Laboratory Facilities for Visualization of Groundwater Flow

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Abstract: Compared to two decades ago the priority training in groundwater hydrology was directed towards methods of exploration and exploitation, the current emphasis of groundwater curriculum lies on the sustainability of the resources with respect to both quantity and quality. The challenges facing today's groundwater hydrologist focus on the study of groundwater systems with the objective of preventing harmful depletion of groundwater system and to control groundwater-related pollution and environmental hazards. Knowledge and feeling of the spatial and temporal characteristics of groundwater systems and their interactions with the environment provides the basis for such sustainable development and environmentally sound planning and management of groundwater resources. The objective of this facility is to provide students who are taking fluid mechanics and groundwater hydrology with an opportunity to visualize flows in porous media under variably saturated condition. The setting in the facility can simulate heterogeneity of porous media and different pumping flow situations within the sand-box. Dye injection can demonstrate the advection and dispersion processes of pollutant material after entering the groundwater system. Mini-tensiometers and TDR sensors for measuring water-content can demonstrate the characteristics of groundwater flow. With the additional help of numerical modeling, students can gain the feeling and intuition on how the flow and pollutant can be constrained or better managed.

Introduction

Groundwater is referred to the water resources under the ground surface and its total storage is account for 98% of fresh water available to human being. This amount is much larger than the other water resources such as river or lakes [1-3]. Since groundwater flow mostly under the ground, it is undetectable to most people. Most people cannot see how groundwater 'flow' in the subsurface, which becomes an obstacle in learning how pollutant is transported by the groundwater in the subsurface. The key to teach a good engineer is to generate some intuition in his mind. To teach groundwater-flow related courses, from my experience, the key thing is to give the students to see and feel the flow pattern.

Based on years' teaching experience of the first author on courses related to groundwater, there are four obstacles for the new learner. The first one is that the physical phenomena, such as dispersion, need some imagination to picture them. The second one is that the theoretical reasoning is too abstract. The third one is that equations describing the phenomena are far too complicated and hard to related to each phenomenon. The fourth one is that numerical methods for solving these equations required long-time training and easy to get frustrated. All the above reasons will drive students far away from the groundwater-related courses once they touch it. Only very few percentage among students would like to dig into these courses.

By going through teacher-students interaction and communication year by year, some directions for improving the teaching contents are as following: (1) Simplification of theoretical deduction and connected them with related courses, such as fluid mechanics, which students has encountered before; (2) Visualization through porous media, such as a sand-box experiment, can give students good intuition towards the physical processes; (3) Numerical modeling interfaced by interactive functionality can avoid difficulty in learning various numerical skills before knowing how it works; and (4) Introduce local problems related to recent Taiwan through newspaper reading and discussion can give students motivation to learn them better.

There are several subsequent actions, such as video taping some typical sand-box experiments, and illustration of measuring data, and animation movie of flow and transport made from simulation results of numerical models. Hopefully, this can minimize the difficulty in learning new concepts.

Framework of Courses

Figure 1 illustrates the structure combining the courses of groundwater hydraulics/hydrology and pollutant transport in the subsurface. Multimedia instruction based on advanced computer software will be the final goal of way of teaching. The whole courses consist two parts. One is the fundamental basis. The other is cases study. In both parts, Visualization is emphasized by both porous media experiments and animation by numerical simulation.

Problem-oriented guiding is also an emphasis. Those problems include land-subsidence due to over-extraction of groundwater resources along the coastal area in Taiwan, groundwater pollution due to landfill leachating or improper industrial operation in Taiwan, which eventually thread the health of near-by population. Newspaper collecting on groundwater pollution in Taiwan is one of the important and easy-to-carry out homework. By combining and analyzing all the newspaper collected, various sources of pollutant in Taiwan can be concluded and the motivation of learning can be raised.

Special Features

Problem-oriented learning is especially work for nowadays students. The following is just an example. We firstly issue a question, such as some special disease emersed at certain location in the country by news media. From this point, a series of questions can be induced and students can walk step by step into the pursuits of groundwater pollution. It can be started from a news column describing a high rate of groundwater consumption as the drinking water in that area. A common symptom can be related to some specific pollutant resource from a local factory. A series of questions can be listed as following, irrespect of the accuracy of any medical examination:

1. How to identify the possible source of groundwater pollution?
2. What is the relation between the time and space of the plume of pollutant?
3. How does the plume move?
4. Is the groundwater induces the moving?
5. How does the groundwater move?
6. What is the driving force?
7. How does the soil matrix affect the pollutant moving?
8. ....

This is a training of thinking toward a problem solving direction. If one can answer the above question one by one, one can solve the problem. In the process of answering questions, students find that they need to be equipped with certain fundamental theories and need to visualize the phenomena. Several figures can illustrate as the aid to the instructor. Figures 2 to 5 are pictures of various experiments with dye to trace the flow movements, which can explain easier how the flow go and what is the driving forces and boundaries. Figure 2 can be the case of leachate under the landfill. The driving force is the head difference and the pollutant is transported by the flow. Figures 3 to 5 is different combination of pumping and geological layout interacted with lake or river, which can give students direct impact of intuition much better than simple theory deduction. Figures 6 to 9 is a demo of software IGW (Interactive Ground Water), which is designed for people who do not need to learn numerical scheme before running the model. Interactive is the emphasis. One starts directly from the windows interface just by drag and click. Interactive means that once you change a new condition or value of parameters, the corresponded results will be shown immediately. Figure 6 and 7 illustrate the heterogeneity effects of the soil matrix for the same boundary conditions. Figures 8 and 9 are the real cases from previous projects. They are all continuous animation and can trace the flow of target pollutant.

Conclusion

Using sand-box experiments together with numerical modeling for visualizing the flow-field patterns within the porous media can enhance the interests and draw attentions from the audience. They can also help students to grab the solid ideas once before were still abstract concepts to them.

Problem-oriented thinking combined with real cases in local or regional Taiwan can attract students' participation and gradually into the tract of an engineer.

Numerical modeling is a very powerful tool in both problem solving as well as teaching. Especially for cases with distant properties, convenience and speed always prove its superiority.

Acknowledgement

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Reference

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[2] Fetter, C. W., Contaminant Hydrogeology, Prentice-Hall, Inc., U.S.A., 1994.
[3]Philip B. B., Hanadi S. R., and Charles, J. N., Groundwater Contamination, Prentice-Hall, Inc., U.S.A., 1994.

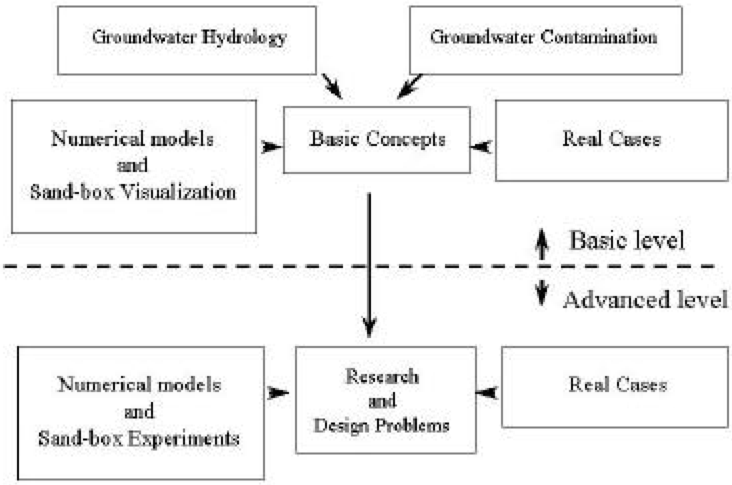

Figure 1. The framework of teaching materials adapted in groundwater and groundwater contaminant transport curriculums.

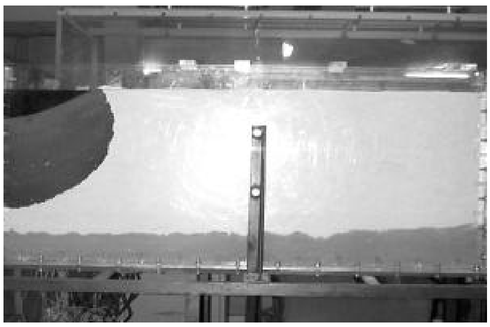

Figure 2. The pollutant infiltrates from the landfill.

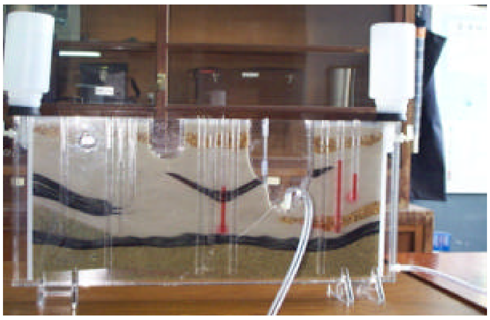

Figure 3. Dye move in the aquifers.

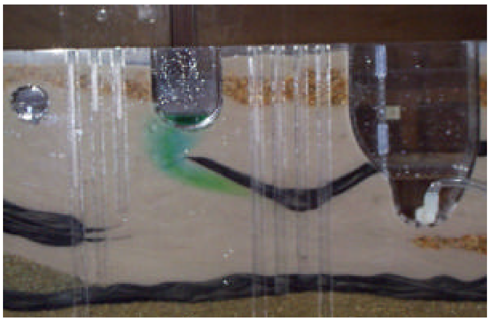

Figure 4. The pollutant infiltrates from the river.

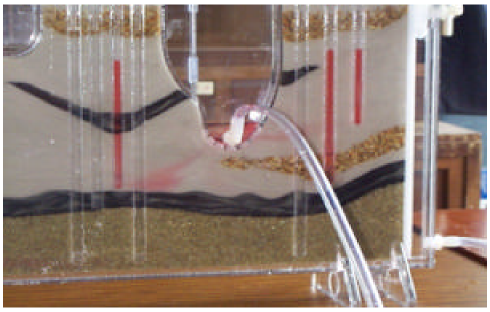

Figure 5. The pollutant infiltrates from the wells.

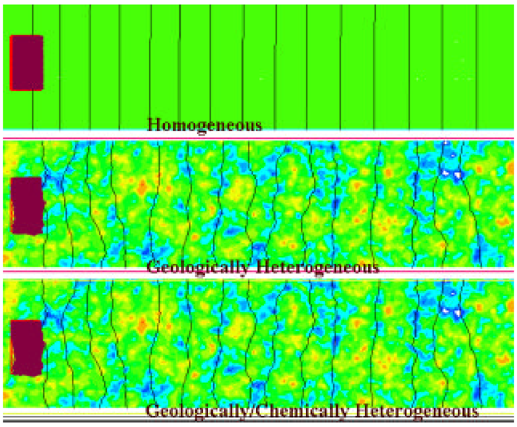

Figure 6. The plume moves in the heterogeneity soil.

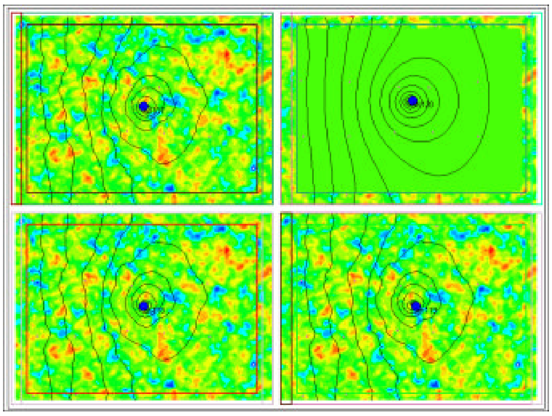

Figure 7. Pump water in heterogeneity soil

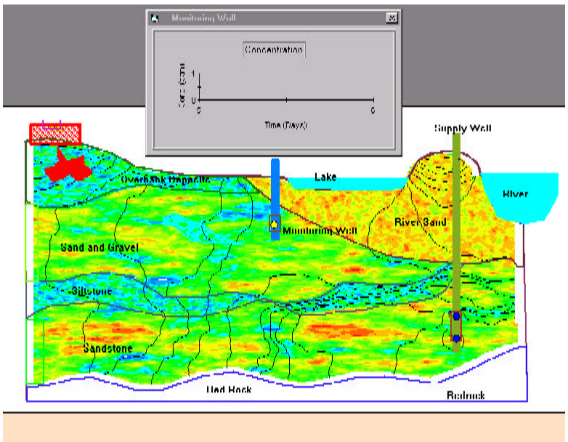

Figure 8. The pollutant discharged to a complex aquifer.

Figure 9. Numerical models can trace the flow of target pollutant discharged from used landfill.