DYNSYSTEM

GROUNDWATER MODELING NOTES

REVIEW OF DYNFLOW AND DYNTRACK GROUNDWATER SIMULATION COMPUTER CODES

Report of Findings
by
Paul K. M. van der Heijde

for
U.S. Environmental Protection Agency
Office of Waste Program Enforcement
Washington D.C. 20460

IGWMC 85-17
May 3, 1985

INTERNATIONAL GROUND WATER MODELING CENTER
Holcomb Research Institute
Butler University, 4600 Sunset Avenue
Indianapolis, Indiana 46208

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN - 3 1985

OFFICE OF
SOLID WASTE AND EMERGENCY RESPONSE

MEMORANDUM

SUBJECT: OWPE Review of Ground Water Model Codes

FROM: Jack Stanton, Director
CERCLA Enforcement Division, OWPE

TO: Addressees

At the request of your respective offices, the Office of Waste Programs Enforcement (OWPE) initiated an independent review of proprietary ground water computer codes previously employed by the REM/FIT Contractor, Camp, Dresser, and McKee in conjunction with the Price Landfill case in Region II. This review was undertaken by Paul Van Der Heijde, Director of the International Ground Water Modeling Center, Holcomb Research Institute in Indianapolis, IN at the recommendation of EPA's Office of Research and Development. The results of Mr. Van Der Heijde's review are included in the attached document entitled "Review of Dynflow and Dyntrack Groundwater Simulation Computer Codes, Report of Findings" dated May 3, 1985. Based on an assessment of Mr. Van Der Heijde's review, it is OWPE's opinion that the Dynflow and Dyntrack computer codes are appropriate for use in simulating ground-water flow and contaminant transport at the Price Landfill site. This opinion is restricted to the technical underpinnings of the Dynflow and Dyntrack computer codes and does not extend to any specific application of the codes at the Price Landfill site. Mr. Van Der Heijde's independent review and limited testing of the codes showed them to be generally based on well-founded theory and capable of accurately reproducing results of selected test problems.

However, the circumstances leading to your request and Mr. Van Der Heijde's subsequent review and commentary also underscored the present deficiency on the part of the Environmental Protection Agency of not having procedures and criteria for

reviewing and approving ground-water computer codes for selection and application by its offices, contractors, or the regulated community. For this reason, I believe it would be premature to consider this memorandum a general endorsement of the Dynflow and Dyntrack codes by the Environmental Protection Agency. Rather, you should consider this as guidance and opinion by OWPE, supported by sound technical review, that the codes are appropriate to be applied at the Price Landfill site.

Under a separate memorandum Gene Lucero is advising key offices in EPA of our review and the necessity to further address the agency's need for sound ground-water model review procedures. I am hopeful that this and subsequent memoranda will be helpful in resolving uncertainties in the selection and application of specific ground water model computer codes. I appreciate your attention and patience during this review period. I believe this has been an important educational experience for all concerned.

Attachment

Addressees
w/attachment: John Wittenborn, DOJ
Sheila Jones, DOJ
Sam Multhrop, US Attorney
Walter Mugdan, EPA Region II
William Sawyer, EPA, Region II
Phillip Boxell, EPA, Region I
Robert Ogg, EPA Region II
John Moebes, EPA Region I
Russ Weyer, OERR

May 3, 1985

BUTLER UNIVERSITY

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International Ground Water Modeling Center

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317-283-9458

Mr. Peter Ornstein
US EPA
Office of Waste Program Enforcement
Washington, DC 20460

Dear Mr. Ornstein:

Enclosed is the report of findings according to the 4th task in the scope of work for the review of the DYNFLOW and DYNTRACK groundwater simulation codes. This report includes the comments received on the draft report sent to you February 20, 1985.

If you have any questions, do not hesitate to call me.

Sincerely,

Paul K.M. van der Heijde
Director
International Ground Water Modeling Center

PVDH:b
enc.

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Report of Findings, May 3, 1985

by Paul K.M. van der Heijde, Director
International Ground Water Modeling Center
Holcomb Research Institute
Butler University
Indianapolis, IN 46208

Introduction

By request of the Office of Waste Program Enforcement of the U.S. Environmental Protection Agency, the DYNFLOW and DYNTRACK models developed by Camp, Dresser and McKee, Inc., have been reviewed. This document and the opinions expressed herein do not represent the position of the Agency on the issues discussed. For the reasons stated below, this review should not be construed to be a complete or comprehensive peer review.

The review, requested by EPA in support of its involvement in the Price landfill case in New York, is aimed at evaluating the validity of the DYNTRACK solute transport simulation code. As stated in the letter from Johanna Miller, EPA, September 21, 1984, the objective of this review is "to comment on the theoretical base and mathematical framework of the CDM model." Because the heads required as input for the DYNTRACK code are generated by the DYNFLOW groundwater flow code, both DYNFLOW and DYNTRACK are subject to this review. The scope of work for this review is described in a letter by PRC Engineering, Inc., Chicago, Illinois, November 21, 1984, through which organization this review was subcontracted to the Holcomb Research Institute. According to the scope of work described in that letter, the key elements of the review should be:

(1) Review of all available documentation pertaining to the DYNFLOW and DYNTRACK computer codes;

(2) Review of modeling theory, the assumptions underlying the models, the equations describing the physics of the real system, the code structures, and the solution techniques;

(3) Review the exercise of example problems of reviewers' computer facilities; and

(4) If allotted time allows, develop additional test problems and run them at reviewer's facilities to test the computer codes and to determine their numerical and physical constraints.

The first three of these elements have been completed and are reported in this document. The fourth element could not be carried out because of time constraints.

The definition of the word *model*, as used in this report, includes the mathematical framework and the computer coding. This definition does not include the simulation of any laboratory or field experiment or field problem.

The standard groundwater model review process as carried out by the International Ground Water Modeling Center (IGWMC) comprises evaluation of the underlying theory, review of the user's manuals, and inspection and testing of the computer code. To carry out a complete review, the Center requires detailed documentation of the model, the computer code for implementation on the Center's computer facilities, and a file with the original test data used for the code's verification.

First, the theory underlying the model is reviewed; that is, its mathematical rigor is assessed and an evaluation is made of the correctness of the description of the modeled processes. Additional criteria include evaluation of the numerical method from an application point of view, with respect to the special rules required for proper utilization of the model (e.g., data assignment according to node-centered or block-centered grid structure, shape of elements, grid size variations, treatment of singularities such as wells, approach to vertical averaging in two-dimensional models, or layered three-dimensional models, and treatment of boundary conditions), and evaluation of

the ease with which the mathematical equations, the solution procedures, and the final results can be physically interpreted.

The documentation is then evaluated through visual inspection, comparison with existing documentation standards and guidelines, and through its use as a guide in operating the relevant code at the IGWMC. Good documentation includes a complete treatment of the equations on which the model is based, of the underlying assumptions, of the boundary conditions that can be incorporated in the model, of the method used to solve the equations, and of the limiting conditions resulting from the chosen method. The documentation must also include a user's manual containing example problems complete with input and output, programmer's instructions, operator's instructions, and a report of the initial verification of the code.

The computer code is then reviewed and tested. In the review, attention is given to the manner in which modern programming principles have been applied with respect to code structure, optimal use of the programming language, and internal documentation. To check for correct coding of theoretical principles and for major programming errors ("bugs") in the code, the code is run using problems for which an analytical solution exists. This stage is also used to evaluate the code sensitivity for grid design for various dominant processes and for a wide selection of parameter values. (Due to time constraints, sensitivity testing was not incorporated into this review.)

Although testing numerical computer codes by comparing results for simplified situations with those of analytical models does not guarantee a fully debugged code, a well-selected set of problems ensures that the code's main program and most of its subroutines, including all of the frequently called ones, are being used in the testing.

To test special features that cannot be handled by simple close-form solutions, as in testing irregular boundary conditions and heterogeneous and anisotropic aquifer properties, hypothetical problems are used. Sensitivity analysis is then applied to determine code characteristics. Finally, data from field sites are used (if available) to validate the model. However, for many types of groundwater models, including three-dimensional solute transport simulation codes (as in DYNTRACK), no such complete set of testing techniques

is currently available. Therefore, to test these three-dimensional solute transport simulation codes, one- and two-dimensional analytical solutions are used.

The code testing by the Center is also used to evaluate the user's guide. Special attention is given during the code testing to the rules and restrictions ("tricks") necessary to operate the code.

General Comments on DYNFLOW and DYNTRACK

The DYNFLOW and DYNTRACK computer codes were reviewed by Paul K.M. van der Heijde, at the IGWMC in Indianapolis. P. Srinivasan of the IGWMC assisted in reviewing the codes and in evaluating their documentation. Additional information regarding the operation of the codes was obtained during a meeting with P.J. Riordan, R.P. Schreiber, and B.M. Harley of the Camp, Dresser and McKee model-developing group at the CDM corporate offices in Boston, Massachusetts, December 4-6, 1984 and during a number of telephone conversations in the period December 1, 1984 through February 15, 1985.

Preliminary reporting to EPA took place by letter of December 10, 1984. Some of the reviewed documents were not received until the last week of November 1984, particularly the DYNTRACK user's manual. Upon his arrival at CDM's offices in Boston, Massachusetts on December 4, 1984, the reviewer was provided with a significantly updated version of the DYNTRACK manual. Also, the last two of the reviewed documents listed on p. 2 were first provided during the meeting with the CDM modelers.

After a preliminary evaluation of the findings was reported on December 10, EPA decided to have a more thorough and independent evaluation of the codes undertaken through implementation and test-running of the codes at IGWMC's computer facilities. This code-testing was performed using the complete set of examples presented in the documentation of the codes. To further check the results of the simulations with analytical solutions, programs developed and implemented at IGWMC were used.

As mentioned earlier, well-documented field data sets are scarce and have not yet been developed for the purpose of testing three-dimensional solute

transport models. Testing of the codes was therefore restricted to the simplified hypothetical problems presented in the sample problem set.

The results of the inspection of the DYNFLOW and DYNTRACK source codes and their documentation and of the evaluation of the run-tests of the codes are presented in this report.

Documents Reviewed

Riordan, P.J., B.M. Harley, and R.P. Schreiber, Three-Dimensional Modeling of Flow and Mass Transport Processes in Groundwater Systems. Proceedings NWWA/IGWMC Conf. on Practical Application of Groundwater Models, Columbus, Ohio, August 15-17, 1984, pp. 112-132.

Camp, Dresser and McKee, Inc., Details of the DYNTRACK model. Appendix D of internal report, 1983.

Riordan, P.J., R.P. Schreiber, and B.M. Harley, Three-Dimensional Modeling of Groundwater Flow. Internal report, Camp, Dresser and McKee, Inc., Boston, Mass., 1983.

DYNFLOW A 3-Dimensional Finite-Element Groundwater Flow Model; Description and User's Manual, Version 3.0, (draft), Camp, Dresser and McKee, Inc., Boston, Mass., Nov. 1984.

DYNTRACK, A 3-Dimensional Contaminant Transport Model for Groundwater Studies: Description and User's Manual, Version 1.0 (draft), Camp, Dresser and McKee, Inc., Boston, Mass. November 1984.

Code listings of DYNFLOW and DYNTRACK

Code listing of analytical solutions used to verify the DYNTRACK code

Computer log of test problems for DYNFLOW and DYNTRACK including test data and complete listing of results

DYNFLOW

Description

DYNFLOW is a Galerkin finite-element model for simulation of three-dimensional groundwater flow in saturated porous media. The code uses one-dimensional, planar two-dimensional, and three-dimensional linear elements. The model solves both linear (confined) and nonlinear (phreatic) groundwater flow equations in terms of piezometric head, and it can accommodate changing aquifer conditions during simulation. The code includes options to simulate a hydraulic connection with a stream, dewatering schemes, the effect of ponding, and seepage surfaces. Through use of the model's restart capability, various changes in parameter values, boundary conditions, and stresses can be evaluated during a simulation. The equations are solved by Gaussian elimination or by a block or out-of-core solver.

Evaluation

Computer Code

The DYNFLOW code is based on a well-established quasi-three-dimensional groundwater flow code, AQUIFEM-N. This widely used code is based on a reliable and theoretically well-developed technique. Because of its many options such as the use of various types of elements and its restart capability, the code is quite versatile. To apply the DYNFLOW code to complex problems, a modeler must be familiar with all of DYNFLOW's characteristics and application rules. The application of the current version is somewhat restricted by the limited number of layers in which the vertical dimension can be divided (a maximum of nine layers are hard-wired into the code). However, it is rather simple to modify the code to handle larger problems.

The structure of DYNFLOW is logical and rather efficient. The use of specially defined commands facilitates both interactive program execution and user-friendly updates of data items, simulation parameters, and input-output controls.

The DYNFLOW code is written using modern structured programming principles. All sections of the code are explained internally by COMMENT statements, e.g., the allocation of storage space, the assignment of upper bounds of variables, and the listing of I/O file information. The extensive use of indentation facilitates easy comprehension of the code's segmented structure. There is no apparant misuse of IF/GOTO statements. Except for a few places, the constants are not hard-wired in the subroutines.

The use of ENCODE/DECODE, for processing of the code commands, limits the code to ANSI FORTRAN-77 or extended FORTRAN-66.

The code contains many WRITE statements to log errors and warnings during a run, which is considered good programming practice. Separate I/O files are used to store head, permeability, grid data, etc., a useful adjunct to pre- and postprocessing. Because subroutines are not documented internally and independently, an understanding of previous sections of the code is necessary at all points.

A program of this size should have documentation of its structure, including description of the variables, to assist the user in understanding the workings of the program. This documentation is lacking.

The code has been applied frequently by CDM in recent years. The experience obtained in applying the code has contributed to improvements, updates, and modifications. The final result is a dependable and versatile code, well-suited for use by experienced modelers in the analysis of various groundwater flow problems.

During testing the code performed without problems. CDM provided the reviewer with a complete set of input data and computed results for the given test problems. The data sets provided by CDM were inspected to check the representation of the analytical model. No major differences between the specifications of the test problems and the data used in DYNFLOW were found. The test data were used to run the DYNFLOW code on the reviewer's in-house computer system (DEC Microvax-1). The results of these computations were compared with those provided by CDM and with pertinent analytical solutions. Using the original data set, the reviewer was able to produce the same results

as obtained by the authors. The comparison with analytical solutions was good. However, this analysis showed the need for a thorough understanding of the code's operational characteristics in interpreting computational results. It should be noted that the ponding subroutine has not been tested by the reviewer. Further evaluation of this routine is needed.

Documentation

A complete statement of the objectives of the model must include the basic flow equation and its underlying assumptions. Also necessary is more extensive referencing regarding the derivation of equations, the definition of elements and boundary conditions, and the discussion of the equation solution methods.

The description of the code elements and the definition of the variables (section 3) is too brief. The code structure, especially, needs more in-depth treatment. The interactive commands for running the code and the explanation of individual commands (e.g., reference manual) are detailed and well-written.

The application section should be expanded to contain instructions on grid design, parameter selection, boundary conditions, the use of special elements, calibration techniques, sensitivity analysis, restart capability, and so forth. Such an extension is necessary because many of the situations which can be simulated by the code require instructions on how to combine its advanced features.

Currently lacking in the documentation are the complete input data sets and listings of the results for the given tests. This information is essential to evaluate the author's claims with respect to accuracy of the program. In addition, without such information the user is unable to verify the proper implementation of the code on the user's computer system.

DYNTRACK

Description

DYNTRACK is a computer model for the simulation of three-dimensional solute transport in saturated groundwater systems. The model has two modes of

operation. In the first, or particle tracking mode, it computes the path of a single, conservative particle undergoing advective transport. In the second mode, the model employs the random walk technique to simulate three-dimensional advective–dispersive transport. In this mode, first-order decay and linear adsorption isotherms can be accounted for. The random walk method solves the transport equation indirectly through simulation of an analogous process, tracing the paths of a statistically significant number of particles, each with a predefined mass of the chemical constituent involved. The result of the computations is a distribution of particles and thus of solute mass. The dependent variable in the transport equation (concentration) is then calculated by dividing the total particle mass in a certain volume by the water volume of that total volume. In DYNTRACK the total volume is a volume assigned to each node.

To displace the particles advectively, the velocities in the flow field must be known. In the DYNTRACK code these velocities are generally derived from the nodal heads computed by the DYNFLOW code. Because of this link between the DYNFLOW and the DYNTRACK codes, the computations in the DYNTRACK code generally take place on the same element grid base as in the DYNFLOW code. Also, due to this link, the velocity across an element boundary is discontinuous in the DYNTRACK code.

The displacement of particles moving through more than one element during a certain timestep is not corrected for changing velocity when the particles leave the element where their displacement originated. To prevent cumulative inaccuracies, the code checks for each timestep if at the end of that timestep the particle is in one of the neighboring elements. If the particle is not in this area, the code displays a "particle lost" message and a smaller timestep must be chosen. This feature is also designed to assure conservation of mass in the model.

This approach to displacement accuracy checking is combined with a routine for the simulation of particles bouncing back from a no-flow boundary. It is an efficient routine directly related to the required accuracy for that location through linking to the element configuration (for high accuracy small elements should be used). Although this feature is included in the code, it is not documented in the manuals.

Through use of a retardation factor, the code can handle adsorption. In the code this is an element property. To account for the loss of mass in the liquid phase, the code corrects the calculated concentrations by dividing by the retardation coefficient, resulting in an increase of the apparent volume.

The approximation of adsorptive processes by a retardation coefficient is currently the most widely used approach to incorporate the effects of adsorption into solute transport models. However, desorption cannot be handled by this approach and calls for a more complex representation of the matrix–liquid interactions. The DYNTRACK code does not allow for desorption.

The code can also handle first-order decay. However, this is considered a global property and cannot be assigned to the individual elements.

Fluid density differences resulting from variations in solute concentration are assumed negligible and are therefore not incorporated.

Evaluation

Computer Code

By taking an analogue approach to solving the transport equation, the random walk method distinguishes itself from other numerical methods. Consequently, its strengths and weaknesses differ from the more established finite-difference method and finite-element method, and from the method of characteristics. The strength of the random walk method lies in the analogy used to represent the transport processes. This physically based analogy can be used to analyze the pathways for the solute movement. In addition, the stochastically based random walk representation of dispersion is a generally accepted way of describing this complex phenomenon. The weaknesses of the method are primarly those intrinsic to the use of an analogy and to the discrete nature of the particle mass. Because of the discrete nature of the particles and the application of stochastic principles, a large number of particles is needed to obtain an accurate solute mass distribution. However, no guidelines can be derived for the minimum number of particles theoretically necessary to achieve a certain accuracy. The analogous approach resulting in a solute mass distribution forces the user to interpret the results at the end

of the simulation in terms of concentrations. Various approaches are possible to map the particle mass over each volume element and convert it into a concentration distribution. The approach adopted for the DYNTRACK code results in irregularly patterned concentration distributions. The developers of the DYNTRACK code have therefore added optional routines to smooth the results. However, such techniques might lead to a loss of information in the final results.

For a modeled system in which significant dispersion occurs, back-scatter (negative or upstream random displacement) can cause problems in models based on the random walk method, especially in areas near the solute sources. Also, the use of a finite number of particles can be the cause of scatter in the results.

Finally, the random walk method is not suited for simulation of transport of pollutants from extensive nonpoint sources relative to the scale of modeling. That is, contaminant sources should not exceed an area of a few elements or nodes; otherwise an excessive number of particles would be needed to achieve reasonable accuracy. Therefore, only simulation of distributed sources of limited areal extent can be handled.

The theoretical treatment of the optional nonconservative processes (adsorption and first-order decay) is in accordance with current theory.[1] Further testing of these optional features has not been performed.

Like the DYNFLOW code, DYNTRACK is written using modern structured programming principles. It is internally well "commented." Its flexibility is obtained through use of a set of specially defined commands comparable with DYNFLOW. Extensive use of error messages and debug options makes the code dependable and facilitates its efficient use. Remarks made regarding the programming of the DYNFLOW code also apply to the DYNTRACK code. The built-in random number generator simplifies code transfer to various host computers.

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[1]Bear, J. (1979). *Hydraulics of Groundwater.* McGraw-Hill, New York, NY, pp. 239–243.

In the testing performed at IGWMC, the code was able, after modification of some of the data sets provided to make them correspond to the input format of the latest version of the code, to simulate various simplified problems accurately. These tests focused on the simulation of advective and dispersive transport processes and showed that the particle tracking routines and the mass-concentration conversions were properly programmed. The analytical solutions used in these test problems were independently programmed and implemented at IGWMC, except for the one in case V.

The six tests performed independently by the reviewer cover four cases presented by the authors of DYNTRACK in the code's documentation. These tests are:

(1) :CDM case I— Convection and dispersion in one dimension
Contaminant slug transport (SLUG1D-data)

(2) :CDM case II(a)— Convection and dispersion in two dimensions
Slug source (SLUG2D-data)

(3) :CDM case II(b)— Convection and dispersion in two dimensions
Continuous source (CONT2D-data)

(4) :CDM case III— Convection and dispersion in three dimensions
Slug source (SLUG3D-data)

(5) :CDM case V(a)— Two-well pulse test
Orthogonal grid (DOUB1T-data)

(6) :CDM case V(b)— Two-well pulse test
Bipolar grid (DOUBL3-data)

The tests (1) through (4) were carried out using the "SOLUTE" package of analytical solution developed at IGWMC. The results of the analytical simulations were compared with the results the reviewer obtained from the DYNTRACK runs on the IGWMC computer system (see appendix).

Tests (5) and (6) were carried out by reviewing the theory as documented by Gelhar[2] and comparing it with the results provided by CDM as well as with the reviewer's own DYNTRACK simulations (see appendix). These last two tests clearly demonstrate inaccuracies and instabilities which might occur in simulation of extreme hydraulic situations. It is not clear whether these instabilities are a result of the method (e.g., random noise at low concentrations), or a result of grid design (limitation on directions of release of contaminants from source). The case with the octagonal grid (5) shows a close fit between theoretical and numerical results. This is clearly less the case with the orthogonal grid. The shift between values computed at IGWMC and at CDM is probably the result of differences in data sets used.

During the testing it became apparent that proficiency with the theoretical concepts and the structure of the code is prerequisite for a correct representation of the simulated problems in the code's data sets. Thorough understanding of the analogous character of the modeling method used in DYNTRACK is necessary for optimal use of the various options of the code and for adequate interpretation of the simulation results.

Documentation

The latest version of the DYNTRACK documentation contains much of the information necessary to understand the principles on which the model is based. It also contains extensive user's instructions regarding the input data for the computer code. However, the section describing the computer code itself is brief. Because the computer code is not included in the documentation, evaluation of the code structure is not possible. Additional flowcharts and an extended discussion of the subroutines, including the pre- and postsimulation processors, are necessary for such an evaluation.

The verification tests provided in the code documentation are incomplete; little mention is made as to how, or from where, analytical solutions have been obtained, nor does the manual explain how the tests were performed. In some of the test cases, smoothing (moving average, contouring) has been used

[2]Gelhar, L. (1982). Analysis of two-well tracer tests with a pulse input. RWH-BW-CR-1318, Rockwell International, Hanford, WA.

to represent the results. The effect of such techniques on the accuracy of the results has not been reported by the DYNTRACK authors.

The application sections (modeling strategies and examples) in the user's manual were not included in the version reviewed. Such sections should contain instructions on how to design grids, how to introduce particles, how many particles should be used, how to incorporate boundary conditions (concentrations, solute fluxes), and so forth, and should discuss the relationship between grid design and model accuracy.

APPENDIX

DYNTRACK Test Runs

The results of the DYNTRACK test runs are presented without smoothing or averaging, except in those cases where vertical averaging is mandatory (one- and two-dimensional cases). The test runs were performed using 2,000 particles. Improvement in accuracies is expected when using a larger number of particles (e.g., 10,000).

```
**************************************************
*                                                *
*    ONE-DIMENSIONAL SOLUTE TRANSPORT EQUATION   *
*    INSTANTANEUS POINT SOURCE                   *
*                                                *
*    MODEL: SLUG1D.BAS                           *
*                                                *
**************************************************
```

USER: P.K.M. van der Heijde

LOCATION: IGWMC Indianapolis

DATE: February 10, 1985

INPUT DATA:

TOTAL MASS INJECTED.....:	25.00	kg
DARCY VELOCITY.....:	0.25	m/d
EFFECTIVE POROSITY.....:	.25	
LONGITUDINAL DISPERSIVITY.....:	0.30	m
DECAY CONSTANT (lambda).....:	0.00	1/d
DISTANCE INCREMENT DELX.....:	1.00	m
NUMBER OF DISTANCE INCREMENTS.....:	19	
INITIAL TIME.....:	4.00	d
TIME INCREMENT DELT.....:	4.00	d
NUMBER OF TIME INCREMENTS.....:	1	

********** RESULTS **********

+------> distance X CONCENTRATION in mg/l (ppm)
|
v time

	source 0.00 m	1.00 m	2.00 m	3.00 m	4.00 m
4.00 d	0.9187	3.9491	11.1916	20.9087	25.7516
8.00 d	0.0232	0.1106	0.4282	1.3468	3.4393

	5.00 m	6.00 m	7.00 m	8.00 m	9.00 m
4.00 d	20.9087	11.1916	3.9491	0.9187	0.1409
8.00 d	7.1308	12.0042	16.4078	18.2091	16.4078

	10.00 m	11.00 m	12.00 m	13.00 m	14.00 m
4.00 d	0.0142	0.0009	0.0000	0.0000	0.0000
8.00 d	12.0042	7.1308	3.4393	1.3468	0.4282

	15.00 m	16.00 m	17.00 m	18.00 m	19.00 m
4.00 d	0.0000	0.0000	0.0000	0.0000	0.0000
8.00 d	0.1106	0.0232	0.0039	0.0005	0.0000

DYNTRACK mass per particle .0125

	0.00 m	1.00 m	2.00 m	3.00 m	4.00 m
4 d	0.900	4.650	11.400	20.000	25.750
8 d	—	0.050	0.150	1.300	4.200

	5.00 m	6.00 m	7.00 m	8.00 m	9.00 m
4 d	20.700	11.350	3.850	1.100	0.200
8 d	7.400	12.100	16.950	17.450	16.700

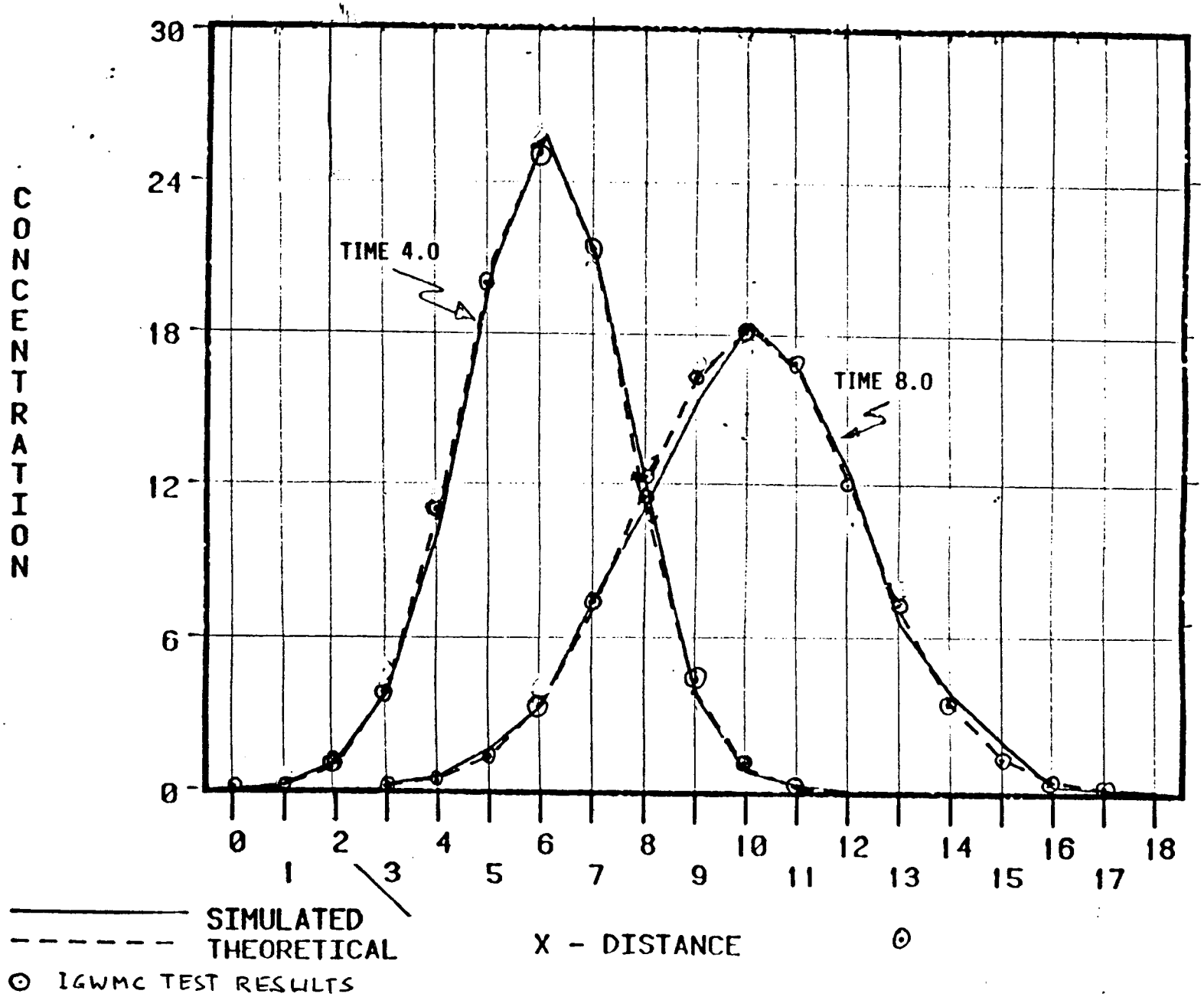


FIGURE 5.1

SLUG1D Data

ONE DIMENSIONAL DISPERSION TEST

SLUG2D data

```
**********************************************************
*                                                        *
*  SLUG INJECTION IN TWO-DIMENSIONAL UNIFORM FLOW        *
*                                                        *
*  MODEL: SLUG.BAS                                       *
*                                                        *
**********************************************************
```

USER: P.K.M. van der Heijde

LOCATION: IGWMC Indianapolis

DATE: February 10, 1985

INPUT DATA:

TOTAL SOLUTE MASS INJECTED.....:	25.00	kg
DARCY VELOCITY.....:	0.25	m/d
EFFECTIVE POROSITY.....:	.25	
LONGITUDINAL DISPERSIVITY.....:	0.30	m
LATERAL DISPERSIVITY.....:	0.10	m
AQUIFER THICKNESS.....:	1.00	m
X-COORDINATE OF THE GRID ORIGIN.....:	0.00	m
Y-COORDINATE OF THE GRID ORIGIN.....:	0.00	m
DISTANCE INCREMENT DELX.....:	1.00	m
DISTANCE INCREMENT DELY.....:	1.00	m
NUMBER OF NODES IN X-DIRECTION.....:	10	
NUMBER OF NODES IN Y-DIRECTION.....:	5	
TIME.....:	4.00	d

SLUGZ5 data

********** RESULTS **********

source (0,0)

⊕-------> X-direction CONCENTRATION in mg/l (ppm)

!

v Y

		0.00 m	1.00 m	2.00 m	3.00 m	4.00 m
0.00	m	409.7524	1761.4380	4991.8030	9325.9140	11486.0200
1.00	m	219.3248	942.8299	2671.9190	4991.8010	6148.0280
2.00	m	33.6345	144.5876	409.7523	765.5178	942.8304
3.00	m	1.4778	6.3527	18.0033	33.6345	41.4251
4.00	m	0.0186	0.0800	0.2266	0.4234	0.5215

		5.00 m	6.00 m	7.00 m	8.00 m	9.00 m
0.00	m	9325.9210	4991.8030	1761.4390	409.7524	62.8377
1.00	m	4991.8020	2671.9200	942.8294	219.3248	33.6346
2.00	m	765.5181	409.7525	144.5876	33.6345	5.1580
3.00	m	33.6345	18.0032	6.3527	1.4778	0.2266
4.00	m	0.4234	0.2266	0.0800	0.0186	0.0029

Results from DYNTRACK are kg/m^3 → factor 1000 compared with mg/l. The source is in x=2, y=5. Particle mass: 0.0125

coordinates		concentration			corrected coordinates		
x	y	level 1	level 2	average	X_o	Y_o	node
6	8	0.1	0	.05	4	3	4
6	7	1.8	1.0	1.4	4	2	7
6	6	6.2	6.1	6.15	4	1	91
6	5	10.8	9.4	10.1	4	0	112
7	5	8.6	7.3	7.95	5	0	113
8	5	6.1	6.1	6.1	6	0	114
9	5	1.4	1.8	1.6	7	0	115
10	5	0.3	0.4	0.35	8	0	116

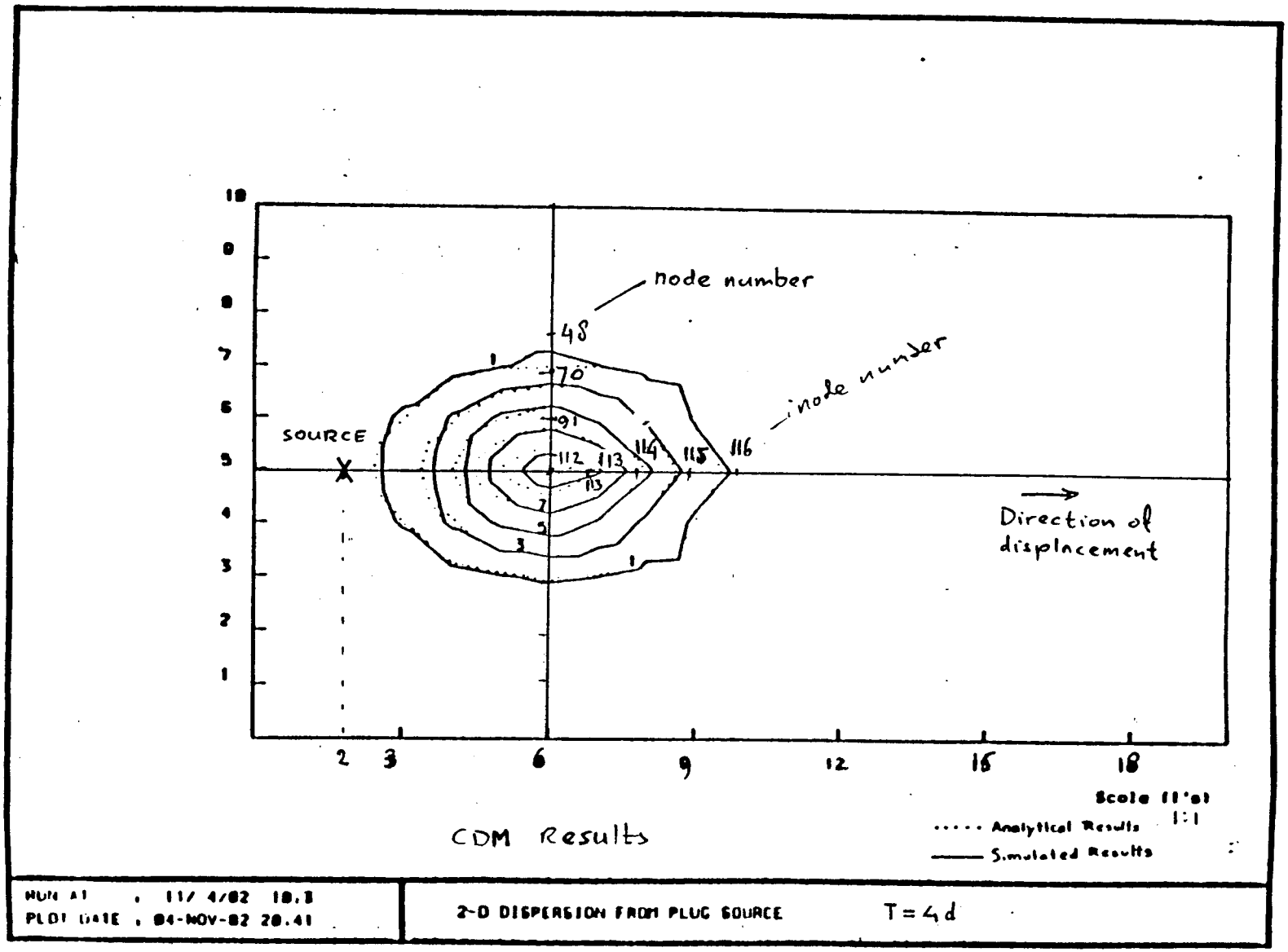


FIGURE 5.2

SLUG2D data

```
**********************************************************
*                                                        *
*  SLUG INJECTION IN TWO-DIMENSIONAL UNIFORM FLOW        *
*                                                        *
*  MODEL: SLUG.BAS                                       *
*                                                        *
**********************************************************
```

USER: P.K.M. van der Heijde

LOCATION: IGWMC Indianapolis

DATE: February 10, 1985

INPUT DATA:

TOTAL SOLUTE MASS INJECTED	25.00	kg
DARCY VELOCITY	0.25	m/d
EFFECTIVE POROSITY	.25	
LONGITUDINAL DISPERSIVITY	0.30	m
LATERAL DISPERSIVITY	0.10	m
AQUIFER THICKNESS	1.00	m
X-COORDINATE OF THE GRID ORIGIN	0.00	m
Y-COORDINATE OF THE GRID ORIGIN	0.00	m
DISTANCE INCREMENT DELX	1.00	m
DISTANCE INCREMENT DELY	1.00	m
NUMBER OF NODES IN X-DIRECTION	10	
NUMBER OF NODES IN Y-DIRECTION	5	
TIME	8.00	d

********** RESULTS **********

Source (0,0)

⊕------> X-direction CONCENTRATION in mg/l (ppm)

!

v Y

	0.00 m	1.00 m	2.00 m	3.00 m	4.00 m
0.00 m	7.3083	34.8681	135.0626	424.7803	1084.7150
1.00 m	5.3472	25.5100	98.8139	310.7757	793.5943
2.00 m	2.0940	9.9899	38.6961	121.7016	310.7760
3.00 m	0.4389	2.0940	8.1112	25.5100	65.1421
4.00 m	0.0492	0.2349	0.9100	2.8622	7.3088

	5.00 m	6.00 m	7.00 m	8.00 m	9.00 m
0.00 m	2248.9950	3786.0220	5174.8870	5743.0110	5174.8870
1.00 m	1645.4000	2769.9140	3786.0210	4201.6820	3786.0230
2.00 m	644.3478	1084.7160	1482.6280	1645.4000	1482.6280
3.00 m	135.0624	227.3683	310.7758	344.8951	310.7755
4.00 m	15.1536	25.5100	34.8681	38.6961	34.8681

Results from DYNTRACK are kg/m³ → factor 1000 compared with mg/l

DYNTRACK: source in X=2, Y=5 ; particle mass : 0.0125

coord. x	coord. y	corrected coordinates x_o	corrected coordinates y_o	node #	concentration level 1	concentration level 2	concentration average
6	8	4	3	49	—	—	—
6	7	4	2	70	0.4	0.5	0.45
6	6	4	1	91	1.0	0.9	0.95
6	5	4	0	112	1.2	1.4	1.1
7	5	5	0	113	3.0	1.6	2.3
8	5	6	0	114	2.6	4.1	3.35
9	5	7	0	115	4.8	5.1	4.95
10	5	8	0	116	5.1	5.6	5.35

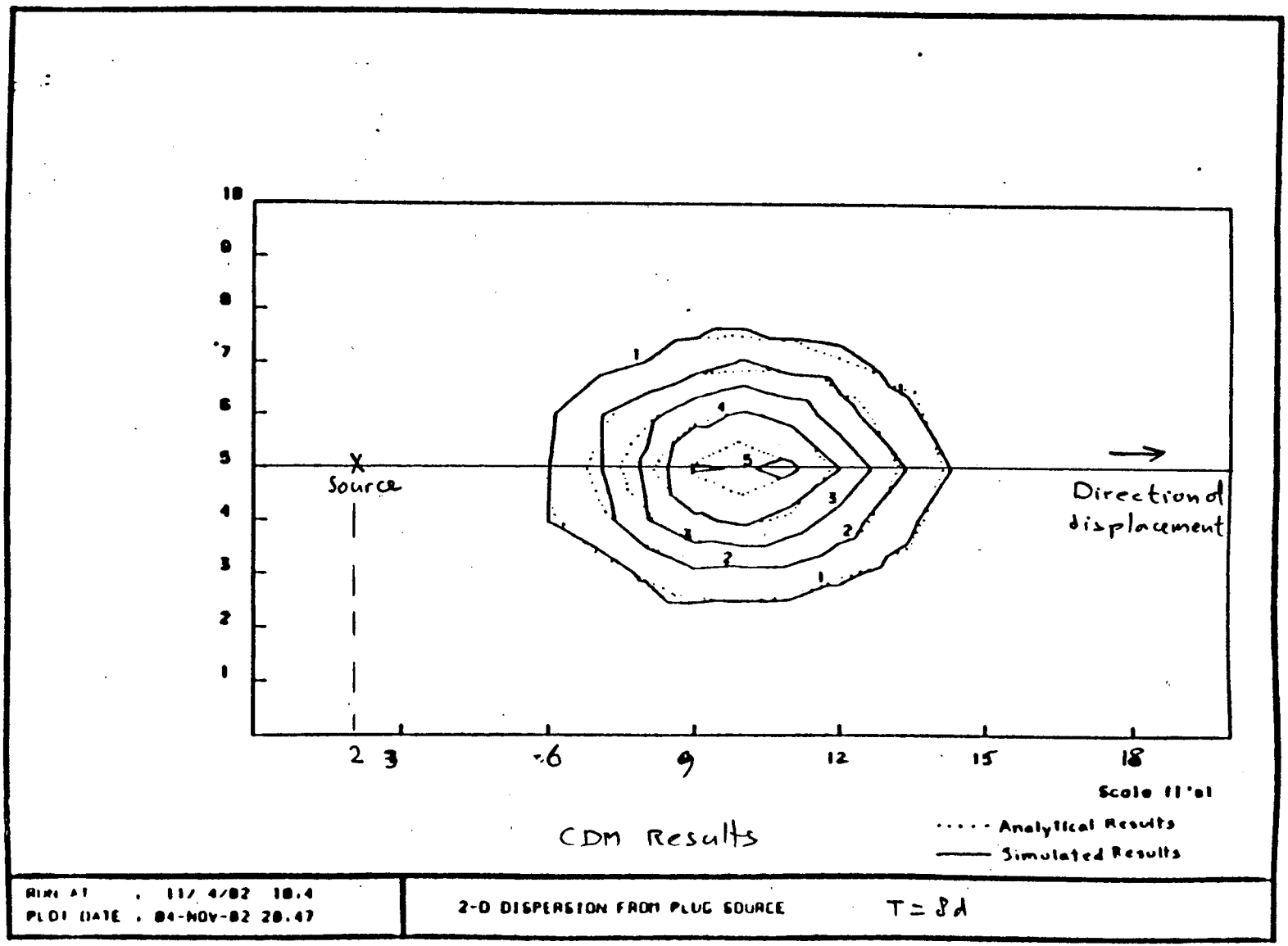


FIGURE 5.3 SLUG2D data

CONT2D data

```
**************************************************
*                                                *
*    SOLUTE TRANSPORT FROM POINT SOURCES         *
*    IN TWO-DIMENSIONAL UNIFORM FLOW             *
*                                                *
*    MODEL: WMPLUME                              *
*                                                *
**************************************************
```

USER: P.K.M. van der Heijde

LOCATION: IGWMC Indianapolis

DATE: February 10, 1985

INPUT DATA:

DARCY VELOCITY	0.25	m/d
EFFECTIVE POROSITY	.25	
AQUIFER THICKNESS	1.00	m
LONGITUDINAL DISPERSIVITY	0.30	m
LATERAL DISPERSIVITY	0.10	m
RETARDATION FACTOR	1.00	
DECAY CONSTANT (lambda)	0	1/d
NUMBER OF POINT SOURCES	1	

SOURCE DATA:

SOURCE NO. 1

X-COORDINATE OF THE SOURCE	0.00	m
Y-COORDINATE OF THE SOURCE	0.00	m
THE SOURCE STRENGTH	2.50	kg/d
ELAPSED TIME OF THE SOURCE ACTIVITY	20.00	d

GRID DATA:

X-COORDINATE OF THE GRID ORIGIN	0.00	m
Y-COORDINATE OF THE GRID ORIGIN	0.00	m
DISTANCE INCREMENT DELX	1.00	m
DISTANCE INCREMENT DELY	1.00	m
NUMBER OF NODES IN X-DIRECTION	20	
NUMBER OF NODES IN Y-DIRECTION	5	

CONT2D data

********** RESULTS **********

source ------> X-direction CONCENTRATION in mg/l (ppm)

v Y

	0.00 m	1.00 m	2.00 m	3.00 m	4.00 m
0.00 m	-1.0000	8920.6210	6307.8320	5150.3210	4460.3020
1.00 m	377.9327	1191.3950	1869.4350	2211.4210	2349.2310
2.00 m	14.9004	61.0869	159.1168	298.0794	450.5890
3.00 m	0.6783	3.0360	9.8881	24.5378	49.0761
4.00 m	0.0328	0.1531	0.5616	1.6523	4.0127
DYNTRACK					
0.00 m	.3	7.4	4.7	4.6	3.8
2.00 m		.2	.3	.4	.5
	5.00 m	6.00 m	7.00 m	8.00 m	9.00 m
0.00 m	3989.3930	3641.7310	3371.3820	3153.0770	2971.3160
1.00 m	2385.6380	2372.8940	2336.3850	2288.6190	2235.6370
2.00 m	595.1167	721.4293	826.9710	912.8252	981.2449
3.00 m	83.3483	125.3780	172.4102	221.7358	271.0492
4.00 m	8.3009	15.0636	24.5977	36.8998	51.6842
DYNTRACK					
0.00 m	4.3	4.1	2.3	4.3	2.9
2.00 m	.9	.9	.7	.7	.7
	10.00 m	11.00 m	12.00 m	13.00 m	14.00 m
0.00 m	2815.4580	2677.0610	2548.2240	2420.5600	2284.8790
1.00 m	2179.9460	2121.5580	2058.4130	1986.3950	1899.6690
2.00 m	1034.3600	1073.4660	1098.6120	1108.3440	1099.8020
3.00 m	318.4551	362.2535	400.6633	431.5586	452.3850
4.00 m	68.4209	86.3511	104.4720	121.5115	135.9409
DYNTRACK					
0.00 m	3.0	1.9	1.7	3.0	2.0
2.00 m	1.4	1.0	1.5	1.3	.8
	15.00 m	16.00 m	17.00 m	18.00 m	19.00 m
0.00 m	2131.7970	1953.3780	1745.4840	1509.9860	1255.7210
1.00 m	1791.5130	1656.0330	1490.3350	1296.6700	1083.2890
2.00 m	1069.2850	1013.4140	930.7179	823.1512	696.8230
3.00 m	460.3555	453.0024	429.0032	388.9927	335.9920
4.00 m	146.0920	150.4159	147.8525	138.2073	122.3755
DYNTRACK					
0.00 m	2.5	1.2	1.5	0.9	1
2.00 m	1.5	1.0	1.4	.8	

Particle mass .0125

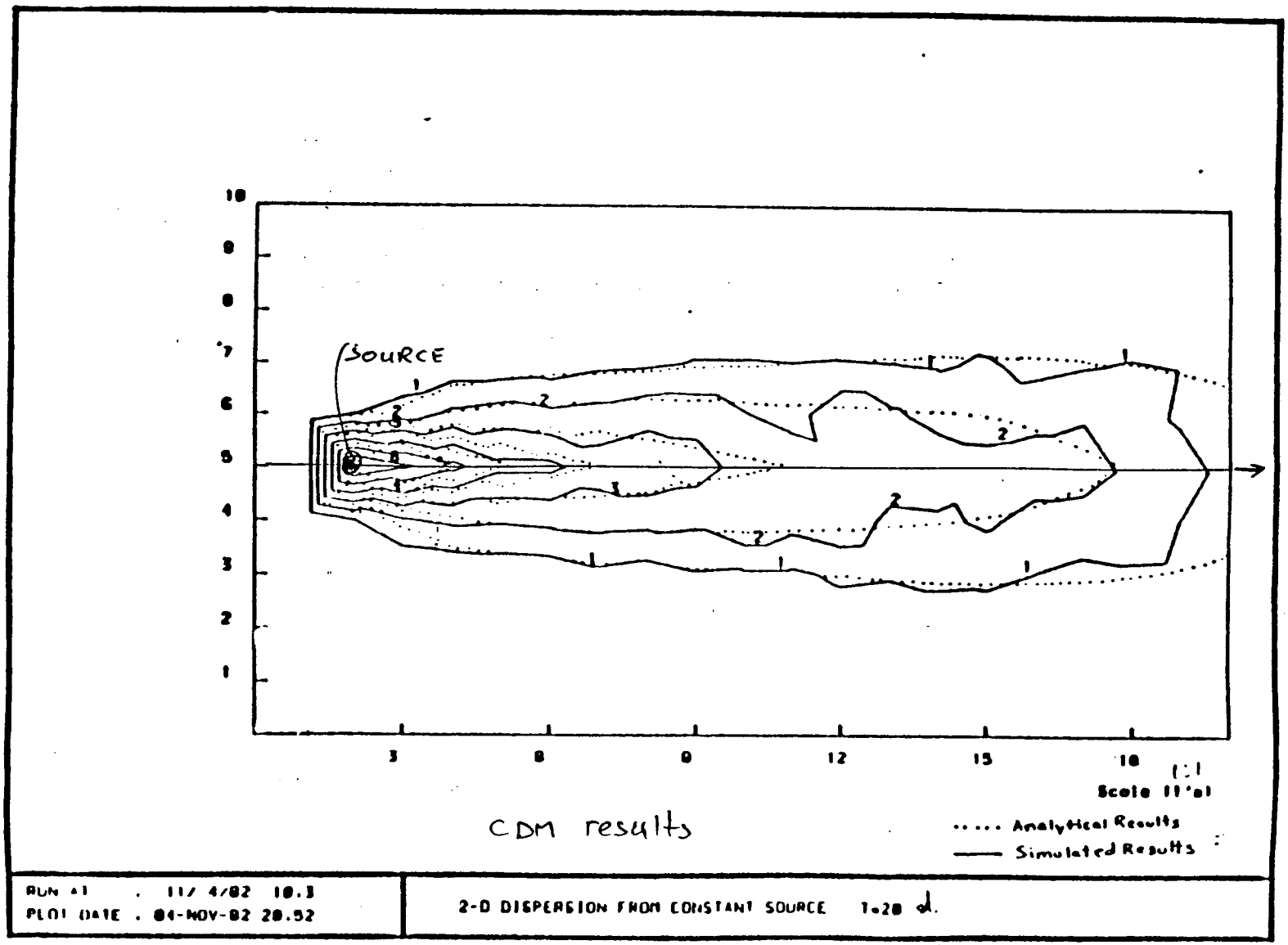


FIGURE 5.4

CONT2D data

SLUG3D data

```
**********************************************************
*                                                        *
*  SLUG INJECTION IN THREE-DIMENSIONAL UNIFORM FLOW      *
*                                                        *
*  MODEL: SLUG3D.BAS                                     *
*                                                        *
**********************************************************
```

USER: P.K.M. van der Heijde

LOCATION: IGWMC Indianapolis

DATE: February 10, 1985

INPUT DATA:

TOTAL SOLUTE MASS INJECTED	25.00	kg
DARCY VELOCITY	0.25	m/d
EFFECTIVE POROSITY	.25	
LONGITUDINAL DISPERSIVITY	0.30	m
LATERAL DISPERSIVITY	0.10	m
VERTICAL DISPERSIVITY	0.03	m
DECAY CONSTANT (lambda)	0	1/d
DISTANCE INCREMENT DELX	1.00	m
DISTANCE INCREMENT DELY	1.00	m
DISTANCE INCREMENT DELZ	1.00	m
NUMBER OF NODES IN X-DIRECTION	15	
NUMBER OF NODES IN Y-DIRECTION	6	
NUMBER OF NODES IN Z-DIRECTION	5	
TIME	8.00	d

********** RESULTS **********

+------> X-direction CONCENTRATION in mg/l (ppm) SOURCE IN [0,0,0]
|
v Y

Z = 0 m

		0.00 m	1.00 m	2.00 m	3.00 m	4.00 m
0.00	m	4.6102	21.9942	85.1953	267.9443	684.2196
1.00	m	3.3729	16.0913	62.3302	196.0322	500.5857
2.00	m	1.3209	6.3014	24.4088	76.7673	196.0322
3.00	m	0.2769	1.3209	5.1164	16.0913	41.0906
4.00	m	0.0311	0.1482	0.5740	1.8054	4.6102
5.00	m	0.0019	0.0089	0.0345	0.1084	0.2769

		5.00 m	6.00 m	7.00 m	8.00 m	9.00 m
0.00	m	1418.6280	2388.1610	3264.2290	3622.5930	3264.2290
1.00	m	1037.8900	1747.2160	2388.1610	2650.3460	2388.1610
2.00	m	406.4438	684.2196	935.2172	1037.8900	935.2172
3.00	m	85.1952	143.4202	196.0322	217.5537	196.0322
4.00	m	9.5586	16.0913	21.9942	24.4088	21.9942
5.00	m	0.5740	0.9664	1.3209	1.4659	1.3209

		10.00 m	11.00 m	12.00 m	13.00 m	14.00 m
0.00	m	2388.1610	1418.6280	684.2196	267.9443	85.1953
1.00	m	1747.2160	1037.8900	500.5857	196.0322	62.3302
2.00	m	684.2196	406.4438	196.0322	76.7673	24.4088
3.00	m	143.4202	85.1952	41.0906	16.0913	5.1164
4.00	m	16.0913	9.5586	4.6102	1.8054	0.5740
5.00	m	0.9664	0.5740	0.2769	0.1084	0.0345

********** RESULTS **********

+-------> X-direction CONCENTRATION in mg/l (ppm)
|
v Y

Z = 1 m

	0.00 m	1.00 m	2.00 m	3.00 m	4.00 m
0.00 m	1.3209	6.3014	24.4088	76.7673	196.0322
1.00 m	0.9664	4.6102	17.8579	56.1642	143.4202
2.00 m	0.3784	1.8054	6.9933	21.9942	56.1642
3.00 m	0.0793	0.3784	1.4659	4.6102	11.7726
4.00 m	0.0089	0.0425	0.1645	0.5173	1.3209
5.00 m	0.0005	0.0025	0.0099	0.0311	0.0793

	5.00 m	6.00 m	7.00 m	8.00 m	9.00 m
0.00 m	406.4438	684.2196	935.2172	1037.8900	935.2172
1.00 m	297.3606	500.5857	684.2196	759.3368	684.2196
2.00 m	116.4481	196.0322	267.9443	297.3606	267.9443
3.00 m	24.4088	41.0906	56.1641	62.3302	56.1641
4.00 m	2.7386	4.6102	6.3014	6.9933	6.3014
5.00 m	0.1645	0.2769	0.3784	0.4200	0.3784

	10.00 m	11.00 m	12.00 m	13.00 m	14.00 m
0.00 m	684.2196	406.4438	196.0322	76.7673	24.4088
1.00 m	500.5857	297.3606	143.4202	56.1642	17.8579
2.00 m	196.0322	116.4481	56.1642	21.9942	6.9933
3.00 m	41.0906	24.4088	11.7726	4.6102	1.4659
4.00 m	4.6102	2.7386	1.3209	0.5173	0.1645
5.00 m	0.2769	0.1645	0.0793	0.0311	0.0099

********** RESULTS **********

+-------> X-direction CONCENTRATION in mg/l (ppm)
!
v Y

Z = 2 m

	0.00 m	1.00 m	2.00 m	3.00 m	4.00 m
0.00 m	0.0311	0.1482	0.5740	1.8054	4.6102
1.00 m	0.0227	0.1084	0.4200	1.3209	3.3729
2.00 m	0.0089	0.0425	0.1645	0.5173	1.3209
3.00 m	0.0019	0.0089	0.0345	0.1084	0.2769
4.00 m	0.0002	0.0010	0.0039	0.0122	0.0311
5.00 m	0.0000	0.0000	0.0002	0.0007	0.0019

	5.00 m	6.00 m	7.00 m	8.00 m	9.00 m
0.00 m	9.5586	16.0913	21.9942	24.4088	21.9942
1.00 m	6.9933	11.7726	16.0913	17.8579	16.0913
2.00 m	2.7386	4.6102	6.3014	6.9933	6.3014
3.00 m	0.5740	0.9664	1.3209	1.4659	1.3209
4.00 m	0.0644	0.1084	0.1482	0.1645	0.1482
5.00 m	0.0039	0.0065	0.0089	0.0099	0.0089

	10.00 m	11.00 m	12.00 m	13.00 m	14.00 m
0.00 m	16.0913	9.5586	4.6102	1.8054	0.5740
1.00 m	11.7726	6.9933	3.3729	1.3209	0.4200
2.00 m	4.6102	2.7386	1.3209	0.5173	0.1645
3.00 m	0.9664	0.5740	0.2769	0.1084	0.0345
4.00 m	0.1084	0.0644	0.0311	0.0122	0.0039
5.00 m	0.0065	0.0039	0.0019	0.0007	0.0002

********** RESULTS **********

+------> X-direction CONCENTRATION in mg/l (ppm)
|
v Y

Z = 3 m

	0.00 m	1.00 m	2.00 m	3.00 m	4.00 m
0.00 m	0.0000	0.0003	0.0011	0.0035	0.0089
1.00 m	0.0000	0.0002	0.0008	0.0025	0.0065
2.00 m	0.0000	0.0000	0.0003	0.0010	0.0025
3.00 m	0.0000	0.0000	0.0000	0.0002	0.0005
4.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
5.00 m	0.0000	0.0000	0.0000	0.0000	0.0000

	5.00 m	6.00 m	7.00 m	8.00 m	9.00 m
0.00 m	0.0185	0.0311	0.0425	0.0471	0.0425
1.00 m	0.0135	0.0227	0.0311	0.0345	0.0311
2.00 m	0.0053	0.0089	0.0122	0.0135	0.0122
3.00 m	0.0011	0.0019	0.0025	0.0028	0.0025
4.00 m	0.0001	0.0002	0.0003	0.0003	0.0003
5.00 m	0.0000	0.0000	0.0000	0.0000	0.0000

	10.00 m	11.00 m	12.00 m	13.00 m	14.00 m
0.00 m	0.0311	0.0185	0.0089	0.0035	0.0011
1.00 m	0.0227	0.0135	0.0065	0.0025	0.0008
2.00 m	0.0089	0.0053	0.0025	0.0010	0.0003
3.00 m	0.0019	0.0011	0.0005	0.0002	0.0000
4.00 m	0.0002	0.0001	0.0000	0.0000	0.0000
5.00 m	0.0000	0.0000	0.0000	0.0000	0.0000

SLUG3D data

********** RESULTS **********

+-------> X-direction CONCENTRATION in mg/l (ppm)
|
v Y

Z = 4 m

	0.00 m	1.00 m	2.00 m	3.00 m	4.00 m
0.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
1.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
2.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
3.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
4.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
5.00 m	0.0000	0.0000	0.0000	0.0000	0.0000

	5.00 m	6.00 m	7.00 m	8.00 m	9.00 m
0.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
1.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
2.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
3.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
4.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
5.00 m	0.0000	0.0000	0.0000	0.0000	0.0000

	10.00 m	11.00 m	12.00 m	13.00 m	14.00 m
0.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
1.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
2.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
3.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
4.00 m	0.0000	0.0000	0.0000	0.0000	0.0000
5.00 m	0.0000	0.0000	0.0000	0.0000	0.0000

GRID INFORMATION FROM FILE SLUGGB.GRF

NUMBER OF NODES..... 231
NUMBER OF ELEMENTS..... 400
HALF BANDWIDTH PLUS ONE.... 23
LAST ELEMENT WHERE IT OCCURRED (INT./EXT. NOS.).. 360 360

NODE NUMBERS		NODAL COORDINATES	
INT.	EXT.	X	Y
1	1	0.00000000	10.00000000
2	2	1.00000000	10.00000000
3	3	2.00000000	10.00000000
4	4	3.00000000	10.00000000
5	5	4.00000000	10.00000000
6	6	5.00000000	10.00000000
7	7	6.00000000	10.00000000
8	8	7.00000000	10.00000000
9	9	8.00000000	10.00000000
10	10	9.00000000	10.00000000
11	11	10.0000000	10.00000000
12	12	11.0000000	10.00000000
13	13	12.0000000	10.00000000
14	14	13.0000000	10.00000000
15	15	14.0000000	10.00000000
16	16	15.0000000	10.00000000
17	17	16.0000000	10.00000000
18	18	17.0000000	10.00000000
19	19	18.0000000	10.00000000
20	20	19.0000000	10.00000000
21	21	20.0000000	10.00000000
22	22	0.00000000	9.00000000
23	23	1.00000000	9.00000000
24	24	2.00000000	9.00000000
25	25	3.00000000	9.00000000
26	26	4.00000000	9.00000000
27	27	5.00000000	9.00000000
28	28	6.00000000	9.00000000
29	29	7.00000000	9.00000000
30	30	8.00000000	9.00000000
31	31	9.00000000	9.00000000
32	32	10.0000000	9.00000000
33	33	11.0000000	9.00000000
34	34	12.0000000	9.00000000
35	35	13.0000000	9.00000000
36	36	14.0000000	9.00000000
37	37	15.0000000	9.00000000
38	38	16.0000000	9.00000000
39	39	17.0000000	9.00000000
40	40	18.0000000	9.00000000
41	41	19.0000000	9.00000000
42	42	20.0000000	9.00000000
43	43	0.00000000	8.00000000
44	44	1.00000000	8.00000000
45	45	2.00000000	8.00000000
46	46	3.00000000	8.00000000
47	47	4.00000000	8.00000000
48	48	5.00000000	8.00000000
49	49	6.00000000	8.00000000
50	50	7.00000000	8.00000000

NODE NUMBERS		NODAL COORDINATES	
INT.	EXT.	X	Y
51	51	8.00000000	3.00000000
52	52	9.00000000	3.00000000
53	53	10.0000000	8.00000000
54	54	11.0000000	8.00000000
55	55	12.0000000	8.00000000
56	56	13.0000000	8.00000000
57	57	14.0000000	8.00000000
58	58	15.0000000	8.00000000
59	59	16.0000000	8.00000000
60	60	17.0000000	8.00000000
61	61	18.0000000	8.00000000
62	62	19.0000000	8.00000000
63	63	20.0000000	8.00000000
64	64	0.00000000	7.00000000
65	65	1.00000000	7.00000000
66	66	2.00000000	7.00000000
67	67	3.00000000	7.00000000
68	68	4.00000000	7.00000000
69	69	5.00000000	7.00000000
70	70	6.00000000	7.00000000
71	71	7.00000000	7.00000000
72	72	8.00000000	7.00000000
73	73	9.00000000	7.00000000
74	74	10.0000000	7.00000000
75	75	11.0000000	7.00000000
76	76	12.0000000	7.00000000
77	77	13.0000000	7.00000000
78	78	14.0000000	7.00000000
79	79	15.0000000	7.00000000
80	80	16.0000000	7.00000000
81	81	17.0000000	7.00000000
82	82	18.0000000	7.00000000
83	83	19.0000000	7.00000000
84	84	20.0000000	7.00000000
85	85	0.00000000	6.00000000
86	86	1.00000000	6.00000000
87	87	2.00000000	6.00000000
88	88	3.00000000	6.00000000
89	89	4.00000000	6.00000000
90	90	5.00000000	6.00000000
91	91	6.00000000	6.00000000
92	92	7.00000000	6.00000000
93	93	8.00000000	6.00000000
94	94	9.00000000	6.00000000
95	95	10.0000000	6.00000000
96	96	11.0000000	6.00000000
97	97	12.0000000	6.00000000
98	98	13.0000000	6.00000000
99	99	14.0000000	6.00000000
100	100	15.0000000	6.00000000

NODE NUMBERS INT.	EXT.	NODAL COORDINATES X	Y
101	101	16.00000000	6.00000000
102	102	17.00000000	6.00000000
103	103	18.00000000	6.00000000
104	104	19.00000000	6.00000000
105	105	20.00000000	6.00000000
106	106	0.00000000	5.00000000
107	107	1.00000000	5.00000000
108	108	2.00000000	5.00000000
109	109	3.00000000	5.00000000
110	110	4.00000000	5.00000000
111	111	5.00000000	5.00000000
112	112	6.00000000	5.00000000
113	113	7.00000000	5.00000000
114	114	8.00000000	5.00000000
115	115	9.00000000	5.00000000
116	116	10.0000000	5.00000000
117	117	11.0000000	5.00000000
118	118	12.0000000	5.00000000
119	119	13.0000000	5.00000000
120	120	14.0000000	5.00000000
121	121	15.0000000	5.00000000
122	122	16.0000000	5.00000000
123	123	17.0000000	5.00000000
124	124	18.0000000	5.00000000
125	125	19.0000000	5.00000000
126	126	20.0000000	5.00000000
127	127	0.00000000	4.00000000
128	128	1.00000000	4.00000000
129	129	2.00000000	4.00000000
130	130	3.00000000	4.00000000
131	131	4.00000000	4.00000000
132	132	5.00000000	4.00000000
133	133	6.00000000	4.00000000
134	134	7.00000000	4.00000000
135	135	8.00000000	4.00000000
136	136	9.00000000	4.00000000
137	137	10.0000000	4.00000000
138	138	11.0000000	4.00000000
139	139	12.0000000	4.00000000
140	140	13.0000000	4.00000000
141	141	14.0000000	4.00000000
142	142	15.0000000	4.00000000
143	143	16.0000000	4.00000000
144	144	17.0000000	4.00000000
145	145	18.0000000	4.00000000
146	146	19.0000000	4.00000000
147	147	20.0000000	4.00000000
148	148	0.00000000	3.00000000
149	149	1.00000000	3.00000000
150	150	2.00000000	3.00000000

NODE NUMBERS		NODAL COORDINATES	
INT.	EXT.	X	Y
151	151	3.00000000	3.00000000
152	152	4.00000000	3.00000000
153	153	5.00000000	3.00000000
154	154	6.00000000	3.00000000
155	155	7.00000000	3.00000000
156	156	8.00000000	3.00000000
157	157	9.00000000	3.00000000
158	158	10.0000000	3.00000000
159	159	11.0000000	3.00000000
160	160	12.0000000	3.00000000
161	161	13.0000000	3.00000000
162	162	14.0000000	3.00000000
163	163	15.0000000	3.00000000
164	164	16.0000000	3.00000000
165	165	17.0000000	3.00000000
166	166	18.0000000	3.00000000
167	167	19.0000000	3.00000000
168	168	20.0000000	3.00000000
169	169	0.00000000	2.00000000
170	170	1.00000000	2.00000000
171	171	2.00000000	2.00000000
172	172	3.00000000	2.00000000
173	173	4.00000000	2.00000000
174	174	5.00000000	2.00000000
175	175	6.00000000	2.00000000
176	176	7.00000000	2.00000000
177	177	8.00000000	2.00000000
178	178	9.00000000	2.00000000
179	179	10.0000000	2.00000000
180	180	11.0000000	2.00000000
181	181	12.0000000	2.00000000
182	182	13.0000000	2.00000000
183	183	14.0000000	2.00000000
184	184	15.0000000	2.00000000
185	185	16.0000000	2.00000000
186	186	17.0000000	2.00000000
187	187	18.0000000	2.00000000
188	188	19.0000000	2.00000000
189	189	20.0000000	2.00000000
190	190	0.00000000	1.00000000
191	191	1.00000000	1.00000000
192	192	2.00000000	1.00000000
193	193	3.00000000	1.00000000
194	194	4.00000000	1.00000000
195	195	5.00000000	1.00000000
196	196	6.00000000	1.00000000
197	197	7.00000000	1.00000000
198	198	8.00000000	1.00000000
199	199	9.00000000	1.00000000
200	200	10.0000000	1.00000000

NODE NUMBERS INT.	EXT.	NODAL COORDINATES X	Y
201	201	11.0000000	1.00000000
202	202	12.0000000	1.00000000
203	203	13.0000000	1.00000000
204	204	14.0000000	1.00000000
205	205	15.0000000	1.00000000
206	206	16.0000000	1.00000000
207	207	17.0000000	1.00000000
208	208	18.0000000	1.00000000
209	209	19.0000000	1.00000000
210	210	20.0000000	1.00000000
211	211	0.00000000	0.000000000E+00
212	212	1.00000000	0.000000000E+00
213	213	2.00000000	0.000000000E+00
214	214	3.00000000	0.000000000E+00
215	215	4.00000000	0.000000000E+00
216	216	5.00000000	0.000000000E+00
217	217	6.00000000	0.000000000E+00
218	218	7.00000000	0.000000000E+00
219	219	8.00000000	0.000000000E+00
220	220	9.00000000	0.000000000E+00
221	221	10.0000000	0.000000000E+00
222	222	11.0000000	0.000000000E+00
223	223	12.0000000	0.000000000E+00
224	224	13.0000000	0.000000000E+00
225	225	14.0000000	0.000000000E+00
226	226	15.0000000	0.000000000E+00
227	227	16.0000000	0.000000000E+00
228	228	17.0000000	0.000000000E+00
229	229	18.0000000	0.000000000E+00
230	230	19.0000000	0.000000000E+00
231	231	20.0000000	0.000000000E+00

DYNTRA RUN OF 4/26/85 AT 17:00:07

SLUG3D THREE DIMENSIONAL DISPERSION TEST CASE: 2000 PART.
UNIFORM FLOW FIELD, V=1.0 - INJECTED MASS = 25 AT (2.0,5.0,2.0)
LONG DISP = .3, VERT DISP = .1, AZ/AX FACTOR = .5, EFF POROS = .25

TIME : 8.0000

CONCENTRATIONS

	LEVEL				
NODE	1	2	3	4	5
10	0.0000E+00	0.1000	0.0000E+00	0.0000E+00	0.0000E+00
28	0.0000E+00	0.0000E+00	0.5000E-01	0.0000E+00	0.0000E+00
29	0.0000E+00	0.0000E+00	0.0000E+00	0.5000E-01	0.0000E+00
33	0.0000E+00	0.0000E+00	0.1000	0.0000E+00	0.0000E+00
47	0.0000E+00	0.0000E+00	0.5000E-01	0.0000E+00	0.0000E+00
48	0.0000E+00	0.0000E+00	0.0000E+00	0.5000E-01	0.0000E+00
50	0.0000E+00	0.1500	0.0000E+00	0.0000E+00	0.0000E+00
51	0.0000E+00	0.5000E-01	0.2500	0.5000E-01	0.0000E+00
52	0.0000E+00	0.0000E+00	0.1500	0.0000E+00	0.0000E+00
53	0.0000E+00	0.1000	0.2000	0.1000	0.0000E+00
54	0.0000E+00	0.5000E-01	0.1500	0.0000E+00	0.0000E+00
55	0.1000	0.5000E-01	0.1000	0.5000E-01	0.0000E+00
56	0.0000E+00	0.0000E+00	0.1000	0.5000E-01	0.0000E+00
57	0.0000E+00	0.0000E+00	0.1500	0.0000E+00	0.0000E+00
58	0.0000E+00	0.0000E+00	0.0000E+00	0.1000	0.0000E+00
68	0.0000E+00	0.0000E+00	0.1000	0.0000E+00	0.0000E+00
69	0.0000E+00	0.5000E-01	0.1000E-01	0.0000E+00	0.0000E+00
70	0.0000E+00	0.2500	0.1000	0.1500	0.0000E+00
71	0.0000E+00	0.5000E-01	0.3000	0.1000	0.0000E+00
72	0.0000E+00	0.2500	0.7500	0.3500	0.0000E+00
73	0.1000	0.1500	0.8500	0.5000	0.1000
74	0.0000E+00	0.4000	1.200	0.5000	0.0000E+00
75	0.0000E+00	0.5500	1.100	0.2000	0.0000E+00
76	0.0000E+00	0.1500	0.6500	0.3000	0.0000E+00
77	0.0000E+00	0.2000	0.4500	0.1500	0.0000E+00
78	0.0000E+00	0.5000E-01	0.1000	0.1500	0.0000E+00
79	0.0000E+00	0.1000	0.1000	0.0000E+00	0.0000E+00
80	0.0000E+00	0.5000E-01	0.5000E-01	0.0000E+00	0.0000E+00
81	0.0000E+00	0.5000E-01	0.0000E+00	0.0000E+00	0.0000E+00
89	0.0000E+00	0.0000E+00	0.1000	0.0000E+00	0.0000E+00
90	0.0000E+00	0.0000E+00	0.2500	0.1000	0.0000E+00
91	0.1000	0.2000	0.6500	0.2000	0.0000E+00
92	0.0000E+00	0.3500	1.100	0.4000	0.0000E+00
93	0.1000	0.5500	2.000	0.4500	0.0000E+00
94	0.0000E+00	0.6500	2.350	1.050	0.0000E+00
95	0.2000	0.9000	2.150	0.9000	0.0000E+00
96	0.0000E+00	0.5500	1.800	0.7500	0.2000
97	0.0000E+00	0.5500	1.600	0.5000	0.2000
98	0.2000	0.1000	0.8500	0.3000	0.0000E+00
99	0.0000E+00	0.2000	0.6500	0.2500	0.0000E+00
100	0.0000E+00	0.1000	0.5000E-01	0.5000E-01	0.0000E+00

101	0.0000E+00	0.0000E+00	0.5000E-01	0.0000E+00	0.0000E+00
110	0.0000E+00	0.0000E+00	0.1000	0.5000E-01	0.0000E+00
111	0.0000E+00	0.0000E+00	0.4000	0.1000	0.0000E+00
112	0.0000E+00	0.4500	0.9000	0.5000E-01	0.0000E+00
113	0.0000E+00	0.4500	1.000	0.6000	0.1000
114	0.3000	0.5000	2.800	1.000	0.0000E+00
115	0.0000E+00	1.050	2.550	0.7000	0.0000E+00
116	0.0000E+00	0.2500	2.200	1.300	0.0000E+00
117	0.1000	0.5000	3.450	0.4000	0.0000E+00
118	0.0000E+00	0.3500	2.050	0.2000	0.0000E+00
119	0.0000E+00	0.4500	1.450	0.2500	0.3000E+00
120	0.0000E+00	0.1500	1.050	0.2000	0.0000E+00
121	0.0000E+00	0.0000E+00	0.1500	0.5000E-01	0.0000E+00
122	0.1000	0.0000E+00	0.5000E-01	0.0000E+00	0.0000E+00
130	0.0000E+00	0.0000E+00	0.0000E+00	0.5000E-01	0.0000E+00
131	0.0000E+00	0.0000E+00	1.5000E-01	0.0000E+00	0.0000E+00
132	0.0000E+00	0.1500	0.1500	0.5000E-01	0.0000E+00
133	0.0000E+00	0.2500	0.3000	0.1500	0.0000E+00
134	0.0000E+00	0.5000E-01	1.050	0.3500	0.0000E+00
135	0.1000	0.7000	1.400	0.4000	0.0000E+00
136	0.1000	0.8500	2.650	0.7000	0.0000
137	0.1000	1.000	2.100	1.550	0.0000E+00
138	0.0000E+00	0.9500	2.250	0.9000	0.0000E+00
139	0.1000	0.6000	1.100	0.3500	0.2500
140	0.0000E+00	0.3000	0.6000	0.5000	0.1000
141	0.0000E+00	0.5000E-01	0.2000	0.2500	0.0000E+00
142	0.0000E+00	0.1000	0.1000	0.5000E-01	0.0000E+00
143	0.0000E+00	0.5000E-01	0.0000E+00	0.0000E+00	0.0000E+00
144	0.0000E+00	0.5000E-01	0.0000E+00	0.5000E-01	0.0000E+00
152	0.0000E+00	0.0000E+00	0.0000E+00	0.5000E-01	0.0000E+00
153	0.0000E+00	0.5000E-01	0.5000E-01	0.0000E+00	0.0000E+00
154	0.0000E+00	0.5000E-01	0.5000E-01	0.0000E-01	0.0000E+00
155	0.0000E+00	0.2000	0.4500	0.5000E-01	0.0000E+00
156	0.0000E+00	0.1000	0.4500	0.1000	0.0000E+00
157	0.0000E+00	0.0000E+00	0.8500	0.5000	0.0000E+00
158	0.0000E+00	0.5000	0.9500	0.3500	0.0000E+00
159	0.0000E+00	0.4000	1.150	0.4000	0.2000
160	0.1000	0.2000	0.6000	0.1500	0.0000E+00
161	0.0000E+00	0.2000	0.4000	0.1500	0.0000E+00
162	0.0000E+00	0.5000E-01	0.4000	0.1000	0.0000E+00
163	0.0000E+00	0.0000E+00	0.5000E-01	0.5000E-01	0.0000E+00
164	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.1000
174	0.0000E+00	0.0000E+00	0.5000E-01	0.5000E-01	0.0000E+00
175	0.0000E+00	0.5000E-01	0.5000E-01	0.0000E+00	0.0000E+00
176	0.0000E+00	0.0000E+00	0.0000E+00	0.1000	0.0000E+00
177	0.0000E+00	0.0000E+00	0.1000	0.0000E+00	0.0000E+00
178	0.0000E+00	0.0000E+00	0.1500	0.5000E-01	0.0000E+00
179	0.0000E+00	0.1000	0.1500	0.1500	0.0000E+00
180	0.0000E+00	0.0000E+00	0.4000	0.5000E-01	0.0000E+00
181	0.0000E+00	0.5000E-01	0.2000	0.1000	0.0000E+00
182	0.0000E+00	0.5000E-01	0.0000E+00	0.5000E-01	0.0000E+00
184	0.0000E+00	0.5000E-01	0.0000E+00	0.0000E+00	0.0000E+00
194	0.0000E+00	0.0000E+00	0.0000E+00	0.5000E-01	0.0000E+00
197	0.0000E+00	0.0000E+00	0.5000E-01	0.5000E-01	0.0000E+00
200	0.0000E+00	0.0000E+00	0.5000E-01	0.0000E+00	0.0000E+00
202	0.0000E+00	0.0000E+00	0.0000E+00	0.5000E-01	0.0000E+00

CONTAMINANT MASS LEFT SYSTEM

LEVEL

NODE	1	2	3	4	5
64	0.0000E+00	0.1250E-01	0.0000E+00	0.0000E+00	0.0000E+00

MASS SUMMARY
============

INITIAL TOTAL NUMBER OF PARTICLES .....: 2000
PRESENT TOTAL NUMBER OF PARTICLES .....: 1999
TOTAL NUMBER OF PARTICLES LEFT SYSTEM :
TOTAL NUMBER OF PARTICLES LOST .....:

INITIAL TOTAL PARTICLE MASS .....: 25.00
PRESENT TOTAL PARTICLE MASS .....: 24.99
TOTAL PARTICLE MASS LEFT SYSTEM .....:0.12502-01
TOTAL PARTICLE MASS LOST .....:0.0000E+00

NUMBER OF CUMULATIVE PARTICLES LOST
===================================

LAYER

ELEMENT	1	2	3	4

NONE

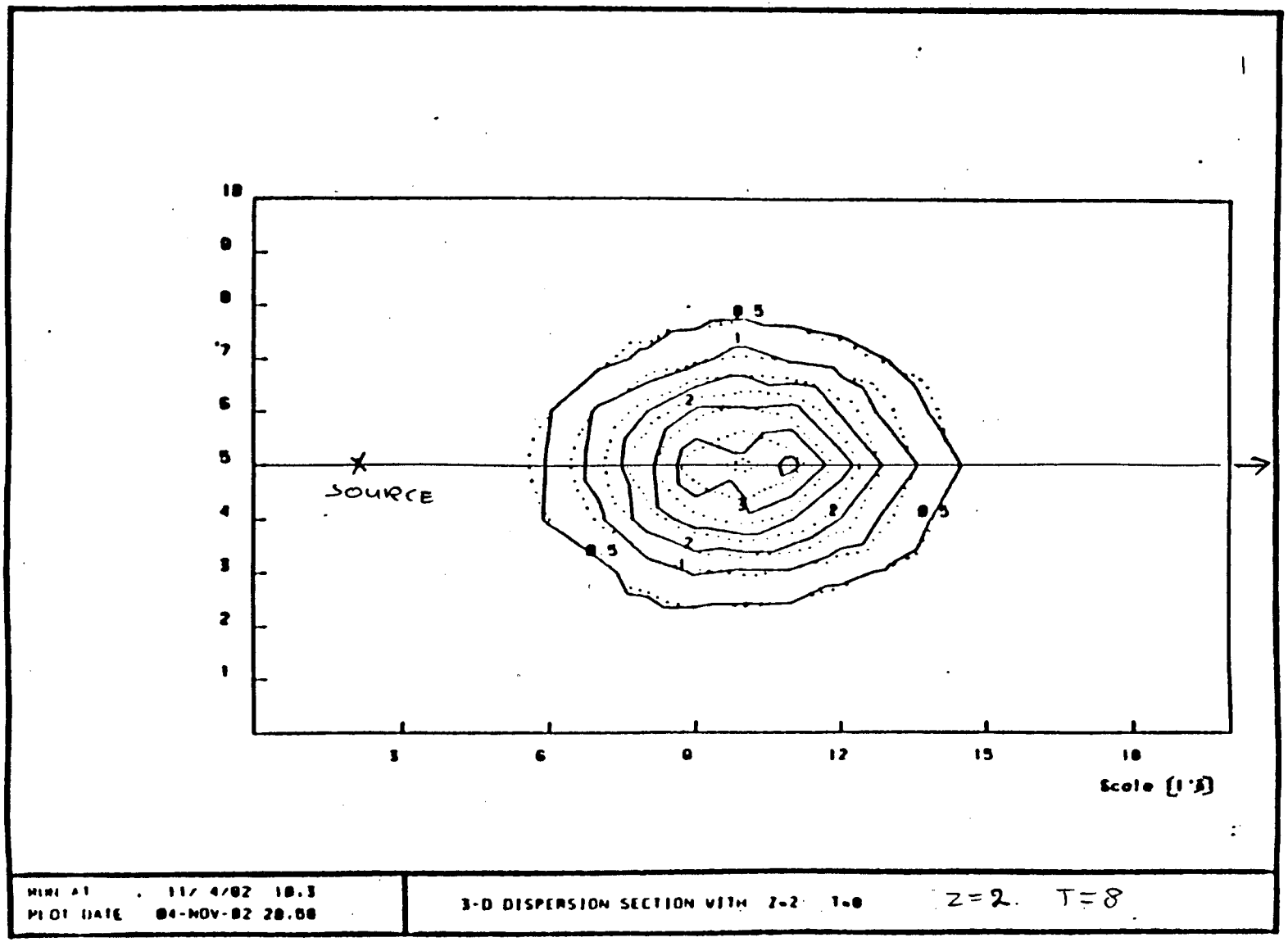
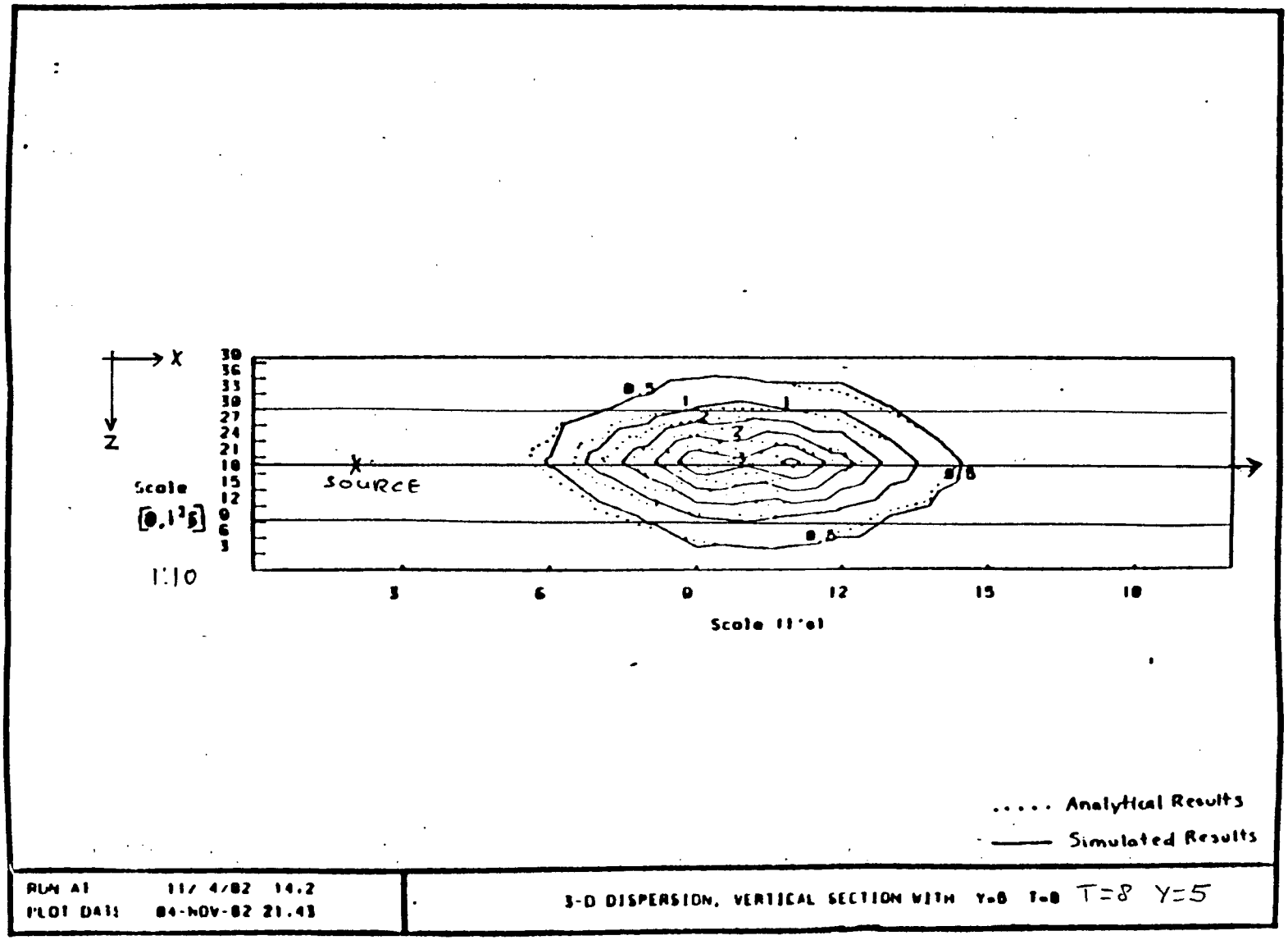


FIGURE 5.5 CDM results SLUG3D data


X
Z
Scale
[0,1³S]
1:10
SOURCE
30
36
33
30
27
24
21
18
15
12
9
6
3
0.5
1
3
0.5
3
6
9
12
15
18
Scale 1:10
..... Analytical Results
—— Simulated Results
RUN A1 11/ 4/82 14.2
PLOT DATE 04-NOV-82 21.43
3-D DISPERSION, VERTICAL SECTION WITH Y=0 T=0 T=8 Y=5

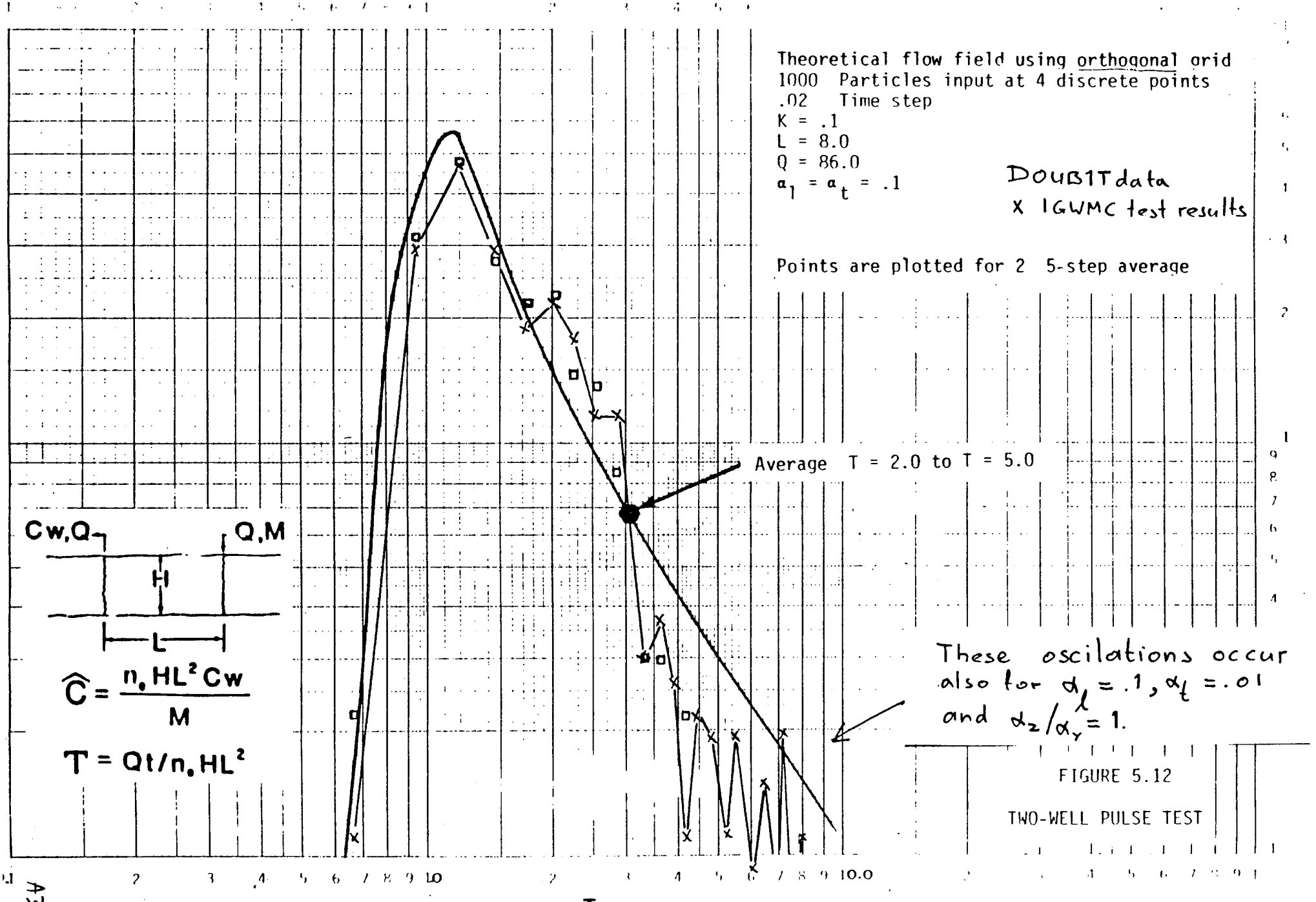


FIGURE 5.12

TWO-WELL PULSE TEST

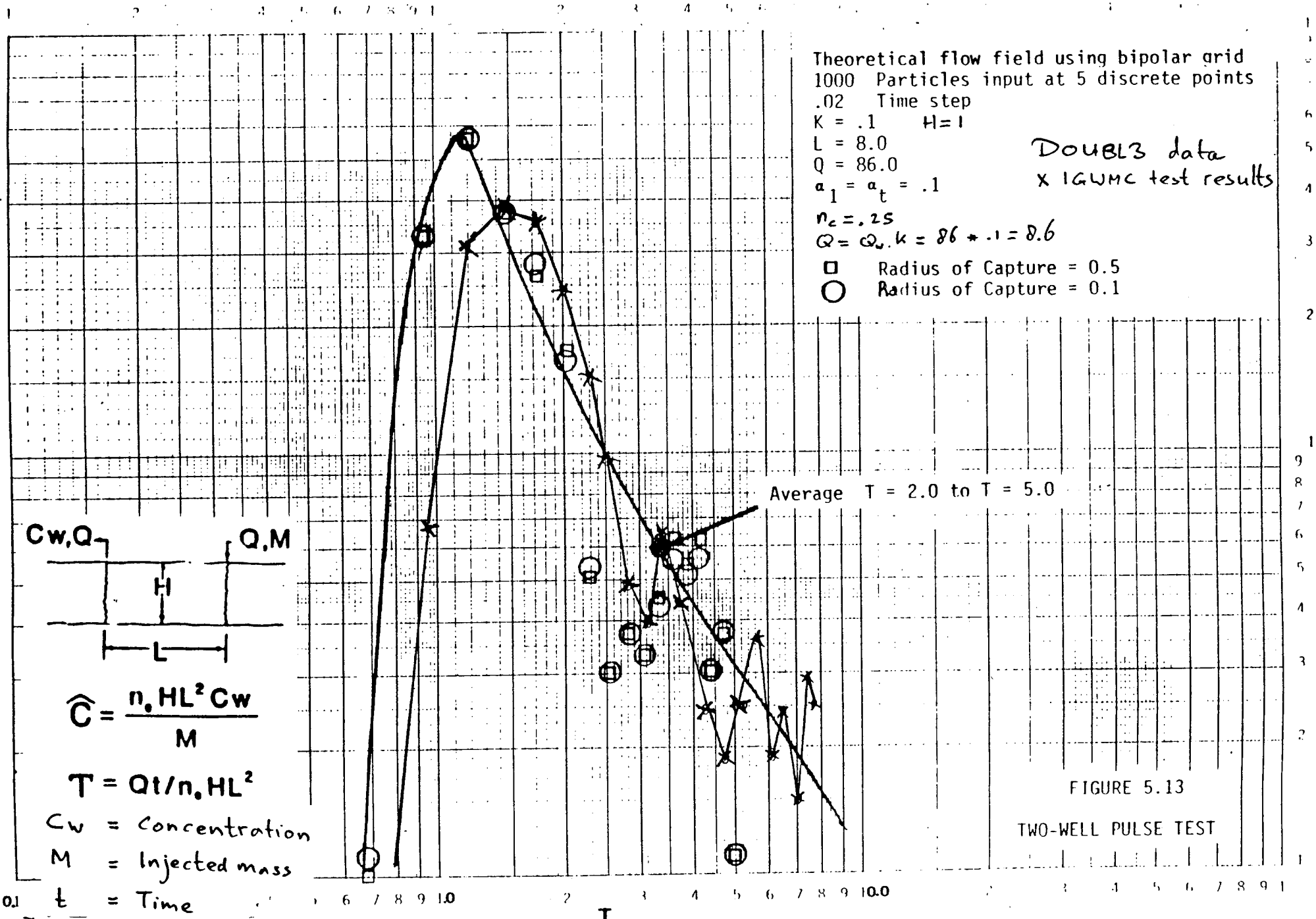


FIGURE 5.13

TWO-WELL PULSE TEST