Scientific Software Group
P.O. Box 23041, Washington, DC 20026-3041
Telephone: (703) 620-9214, FAX: (703) 620-6793

PRINCE

INTRODUCTION

Prince is the Princeton Analytical Models of Flow and Mass Transport. Prince contains 10 analytical models, 7 of which are mass transport models and the remaining are flow models. The mass transport models are for unsteady-state, one, two and three-dimensional problems. The 3 flow models are for two-dimensional, unsteady-state problems. The package was written in the C language and has an outstanding graphics user interface (GUI). Two-dimensional flow and transport models can import overlay site maps as DXF files and all the models can print report-quality graphics on laser printers.

A Brief History of Prince

The Princeton package was originally developed at Princeton University as part of an EPA 208 project from 1975-1977. The project involved developing numerical models to simulate contamination and flow in the saturated and unsaturated zones on Long Island, New York. At the time, very few multi-dimensional analytical models existed for testing the numerical codes. Thus, the reason for developing this suite of analytical tools. At the end of the project, we were surprised to find the analytical models, which were developed only as testing tools, were more popular with the public agency on Long Island than the numerical models. The original report (Cleary and Ungs, 1978, now out of print) containing the analytical solutions as well as the Fortran codes was distributed over the years to several hundred researchers throughout the U.S. and the world. It was the first comprehensive collection of mass transport and flow analytical models in the groundwater field and is considered a classic report.

The Princeton models have been popular since their introduction in the mid-seventies. From their introduction until the end of the eighties, they were generally run on mainframe computers. With the advent of personal computers and the development of graphics-rich languages like C, we thought it was time to port the models to the PC environment. Version 1.0, released in 1988, had simple menus, crude screen graphics (CGA) and no ability to print to a laser printer. One could only do crude screen dumps to dot matrix printers at 72 dpi. But it was 1988, and that was considered acceptable results in those days.

In the spring of 1990, we decided to completely re-do Prince with pull-down menus, graphics options and the ability to print to a laser printer. This was Version 2.0. It could not, however, import DXF site maps or handle regional groundwater flow. The contour interval also could not be changed and occasionally the program tried to contour zeros, resulting in small, irritating line segments.

Version 3.0, the latest version, is a major upgrade. It was developed through Waterloo Hydrogeologic Software from the fall of 1993 to the spring of 1994. It added the ability to be able to import overlay site maps as DXF files. In addition, regional flow capability was added to Model 10 and the uniform velocity in the two-dimensional mass transport models could be fixed at any angle from 0 to 360 degrees. Smoother contouring through the addition of more data points [the exact number is selectable by the user] and the ability to change the contour interval was also added.

PRINCE MODELS SUMMARY

In this section, all the models are briefly described.

MODEL 1: One-Dimensional Mass Transport; Type One Concentration

Model 1 solves the one-dimensional solute transport equation as a function of distance from the source and of time. The code predicts solute concentrations as a fraction of the initial source concentration. The model calculates these relative concentrations beneath a source and downgradient of the source.

MODEL 2: One-Dimensional Mass Transport; Type Three Concentration

Model 2 solves the one-dimensional solute transport equation as a function of distance from the source and of time. The code predicts solute concentrations as a fraction of the initial source concentration. The model calculates these relative concentrations beneath a source and downgradient of the source.

MODEL 3: Two-Dimensional Mass Transport; Wilson-Miller Injection Wells

The modified Wilson-Miller solution describes plumes caused by any number of injection wells operating in an aquifer with uniform groundwater flow. This modified solution allows any number of wells, at any location, and with different mass injection rates which may be individually turned on and off. In addition, the uniform groundwater velocity may be at any angle with respect to the X-axis.

MODEL 4: Two-Dimensional Mass Transport; Infinite Aquifer; Infinite Strip Source

Model 4 solves the two-dimensional solute transport equation as a function of distance from the source and of time. The code predicts solute concentrations as a fraction of the initial source concentration. The model calculates these relative concentrations beneath a source and downgradient of the source.

MODEL 5: Two-Dimensional Mass Transport; Infinite Aquifer; Gaussian Source

Model 5 solves the two-dimensional solute transport equation as a function of distance from the source and of time. The code predicts solute concentrations as a fraction of the initial maximum source concentration. The model calculates these relative maximum source concentration. The model calculates these relative concentrations beneath a source and downgradient of the source.

MODEL 6: Three-Dimensional Mass Transport; YZ Confined Aquifer; Patch Source

Model 6 solves the three-dimensional solute transport equation as a function of distance from the source and of time. The code predicts solute concentrations as a fraction of the initial source concentration. The model calculates these relative concentrations beneath a source and downgradient of the source.

MODEL 7: Three-Dimensional Mass Transport; Infinite Aquifer; Gaussian Source

Model 7 solves the three-dimensional solute transport equation as a function of distance from the source and of time. The code predicts solute concentrations as a fraction of the initial maximum source concentration. The model calculates these relative concentrations beneath a source and downgradient of the source.

MODEL 8: Two-Dimensional Groundflow; Semi-infinite Aquifer; Recharge Boundary

Model 8 numerically computes the solution to the two-dimensional flow equation for a confined aquifer with infinite lateral dimensions. The aquifer has one constant head recharge boundary condition.

MODEL 9: Hantush & Jacob Solution for Two-Dimensional, Anisotropic, Nonsteady Flow in a Confined, Leaky Aquifer of Infinite Extent

Model 9 considers the case of a two-dimensional confined aquifer with one or more fully penetrating wells. The confined aquifer is anisotropic, but it is overlain by a semi-pervious stratum and underlain by an impermeable stratum. A constant head is maintained on top of the semi-pervious stratum, but the storativity of this layer is neglected. Leakage through the semi-pervious stratum is vertical and is assumed to be proportional to the drawdown in the confined aquifer.

MODEL 10: Two-Dimensional Groundflow; Infinite Aquifer; No Recharge Boundary

Model 10 numerically computes the solution to the two-dimensional flow equation for a confined aquifer with infinite lateral dimensions.

THE USE OF ANALYTICAL MODELS IN GROUNDWATER POLLUTION AND HYDROLOGY

Analytical models may be used as primary tools of analysis where costs or lack of a multi-dimensional data base preclude the use of sophisticated numerical models. Where numerical models can be justified, analytical models are excellent for testing the accuracy of the models or for inexpensive, exploratory parametric manipulation in preparation for designing computer experiments with the numerical model. Analytical models are much easier to apply than numerical models. They do not require knowledge of numerical methods and parametric data can be input quickly and inexpensively.

In any event, models should be selected to be commensurate with the questions being asked. Most problems the average groundwater hydrologist deals with do not require sophisticated numerical models. Analytical models may satisfy as much as 70% or more of one's quantitative analysis needs. Some practical applications of analytical models include:

- Design of pump and treat systems
- Cost apportionment for cleanup when several plumes from different companies make up one large plume
- Predicting the impact of a potential source of contamination
- In risk assessment when concentration vs. time predictions at sensitive receptors is needed

A recent example of cost apportionment involving between $60 million and $100 million is the M.E.W. Superfund site in Mountain View, California. The public case involves seven nationally-known companies, each with an individual plume. Although the site has heterogeneities, indicating a numerical model, the companies agreed to use an analytical model for cost apportionment. They felt adequate data collection for a numerical model would be very costly and the cost apportionment in the end would probably not be all that different from using an analytical model. The companies chose Model 4 [two-dimensional mass transport with a strip source] from Prince to simulate the individual plumes and cost was apportioned according to the resulting size of each plume. The case is not officially published, but information can be obtained from the Superfund section of the U.S. EPA in San Francisco.

LIMITATIONS OF ANALYTICAL MODELS

Analytical models are derived from solving partial differential equations. These equations have coefficients in front of the derivatives which are called parameters. The most important coefficients or parameters in flow models are the transmissivities and the storage coefficients; in mass transport models, the parameters of most importance are the dispersion coefficients, the velocity, the first order decay constant and the linear, equilibrium, sorption coefficient.

In general, analytical solutions can be obtained for partial differential equations only for cases of constant coefficients. The coefficients, although they must be constant, can have different numerical values (anisotropy can easily be handled). In practical terms, constant coefficients means uniform properties in an aquifer or *homogeneous conditions.* All aquifers are heterogeneous to one degree or another and therefore analytical models are only approximations. These approximations in practice, however, can be quite useful. And in many cases, even if one wanted to describe the full heterogeneity of an aquifer with a numerical model, there wouldn't be enough data to do so. So despite the ability to handle heterogeneities, most applications of numerical models use homogeneous data or surprisingly little heterogeneous information. In such cases, the analytical model might be just as useful and its a lot less costly and easier to use.