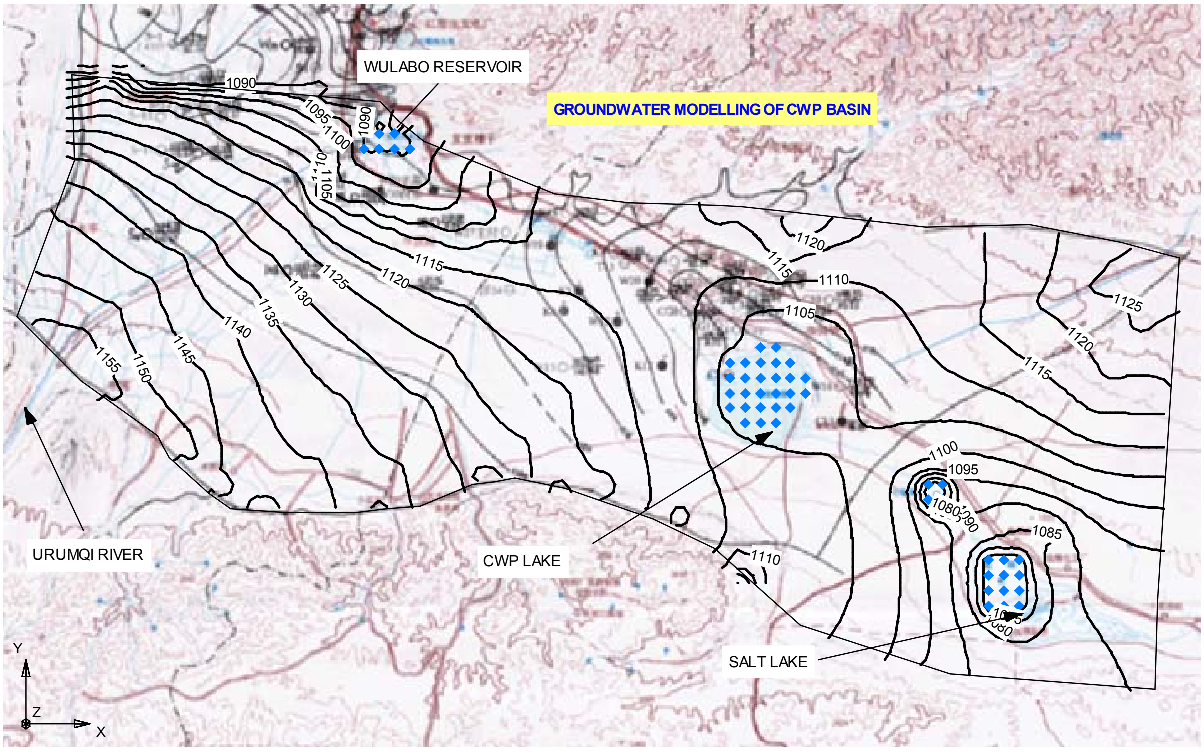
Yangxiao Zhou , PhD

LN0113/02/1

Applied Modelling of Groundwater Flow and Contaminant Transport



UNESCO-IHE
Institute for Water Education

Applied Modelling of Groundwater Flow and Contaminant Transport

Postgraduate Short Course on

Applied Modelling of Groundwater Flow and Contaminant Transport

TABLE OF CONTENTS

Postgraduate Short Course on

Applied Modelling of Groundwater Flow and Contaminant Transport

---

Chapter 1 Introduction

1. Introduction

1.1 Groundwater resources and management

There are many countries in the world where groundwater is one of the major sources of drinking water. With the increasing development of the groundwater resources and the growing impacts of human activities on the aquifers, problems such as declines of groundwater heads and deterioration of groundwater quality have been observed in many places in last decades. Approaches of sustainable development and integrated groundwater resources management must be developed and implemented to guarantee the right of use of the limited water resources for our future generations.

To formulate technically-sound groundwater resources management polices, decision makers always ask questions like:

- How long can an aquifer maintain the current rate of groundwater abstraction? What is the safety yield that the aquifer can sustain the continuous abstraction?

- What is the capture zone of a water supply well field? What is the most likely pathway of contaminants from domestic wastewater and leaches from solid waste disposal sites? What are the chances that the pollutants from those sources would arrive at water supply wells? and how long it takes? In order to protect the well fields from pollution, a protection zone should be delineated. What is the size of the protection zone?

Providing answers to these questions involves the understanding of behaviour of groundwater flow system and the prediction of the system's response to any stresses. The best tool available to help groundwater hydrologists to meet the challenges of the prediction is usually a groundwater model.

1.2 Groundwater modelling

The process of groundwater modelling involves a number of different steps. The essential steps are shown in the following diagram.

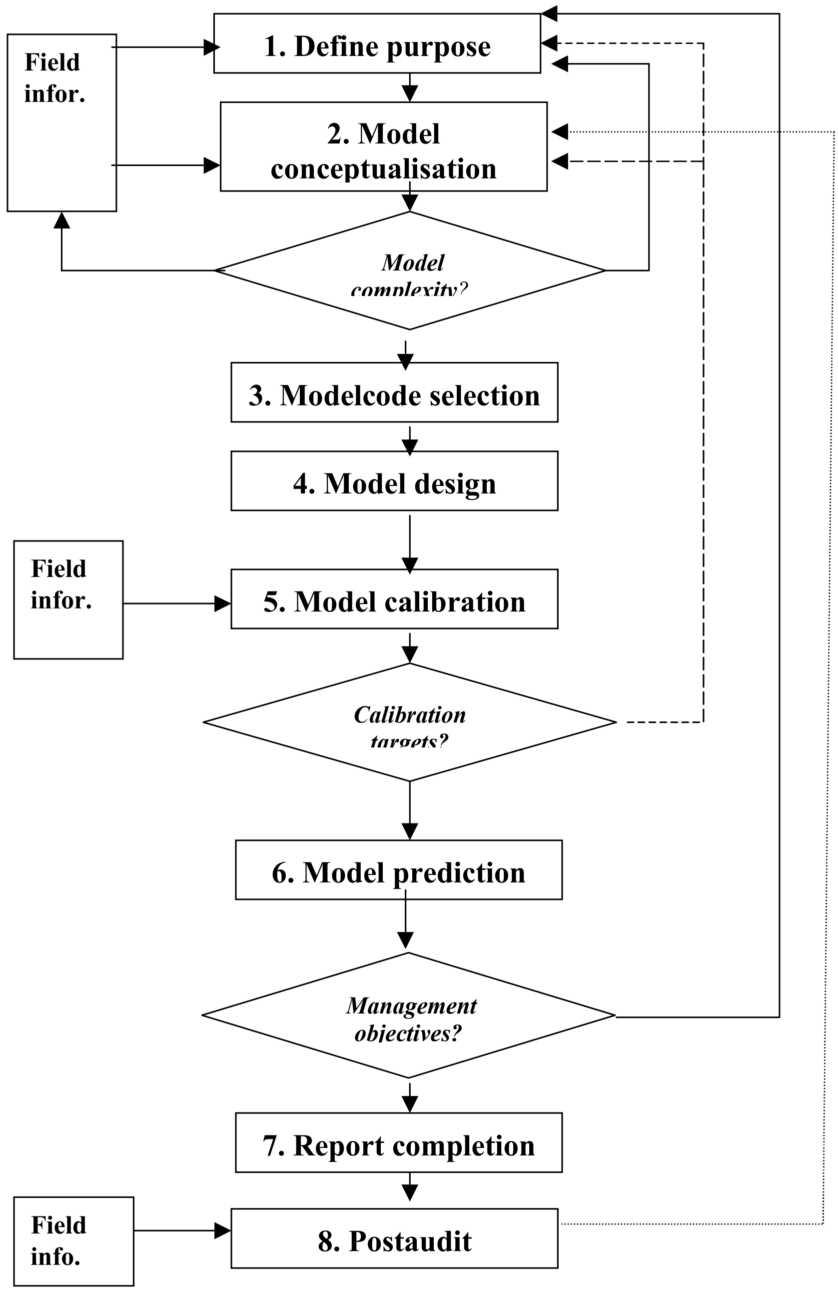


Figure 1.1 Flow chart of groundwater modelling

- **Defining purpose**: Groundwater models are usually applied for predicting the consequences of a proposed actions such as groundwater development scenarios or waste disposal. Models can be used for analysing groundwater flow system by assembling and organising field data and formulating ideas about dynamics of flow systems. Models can be also used for studying processes in generic geologic settings like river-aquifer systems. It is essential to identify clearly the purpose of modelling so that the needs of modelling efforts and accuracy are determined. The purpose of modelling also decides on the dimensionality and time dependency of a model.

  Answers to the following questions will help in the determination of the types of model applications and the levels of modelling efforts:
  (1) Will the model be used for the prediction of system's response, analysis of flow systems, or study of the processes in a certain generic geologic settings?
  (2) What questions do you want the model to answer?
  (3) Can an analytical model provide the answer or must be a numerical model be constructed?

- **Building conceptual model**: Conceptual model is a quantitative representation of groundwater systems in terms of aquifer-aquitard layers, boundary conditions, hydrogeological parameters, hydrological stresses, flow patterns, and water balance components. Field visits are necessary to gain the modeller first impression about the area to be modelled.

- **Selecting computer code**: A computer code is a computer programme which solves the mathematical model of groundwater flow or contaminant transport numerically. There are many computer codes available. The selection of a suitable code depends on the complexity of the conceptual model and the purpose of study. The main considerations are: (1) types of model: flow model, particle tracking or solute transport model; (2) time dependency: steady or transient model; (3) dimensionality: one-, two-, quasi-three, or fully three dimensional model; (4) ability to describe the aquifer properties: homogeneous or heterogeneous; isotropic or anisotropic media; (5) ability to include various hydrological stresses; (6) user friendliness; and (7) requirements on the computer facility.

- **Designing numerical model**: The design of numerical model includes the design of model grids, selection of stress periods and time steps and setting model boundaries. The conceptual model will be the bases for the design of the numerical model. The purpose of the modelling will dictate the sizes of grids and time steps. The memory and computing time of computers and the computer code may have limitations on total number of grids and time steps.

- **Determination of model inputs**: The inputs to the model include initial and boundary conditions, hydrogeological parameters, and hydrological stresses. The data for all these inputs have to be entered to all grid points for all stress periods.

- **Calibration of the model**: The purpose of calibration is to establish that the model can reproduce the field measured groundwater heads or concentrations. The calibration forces the model calculations approximate the field measured values through the adjustment of aquifer parameters or stresses by trial-and-error method or automated parameter estimation method. Sensitivity analysis is followed to evaluate the influences of uncertainties of model parameters and boundary conditions on the model results.

- **Verification of the model**: To check whether the calibrated model has the predictive power, the calibrated model is applied to another period of time where a second set of field data are available. The model should also be able to reproduce the field measured values of groundwater heads or concentrations with hydrological stresses in this period.

- **Application of the model**: The calibrated model is used to predict the response of the aquifer system to future events. In the prediction the model is run with calibrated aquifer parameters and future hydrological stresses. Some hydrological stresses are the proposed actions (such as abstraction). Others are natural uncontrolled stresses (such as recharge from precipitation).

- **Presentation of results**: Clear presentation of modelling processing and results is essential fro the effective communication of the modelling effort. The report on the modelling study should include chapters like (1) Introduction; (2) Hydrogeological conceptual model; (3) Numerical model set-up; (4) Model calibration; (5) Model application; and (6) Summary and conclusions.

Groundwater modelling is an iterative process. Steps outlined above may have to be repeated. Assumptions and even simplifications are necessary in the modelling because of the complexity of hydrogeological formations on the one hand and the lack of sufficient field data on the other hand. Models are only approximations of reality, but not reality itself. Therefore, groundwater modelling is not only a science but also an art. The science behind modelling can be learned relatively easily from many standard text books and short courses like this one. However, the art of modelling can only be learned from practising how to apply models. A successful modeller will have to know the science of the modelling and practice the art of modelling. This short course on Applied Groundwater Modelling will introduce the science of modelling and demonstrate the art of modelling with hands-on training exercises on computer workshops.

1.3 Objectives of the course

The course was developed for professionals in hydrogeology and water resources management from Northwest China; who are engaged in groundwater investigation, management, and the protection of groundwater resources. The course will provide participants with principles of groundwater modelling and the use of computer models for groundwater resources management and protection. The experiences of modelling will be obtained through a series of hands-on training in computer workshops.

The course will focus on
- Principles of groundwater modelling,
- Procedures of building a groundwater model,
- Introduction of most popular groundwater model codes,
- Application of groundwater models for evaluation of groundwater development scenarios, determination of capture zone of well fields and prediction of pollutant plume development.

In addition to lectures, computer workshops will be organised to gain participants the experiences in groundwater modelling. The popular groundwater model MODFLOW and MT3D and its graphic processor PMWIN will be used in modelling exercises. Instructions on user friendly PMWIN-MODFLOW and MT3D will provide participants with sufficient working knowledge for the workshops and for future application.

1.4 Acknowledgement

For the compilation of the lecture note, the following books were used:
- Anderson, M. P., and W. W. Woessner, 1992, Applied Groundwater Modeling: Simulation of Flow and Advection Transport, Academic Press, Inc.
- Chiang, W.H. and W. Kinzelbach, 2001, 3D-Groundwater Modeling with PMWIN, Springer.
- Zheng, C. and G.D. Bennett, 1995, Applied Contaminant Transport Modeling, Theory and Practice, Van Nostrand Reinhold, New York.