REFERENCES

Andersen, P.F. (1993). A manual of instructional problems for the USGS MODFLOW model. Robert S. Kerr Environmental Research Laboratory, Office Of Research and Development, US Environmental Protection Agency, Ada, OK, EPA/600/R-93/010.

Arulanandan, K., et al. (1985). Centrifuge modeling of advection and dispersion processes during pollutant travel in soil. Proceedings of the Second Symposium on the Interaction of Non-Nuclear Munitions with Structures. Panama City Beach, Fla: 418-423.

Arulanandan, K., Thompson, P.Y., Kutter, B.L., Meegoda, N.J., Muraleetharan, K.K. and Yogachandran, C. (1988). Centrifuge modeling of transport processes for pollutants in soils. Journalof Geotechnical Engineering. ASCE: 185-205.

Bachmat, Y. (1967). The similitude of dispersion phenomena in homogeneous and isotropic porous media. Water Res Res. 3(4): 1079-1083.

Bear, J. (1972). Dynamics of fluids in porous media. American Elsevier Publishing Company, Inc., N.Y.

Cheng, X., Anderson, M.P. (1993). Numerical simulation of groundwater interaction with lakes allowing for fluctuating lake levels. Ground Water 31(6): 020-933.

Carbonell, R.G., and Whitaker, S. (1982). Dispersion in pulsed system-II. Theoretical developments for passive dispersion in porous media. Chem. Eng. Sci., 38(11): 1795-1802.

Fenske, J.P., Leake, S.A. and Prudic, D.E. (1996). Documentation of a computer program (RES1) to simulate leakage from reserviors using the modular finite-difference groundwater flow model (MODFLOW). US Geological Survey Open-File Report. 51: 96-364.

Freeze, R.A., and Cherry, J. A. (1979). Groundwater. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Geragthty and Miller Software Newsletter (1992). Geragthty and Miller survey results 4(summer): 1-2.

Goode, D.J., Appel, C.A. (1992). Finite-difference interblock transmissivity for unconfined aquifers and for aquifers having smoothly varying transmissivity. US Geological Survey Water Resources Investigations Report. 79: 92-4124.

Greenkorn, R.A. (1983). Flow phenomena in porous media. Marcel Dekker, Inc., N.Y.

Hansen, A.J. (1993). Modifications to the modular finite-defference groundwater flow model used for the Columbia Platea region aquifer-system analysis. Washington, Oregon and Idaho. US Geological Survey Open-File Report. 162: 91-532.

Harbaugh, A.W. (1990a). A simple contouring program for gridded data. US Geological Survey Open-File Report. 162: 91-532.

Harbaugh, A.W. (1990b). A computer program for calculating subregional water budgets using results from the US Geological Survey modular three-dimensional finite-difference groundwater flow model. US Geological Survey Open-File Report. 46: 90-392.

Harbaugh, A.W. (1992). A generalized finite-difference formulation for the US Geological Survey modular three-dimensional finite-difference groundwater flow model. US Geological Survey Open-File Report. 60: 91-494.

Harbaugh, A.W. (1994). A data input program (MFI) for the UD Geological Survey modular finite-difference groundwater flow model. US Geological Survey Open-File Report. 24: 94-468.

Harbaugh, A.W. (1995). Direct solution package based on alternating diagonal ordering for the US Geological Survey modular three-dimensional finite-difference groundwater flow model. US Geological Survey Open-File Report. 46: 95-288.

Harbaugh, A.W., McDonald, M.G. (1996a). User's documentation for MODFLOW-96: an update to the US Geological Survey modular finite-difference groundwater flow model. US Geological Survey Open-File Report. 56: 96-485.

Harbaugh, A.W., McDonald, M.G. (1996b). Programmer's documentation for MODFLOW-96: an update to the US Geological Survey modular finite-difference groundwater flow model. US Geological Survey Open-File Report. 220: 96-486.

Hellawell, E.E., Savvidou C. and Booker J.R. (1993). Modelling contaminated land reclamation. submitted for publication in Soils and Foundations, Japan and CUED report, TR 250.

Hensley, P.J. (1988). Geotechnical centrifuge modelling of hazardous waste migration, in Land Disposal of Hazardous Waste. Engineering and Environmental Issues. Gronow, J.R., Schofield, A.N. and Jain, R.K. Eds. Ellis HorwoodLtd., Chicester: 139-151.

Hensley, P.J., Savvidou, C. (1992). Modelling pollutant transport in soils. Australian Geomechanics.

Hensley, P.J., Savvidou, C. (1993). Modelling coupled heat and contaminant transport in groundwater. Int J. for Num. and Analyt. Methods in Geomechanics. vol. 7: 493-527.

Hill, M.C. (1990). Preconditioned conjugate-gradient 2 (PCG2), a computer program for solving groundwater flow equations. US Geological Survey Water-Resources Investigations Report. 43: 90-4048.

Hill, M.C. (1992). A computer program MODFLOWP for estimating parameters of a transient, three-dimensional, groundwater flow model using nonlinear regression. US Geological Survey Open-File Report: 91-484.

Hill, M.C. (1994). Five computer programs for testing weighted residuals and calculating linear confidence and prediction intervals on results from the groundwater parameter-estimation computer program MODFLOWP. US Geological Survey Open-File Report: 93-481.

Hsieh, P.A. and Freckleton, J.R. (1993) Documentation of a computer program to simulate horizontal-flow barriers using the US Geological Survey modular three-dimensional finite-difference groundwater flow model. US Geological Survey Open-File Report. 32: 92-477.

Javandel, I., Doughty, G., and Tsang, C.F. (1984). Groundwater transport, handbook of mathematical models. American Geophysical Union, Washington, D.C.

Kipp, K.L. (1987). HST3D: A computer code for simulation of heat and solute transport in three-dimensional groundwater flow systems. U.S. Geological Survey. Water resources Investigations Report: 86-4095.

Konikow, L.F., Goode, D.J., Hornberger, G.Z. (1996). A three-dimensional method-of-characteristics solute transport model (MOC3D). US Geological Survey Water Resources Investigations Report. 87: 96-4267.

Laut, K.L. (1975). Application of centrifuge model tests in connexion with studies of flow patterns of contaminated water in soil structures. Geotechnique. 25: 401-407.

Neild, D.A. (1968). Onset of thermohaline convection in porous medium. Water Resources Res.

Orlob, G.T. (1984). Mathematical modeling of water quality. Wiley Interscience, N.Y. and London.

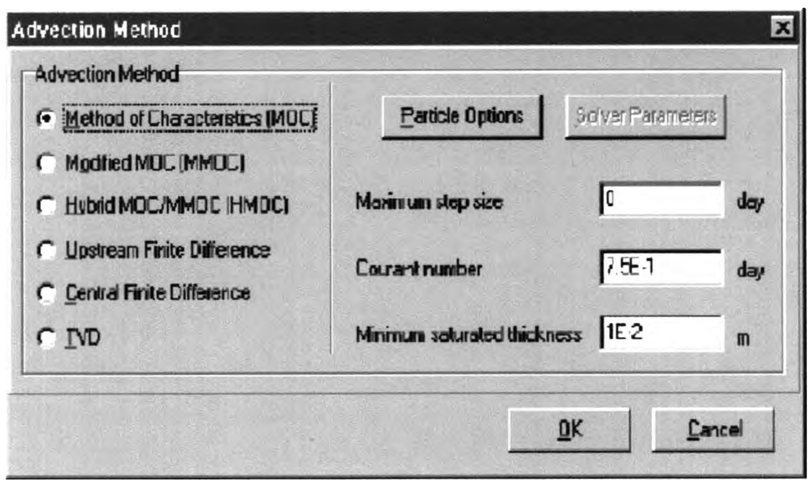
Rowe, R.K. and Booker, J.R. (1985). 1-D pollutant migration in soils of finite depth. J. Geotech. Engrg., ASCE. 111(4): 479-499.

Wooding, R.A. (1959). The stability of a viscous liquid in a vertical tube containing porous material. Proc. Of the Royal Soc. Of London, Series A, Vol. 252: 120-134.

APPENDIX

Advection Method

The advection settings are used to select the numerical method used to solve the advective part of the transport equation and to customize the settings for the selected method. Modifying the default advection parameters require some understanding of the techniques used to solve the advection component of mass transport. The Advection Method dialog for the MT3DMS transport engine is shown in the following figure;



The available Advection Methods (MIXELM) is;

1. Method of Characteristics (MOC)

The MOC method is available in all versions of MT3D. The MOC method uses a conventional particle tracking technique based on a mixed Eulerian-Lagrangian method for solving the advection term. The dispersion, sink/source mixing and chemical reaction terms are solved with the finite difference method. The MOC technique tracks a large number of moving particles forward in time and keeps track of the concentration and position of each particle. The main advantage of the MOC technique is that it is virtually free of numerical dispersion. However, the drawback of the MOC technique is that it can be slow and can require a large amount of computer memory.

2. Modified Method of Characteristics (MMOC)

The MMOC method is available in all versions of MT3D. The MMOC was developed to improve computational efficiency of the MOC technique. Unlike the MOC technique, which tracks the position and concentration of a large number of moving particles, the MMOC technique places a particle at the mid-point of each cell at each new time level. The particle is tracked backward to find its position at the old time level and the concentration associated with the old time level is used to approximate the concentration at the new time level. The MMOC technique is both faster and requires less computer memory than the MOC technique. However, with the lower-order interpolation scheme available with MT3D the MMOC technique introduces some numerical dispersion.

3. Hybrid Method of Characteristics (HMOC)

The HMOC method is available in all versions of MT3D. The HMOC technique combines the strengths of the MOC and the MMOC techniques by using an automatic adaptive scheme that uses the MOC technique at sharp concentration fronts and the MMOC technique away from the fronts. By selecting an appropriate criterion for controlling the switch between the MOC and MMOC techniques, the HMOC scheme can provide accurate solutions for both sharp and non-sharp front problems.

4. Upstream Finite Difference Method

The Upstream Finite Difference method is available in all MT3D versions. Since, the finite-difference method does not involve particle tracking or concentration interpolations, it is normally more computationally efficient than the Method of Characteristics (MOC). In addition, the finite difference method normally has very small mass balance errors because it is based on the principle of mass conservation. However, the Upstream Finite-Difference method can lead to significant numerical dispersion for problems having sharp concentration fronts.

5. Central Finite Difference Method

The Central Finite Difference method is only available in MT3DMS, MT3D99 and RT3Dv.2.5. The central finite difference method does not exhibit the numerical dispersion problems like the Upstream Finite Difference method, but is susceptible to excessive artificial oscillations in advection dominated problems.

6. TVD Method

The TVD method is available only with MT3DMS, MT3D99 and RT3Dv.2.5. The third-order total-variation-diminishing (TVD) scheme, which is mass conservative, solves the advection term based on ULTIMATE algorithm (Universal Limiter for Transient Interpolation Modeling of the Advective Transport Equations). As in the particle-based methods, the TVD scheme solves the advection component independent of the other terms in the transport equation. Results from the third-order TVD scheme may exhibit minor numerical dispersion and minor oscillations in problems having sharp concentration fronts. Since the algorithm is explicit there is a stability constraint on the step size. The maximum allowed value for the time step is the minimum time step calculated for every active cell.

Dispersion equation

Dispersion is a mechanical process that tends to 'disperse', or spread, the contaminant mass in the X, Y and Z directions along the advective path of the plume and acts to reduce the mass concentration. Dispersion is caused by the tortuosity of the flowpaths of the groundwater as it travels through the interconnected pores of the soil. Dispersion is calculated using the equation;

$$D = \alpha_L * \frac{V_L^2}{|V|} + \alpha_H * \frac{V_H^2}{|V|} + \alpha_V * \frac{V_V^2}{|V|} + D^*$$

Where;	D	is the Dispersion
	α_l	is the longitudinal dispersivity (units of 1/length)
	V_L	is the longitudinal velocity of flow along the plume migration pathway
	α_H	is the horizontal dispersivity (units of 1/length)
	V_H	is the horizontal velocity of flow along the plume migration pathway
	α_V	is the vertical dispersivity (units of 1/length)
	V_V	is the vertical velocity of flow along the plume migration pathway
	D^*	is the diffusion coefficient (no units)

MT3D calculates the Dispersion tensor for the mass transport model using the following parameters:

- Longitudinal Dispersivity for each transport grid cell
- Ratio of Horizontal to Longitudinal Dispersivity for each layer
- Ratio of Vertical to Longitudinal Dispersivity for each layer
- Molecular Diffusion Coefficient for each layer

BIOGRAPHY

Mr.Itti Chinratanapisit was born in Bangkok, Thailand, on December, 30^{th} 1979. He finished his high secondary school from Assumption College in 1997. In 2001, He graduates in Bachelor of Science (General Science) from faculty of Science, Chulalongkorn University, Thailand. In 2002 He continued further study for Master degree of Science in Environmental Management inter-Department Program in Environmental Management, Graduate School, Chulalongkorn University.