels must be remediated to remediation concentration goals, which for a site where the drinking water standards of the Contaminated Sites Regulation apply, would result in the restoration of the groundwater suitable for drinking water purposes.

Obtaining a contaminated sites legal instrument

Parcels using MNA or EA are considered to use the risk management approach to site remediation. For those where the risk-based remediation standards are not met before remediation begins, MNA and EA could be carried out under an Approval in Principle or by independent remediation. Once the numerical or risk-based remediation standards are met, an application could be made to the ministry for a Certificate of Compliance either to the risk-based or numerical remediation standards, as applicable.
If the risk-based remediation standards are met before MNA or EA begin, then remediation could be performed under a risk-based remediation standards Certificate of Compliance. When numerical standards are met, an application could be made for a new Certificate of Compliance or an amendment to an existing risk-based standards Certificate specifying that the numerical standards were met. Please consult Fact Sheet 46, "Contaminated Sites Legal Instruments" for a summary of the benefits of, and requirements for Certificates of Compliance.

A covenant under section 219 of the *Land Title Act* may be requested by the ministry to restrict the use of the groundwater until remediation to the remediation concentration goal is complete.

Reporting requirements

Reporting requirements would normally be included in Schedule B (conditions) of an Approval in Principle, Certificate of Compliance, or imposed by a Director under independent remediation.

Notifications of Independent Remediation (NIR)

The ministry expects Notifications of Independent Remediation to be submitted when EA and MNA are carried out. In accordance with section 54 of the Act and section 57 of the Regulation, any person undertaking independent remediation of a contaminated site must provide written notification to a Director within 3 days after any remediation activity is initiated. A Director must also be notified in writing within 90 days of completion of independent remediation.

For the purposes of these notifications, remediation activity includes the handling, management or treatment of contamination.

"Remediation activity" therefore includes contamination treated in groundwater whether or not the treatment is passive (in the case of MNA) or active (in the case of EA). Please consult Administrative Guidance 9, "Independent Remediation of Contaminated Sites" for further information. Note that under section 54 (3) (d) of the Act, a Director may impose requirements for monitoring and reporting for MNA or EA.

Discharge authorizations for EA

The Act's Waste Discharge Regulation prescribes industries, trades, businesses, activities and operations which require some form of authorization in order to introduce waste into the environment. Waste discharge authorizations are most frequently issued as permits and approvals.

"Contaminated site contaminant management" is a prescribed activity and is defined under Schedule 1 of the Waste Discharge Regulation. Based on this definition, the application of materials for chemical or biological enhancement may require authorization. For information on the authorization application process, refer to the ministry's Waste Discharge Authorizations webpage. You might require a discharge authorization associated with the treatment or management of wastes at a contaminated site undergoing EA. Please contact us at site@gov.bc.ca for advice.

> **Note**
> Those wishing to discharge waste to the environment should be aware of the requirements of other agencies such as local governments which, for example, may have bylaws governing discharges to sewer systems and to the atmosphere. Federal agencies such as Environment Canada and Fisheries and Oceans Canada may also need to be contacted in conjunction with discharge

Note: This document is solely for the convenience of the reader. It does not contain and should not be construed as legal advice. The current legislation and regulations should be consulted for complete information.

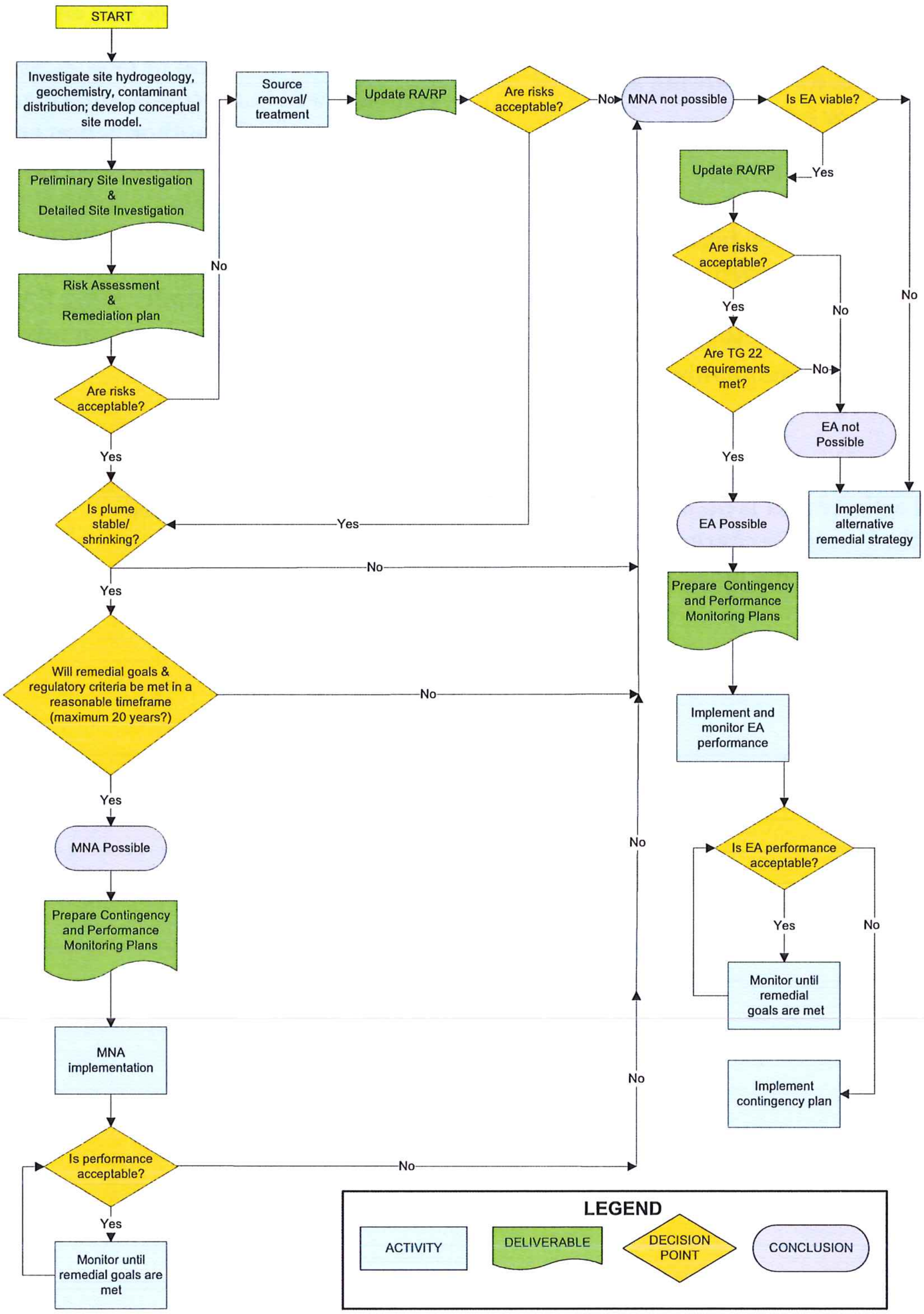
For more information, contact the Environmental Emergencies and Land Remediation Branch at (250) 387-4441.

Revision history

Approved Date	Effective Date	Document Version	Notes
		1.0	

Appendix 1

Monitored Natural Attenuation / Enhanced Attenuation Decision Diagram for Groundwater Remediation



Appendix 2

Monitored Natural Attenuation and Enhanced Attenuation References

General – Multiple contaminant types

Chapelle, F.H., J. Novak , J. Parker, , B.G. Campbell, and M.A., Widdowson, 2007, "A Framework for Assessing the Sustainability of Monitored Natural Attenuation", U.S. Geological Survey Circular 1303. http://toxics.usgs.gov/highlights/mna_circ.html

EPA, Office of Research and Development, National Risk Management Research Laboratory, Ada, OK. EPA 600/R-11/204, "An Approach for Evaluating the Progress of Natural Attenuation in Groundwater", December 2011. http://www.epa.gov/nrmrl/pubs/600r11204/600r11204.pdf

Petroleum hydrocarbons and petroleum hydrocarbon additives

ASTM E1943-98(2010), "Standard Guide for Remediation of Ground Water by Natural Attenuation at Petroleum Release Sites", ASTM International, 2010. http://www.astm.org/

Washington State Department of Ecology, Toxics Cleanup Program Publication 05-09-091, "Guidance on Remediation of Petroleum-Contaminated Ground Water by Natural Attenuation", 2005. http://www.ecy.wa.gov/biblio/0509091.html

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American Petroleum Institute, API Publication 4761, "Technical Protocol for Evaluating the Natural Attenuation of MTBE", May 2007. http://www.api.org/ehs/groundwater/oxygenates/upload/4761new.pdf

Wilson, J.T., P.M. Kaiser, and C. Adair, U.S. EPA National Risk Management Research Laboratory, Ada, OK. EPA 600-R-04-179, "Monitored Natural Attenuation of MTBE as a Risk Management Option at Leaking Underground Storage Tank Sites", January 2005. http://www.clu-in.org/download/remed/mna_for_risk_%20managment_of_mtbe.pdf

Air Force Center for Environmental Excellence (AFCEE), Brooks City-Base, Texas, "Technical Protocol for Implementing Intrinsic Remediation with Long-term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater", March 1999. http://www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/monitorednaturalattenuation/protocolsandreports/index.asp

Chlorinated organics

Interstate Technology & Regulatory Council (ITRC), "Enhanced Attenuation: Chlorinated Organics". EACO-1, 109 pp, 2008 http://www.itrcweb.org/

Wisconsin Department of Natural Resources, April 2003, "Understanding Chlorinated Hydrocarbon Behavior in Groundwater: Investigation, Assessment and Limitations of Monitored Natural Attenuation". http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR699.pdf

Air Force Center for Environmental Excellence (AFCEE), Brooks City-Base, Texas, "Field-Scale Evaluation of Monitored Natural Attenuation for Dissolved Chlorinated Solvent Plumes", 2009. http://www.clu-in.org/techfocus/default.focus/sec/Natural_Attenuation/cat/Guidance/

Inorganics

EPA, "Site Characterization to Support Use of Monitored Natural Attenuation for Remediation of Inorganic Contaminants in Ground Water", November 2008, EPA/600/R-08/114. http://www.epa.gov/nrmrl/pubs/600r08114/600r08114.pdf

EPA, "Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 1 - Technical Basis for Assessment", October 2007, EPA/600/R-07/139. http://www.epa.gov/nrmrl/pubs/600R07139/600R07139.pdf

EPA, "Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 2 - Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium", October 2007, EPA/600/R-07/140. http://www.epa.gov/nrmrl/pubs/600R07140/600R07140.pdf

Lieberman, M.T. and R.C. Borden, Environmental Security Technology Certification Program (ESTCP), "Natural Attenuation of Perchlorate in Groundwater: Processes, Tools and Monitoring Techniques", August 2008, ESTCP Project ER-0428. http://www.estcp.org/content/search?cqp=Standard&SearchText=ER-0428

Appendix 3

Additional Resources, Computer Applications, and Useful Links

Resources

The AFCEE preliminary screening tool for anaerobic biodegradation can be found at http://www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/monitorednaturalattenuation/index.asp

EPA, "A Guide for Assessing Biodegradation and Source Identification of Organic Ground Water Contaminants Using Compound-Specific Isotope Analysis (CSIA)", December 2008, EPA/600/R-08/148. http://www.epa.gov/nrmrl/pubs/600r08148/600r08148.pdf

Brauner, S.J., D. C. Downey, and R. Miller, "Using Advanced Analysis Approaches to Complete Long-Term Evaluations of Natural Attenuation Processes on the Remediation of Dissolved Chlorinated Solvent Contamination", Strategic Environmental Research and Development Program (SERDP) Project ER-1348, October 2008. http://www.clu-in.org/download/techfocus/na/NA-ER-1348-FR.pdf

U.S. Department of Defense, Environmental Security Technology Certification Program, Project ER-0436, June 2008, "ESTCP Cost and Performance Report: Estimating Cleanup Times Associated with Combining Source-Area Remediation with Monitored Natural Attenuation" http://serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Monitoring/ER-200436/ER-200436/(language)/eng-US

Interstate Technology & Regulatory Council (ITRC), "A Decision Flowchart for the Use of Monitored Natural Attenuation and Enhanced Attenuation at Sites with Chlorinated Organic Plumes", March 2007. http://www.itrcweb.org/Documents/EACODecisionFlowchart_v1.pdf

Savannah River National Laboratory (SRNL), "Scenarios Evaluation Tool for Chlorinated Solvent MNA", February 7, 2007. http://www.osti.gov/bridge/purl.cover.jsp?purl=/899964-cuFtbW/

EPA, "Performance Monitoring of MNA Remedies for VOCs in Ground Water", April 2004, EPA/600/R-04/027. http://www.epa.gov/nrmrl/pubs/600R04027/600r04027.html

U.S. Geological Survey, "Methodology for Estimating Times of Remediation Associated with Monitored Natural Attenuation", 2003, Water-Resources Investigations Report 03-4057. http://pubs.usgs.gov/wri/wri034057/

Air Force Center for Environmental Excellence (AFCEE), Brooks City-Base, Texas, "Designing Monitoring Programs to Effectively Evaluate the Performance of Natural Attenuation", January 2000.http://www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/monitorednaturalattenuation/protocolsandreports/index.asp

Computer applications

Computer models can be useful when evaluating and verifying MNA or EA processes. Examples of both analytical and numerical fate and transport models are listed below. The list is not intended to be all inclusive and other applicable models can be used.

Name of Model	Source of Model	Description
Bioscreen	USEPA	Bioscreen is a 3D analytical screening model for dissolved hydrocarbons based on the Domenico fate and transport model. The model includes advection, dispersion, adsorption, first-order decay, and instantaneous biodegradation under aerobic and anaerobic conditions.
Footprint	USEPA	Footprint is a 1D analytical screening model based on the Domenico fate and transport model. The model includes advection, dispersion, adsorption and either first- or zero order decay.
Biochlor	USEPA	Biochlor is a 1D analytical screening model for chlorinated solvents based on the Domenico fate and transport model. The model includes advection, dispersion, adsorption and reductive dechlorination following first-order processes within one or two reaction zones.
REMChlor	USEPA	REMChlor (Remediation Evaluation Model for Chlorinated Solvents) is a 1D analytical screening model for chlorinated solvents based on the Domenico fate and transport model. The model includes advection, dispersion, linear adsorption and first-order decay.
Bioplume III	USEPA	Bioplume III is a 2D finite difference model based on the USGS solute transport code MOC. The model includes advection, dispersion, sorption and biodegradation following first-order decay, instantaneous reaction or Monod kinetics.
NAS	Virginia Tech, USGS and NAVFAC (Naval Facilities Engineering Command)	NAS (Natural Attenuation Software) is a combined 2D analytical and 3D numerical solute transport model. The model includes advection, dispersion, sorption, NAPL dissolution and biodegradation.
MT3D	USEPA	MT3D is a 3D finite difference transport model. The model interfaces directly with the USGS finite difference groundwater model, MODFLOW. The model includes advection, dispersion, linear or nonlinear sorption, sink/source mixing and first-order decay or biodegradation.
RT3D	US Department of Energy and Pacific Northwest National Laboratory (PNNL)	RT3D is a 3D finite difference transport model. The model interfaces directly with the USGS finite difference groundwater model, MODFLOW. The model includes advection, dispersion, linear or nonlinear sorption and sink/source mixing. RT3D comes with a set of pre-programmed reaction modules including the RT3D MNA and EA modules.
PHREEQC	USGS	PHREEQC can simulate both batch reactions and 1D finite difference transport. The 1D transport model includes advection, dispersion and optionally diffusion in stagnant zones. The model can simulate a wide variety of aqueous geochemical calculations involving reversible and irreversible reactions.