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Thesis

Experimental Education in Groundwater Hydrology: Bridging the Technical-Policy-Populace Gap Final Report

A. F. B. Tompson, R. M. Maxwell, J. H. Richardson, W. A. El Sha'r, J. F. F. Rihani, H. El-Naser, K. Al-Hadidi, M. Al-Awamleh, A. Subah, M. Al-Foqaha, O. Abu-Eid, R. A. Hayyaneh

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Final report:

Experiential Education in Groundwater Hydrology: Bridging the Technical – Policy – Populace Gap

Andrew F. B. Tompson
Reed M. Maxwell
Jeffrey H. Richardson
Lawrence Livermore National Laboratory, University of California, Livermore, California

Wa'il Abu El Sha'r
Jehan F. F. Rihani
Jordan University of Science and Technology, Irbid, Jordan

Hazim El-Naser
Khair Al-Hadidi
Mohammed Al-Awamleh
Ali Subah
Jordan Ministry of Water and Irrigation, Amman, Jordan

Manal Al-Foqaha
Omar Abu-Eid
Raed Abu Hayyaneh
Royal Society for the Conservation of Nature, Amman, Jordan

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1. Introduction

It is well recognized that half the countries in the world will face significant fresh water shortages in the next 20 years, due largely to growing populations and increased agricultural and industrial demands (Gleick, 1997). These shortages will significantly limit economic growth, decrease the quality of life and human health for billions of people, and could potentially lead to violence and conflict over securing scarce supplies of water. In the Middle East, groundwater represents an important part of water supply in most locations, yet it is the least understood and one of the most fragile components of the entire water resource system. The occurrence of water underground contributes to the illusion of an infinite resource that is immune to anthropogenic activities. Nevertheless, as has been learned in the West, it can become highly impaired through the actions of man – through the disposal of human, animal, or industrial wastes, from excessive irrigation and fertilization practices in agriculture, or from simple overproduction and overexploitation – and can remain so for decades or even centuries.

Finding solutions to groundwater resource and quality problems can be complex, time consuming, and costly. As is the case in many places in the world, but especially in the Middle East, there is a large gap between professionals, policy makers, and the general population with respect to their understanding of groundwater, its abundance, distribution, movement, and pollution. In a region where water supply and quality problems can be extremely acute, it becomes that much more necessary to protect and preserve the water that does exist. To sustain groundwater as a long-term reliable resource, increased understanding of factors affecting both the quality and quantity of groundwater must be better understood by all aspects of society.

This report describes the outcome of a collaborative project between Lawrence Livermore National Laboratory (LLNL) in the US and the Jordan University of Science and Technology (JUST), the Ministry of Water and

Irrigation (MWI), and the Royal Society for the Conservation of Nature (RSCN), all in Jordan. The project was funded by the United States Information Agency (now known and the Bureau of Educational and Cultural Affairs of the US Department of State) and the Lawrence Livermore National Laboratory, University of California. It was designed to develop, utilize, and distribute a series of educational tools across a wide spectrum of the population in Jordan to illustrate the impact of human activities and policies on the use and preservation of groundwater as an increasingly precious resource.

The educational tools involved (1) portable, two-dimensional physical groundwater models for use in educating primary-aged children, laypersons, academic, government, other technical professionals, and farming communities on basic groundwater issues, and (2) computer-based simulation software, which can be used to assess the accrual and movement of groundwater in actual geologic formations, as well as the fate of contaminants that reach and dissolve within groundwater. These tools have an uncommon capacity to illustrate the impact of human activities and policies to a broad spectrum of the population that includes school children, college and post-graduate students, government officials, civic groups, professional organizations, and all citizens.

We regard this partnership as the first step in a regional program that we hope to broaden beyond Jordan in the future. The project was developed and implemented along three principal thrust or activity areas that will be explained further below. In the first, we developed, delivered and demonstrated a series of prototype physical models with our Jordanian partners, and began the development of an educational curriculum for further demonstrations of the prototype (and successive models) in Jordan. In the second activity, a series of technical exchanges, primarily between LLNL, JUST and MWI, were developed regarding the use and application of new LLNL groundwater computer models in Jordan. In the final activity, the partner organizations developed a plan to broaden or expand this activity into Syria.

Initial contacts were made in order to develop a new proposal to support this activity.

2. Scaled Physical Groundwater Models

Our first activity involved a series of educational activities centered upon a scaled, physical model of groundwater flow and contaminant transport. As part of this activity, an older model was initially introduced and demonstrated to the Jordanian partners (RSCN, MWI, JUST) during an LLNL visit to Amman (Figure 1) and during a Jordanian visit (MWI, JUST) to LLNL, both in 2001. Appendix A shows several photographs of an older model and provides a brief review of its operation. It is notable that, on the initial visit of LLNL to Jordan in 2001, we were also able to show the model to Ms. Hanan Kurdi in the Royal Palace, for possible consideration as an element of a proposed Children's Museum in Amman. There is still some possibility fort his to happen, but a much larger model would be required, and interactions continue with JUST on this matter.

Figure 1. Demonstration of an older physical groundwater model to representatives of RSCN during an initial LLNL visit to Jordan (February 2001).

Following the initial visit to Jordan, LLNL began the design and construction of a new physical groundwater model based upon the solicited input of RSCN and JUST. The new model was intended to be more appropriate for Jordan-specific lessons in the sense that a hydraulically separate lower aquifer unit was included as a way to demonstrate the role and impacts of fossil water – often highly saline – that can be drawn into shallower aquifers and contaminate drinking water wells. Appendix B shows some schematics of the new model developed in this project.

Figure 2. Demonstration of the new Physical Groundwater Model to students at JUST (April 2002).

In April 2002, LLNL brought the first of the new physical models to Jordan and delivered it to RSCN. It was initially demonstrated to a university class at JUST (Figure 2) and was later brought to the Azraq Wetlands Visitors center

(operated by RSCN) for a demonstration to a group of teachers and primary-aged children (Figure 3 and Appendix C). The schoolchildren were remarkably interested in the model, despite the language barrier (the presentation was translated into Arabic). As shown in Figure 3, they were also given an opportunity to operate the model themselves. They were also quizzed on the presentation and asked very intelligent questions

Figure 3. Demonstration of the new Physical Groundwater Model by A. Tompson to schoolchildren at the Azraq Wetlands Visitors Center (April 2002).

For example, there was a group of boys who were members of a bird watching club. They asked how birds are affected by groundwater. Two example lessons were provided in response: (1) Birds come to the wetlands for water, as they have been doing so for thousands of years. Excessive pumping of groundwater for delivery to Amman has lowered the water table and drained most of the wetlands (shown in the physical model). If it were not for the small, restored ponds maintained by RSCN outside of the Visitors Center, there would be no birds to watch at all. (2) A story relevant to the US

was also provided. Near LLNL is a large agricultural region in California in which irrigation is primarily used to water crops. Once applied to the ground surface, the irrigation water eventually drains out of the ground into several surface waterways that flow naturally to a similar type of wetland area. This area is known as the Kesterson Wetlands. In this case, Kesterson did not dry up. However, several yeas ago, many of the fish and waterfowl died as a result of selenium poisoning. Selenium is a naturally occurring element in the soils underlying the irrigated crops, and it is leached out into solution in the draining irrigation water. Selenium then accumulates in the wetlands, and even though the water evaporates, selenium remains in the water at higher and higher concentrations. Eventually, it poisoned the fish and birds. More recently, the Jordanian partners are beginning to use these models, along with preliminary curricula material, for further teaching demonstrations.

As part of this project, RSCN and JUST have developed a list of secondary schools and secondary school teachers that will form the core of a broader outreach team who are being taught on the use of the model and the lessons that can explained with it. Our partners at JUST are in the process of building additional versions of these models on their own to support this effort. In January 2003, LLNL brought two more physical models to Jordan, one being an additional unit for RSCN (Figure 4), and the other being delivered to MWI.

The model provided to MWI is for use in their outreach activities. In Figure 5, the model is being presented to the Minister, Hazim El Naser and MWI project member Khair Al Hadidi. The Minister was extremely happy. Not only that, he invited us to bring a physical model to his session at the recent World Water forum in Kyoto in March 2003 (we were unable to attend). He discussed his desire to develop his own water museum (different from the Queen's Children's museum discussed above) and his impression that the model would fit well in it. The Minister also discussed his Red-Dead sea project and challenged us to build a physical model to describe its operation (he needs it;

we said we'd look into it)[1]. Later in this visit, the model was demonstrated in the Minister's conference room, and the demonstration was videotaped for the benefit of MWI, RSCN, and JUST.

Figure 4: New Physical Groundwater Model being presented to (L to R) Omar Abu-Eid, Osama Hasan, and Manal Al-Foqaha of RSCN (January 2003).

[1] Briefly, the Red-Dead sea project is a proposed Israeli/Jordanian venture designed to pump sea water from the Red Sea to the Dead Sea that will (1) arrest declining Dead Sea elevations and (2) provide power generation opportunities – for desalination – because the Dead Sea is 400 m lower in elevation that the Red Sea. The chief roadblock to the project is in securing the initial capital to build it and lingering concerns about its environmental impact.

Figure 5: Presentation of physical groundwater model by A. Tompson (seated, L) to the Jordanian Water Minister, Hazim El Naser (seated, R), Khair Al Hadidi (standing, L), and Moh'd Al-Awamleh (standing, second from R).

3. Groundwater Computer Models

The second aspect of the project involved more technically oriented exchanges, primarily between LLNL, JUST and MWI, regarding the use of new LLNL groundwater computer simulation models (Tompson et al., 1998). In this phase of the project, a delegation of participants from Jordan (specifically, Engr. Ali Subah, Mr. Mohammad Al-Awamleh, and Dr. Khair Al Hadidi from MWI and Prof. Dr. Wa'il Abu-El-Sha'r and his student, Ms. Jehan Rihani from JUST) traveled to LLNL in September 2001 to attend a weeklong workshop (Appendix D) on the use of LLNL groundwater modeling software. The purpose of the workshop was (1) for the participants to review the water and groundwater situation in Jordan through a series of colloquia, (2) for LLNL to introduce its groundwater computing software to the project participants, (3) for the group as a whole to consider how and where the LLNL groundwater software can be applied, at least initially, by the participants in Jordan, and (4) for a series of hands-on demonstrations and training with the software.

In the first portion of the workshop, Engr. Ali Subah and Dr. Khair Al Hadidi made a pair of presentations entitled, "Water Resources Management in Jordan" and "Groundwater Management in Azraq Basin". In these seminars, the criticality of water supply in Jordan was revealed and the strategy of the MWI for meeting future needs through the next 20 years was reviewed. Important aspects of the first presentation included a discussion of the roles of surface water and groundwater, conservation practices, water treatment and reuse issues, illegal wells, and management of water supplies affected or controlled by the Jordan-Israeli peace treaty.

In the second presentation, the groundwater resources of the Azraq Basin (Figure 6) and their overall importance to the water supply of Jordan were discussed. The Azraq Basin underlies the central part of Jordan and its extremities reach into parts of Syria and Saudi Arabia. Groundwater is normally recharged from precipitation over the basin (yet concentrated in the higher areas around its perimeter) and tends to move in several underground

aquifer units towards lower areas near the basin center. Historically, groundwater collecting at the basin center has up welled from the upper aquifer unit into the Azraq Oasis, a wetlands area that has been in existence for thousands of years (RSCN, 1998). More recently, however, excessive pumping has effectively lowered the water table and dried many of the wetland areas, with the exception of a small portion being restored by the RSCN. Excessive pumping has also produced, in places, older and highly saline waters that are not part of the normal recharge cycle. The MWI presentation focused on computer simulations that have been completed to date as a means for more effectively managing the water and salt balance in the basin. This issue also forms the basis of an important demonstration concept with the physical groundwater model (as discussed above and in Appendix A).

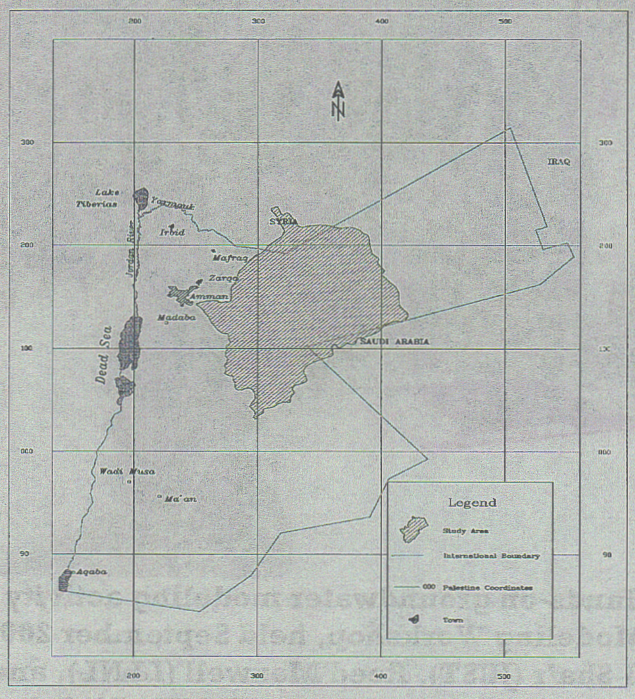

Figure 6: Location of the Azraq Groundwater Basin in Jordan. The Oasis is located in the central part of the shaded area.

Overall, it was ultimately decided by the group that the Azraq Basin would form an excellent location for application of the LLNL groundwater model PARFLOW. It was recognized by the MWI, JUST, and LLNL teams that PARFLOW has a greater capacity to represent and resolve much of the complicated geologic structure of the Azraq aquifers. Over time, the use of PARFLOW could offer a number of new approaches for managing the water extractions and track the migration and origin of saline and other recharged waters, especially if coupled with a number of other chemical and isotopic characterization techniques utilized at LLNL.

Figure 7. Hands-on groundwater modeling activity at the LLNL Groundwater Modeling Workshop, held September 2001. Standing (L to R): Wa'il Abu-El-Sha'r (JUST), Reed Maxwell (LLNL), and Khair Al Hadidi (MWI). Seated (L to R): Jehan Rihani (JUST), Ali Subah (MWI), and Mohammad Al-Awamleh (MWI).

During the reminder of the workshop, PARFLOW was formally introduced to the group in a series of hands on working sessions (Figure 7). As an exercise, the group began to develop an initial application of Parflow for the Azraq Basin. The effort utilized characterization data that MWI brought to LLNL, and paralleled the conceptualization utilized in the existing MWI groundwater model. The group agreed that completion of such an effort, with suitable comparisons to the existing model, would represent an important first step in a longer-term effort to utilize Parflow to explore more complicated groundwater flow and groundwater quality management questions at Azraq. Ultimately, it was agreed that completion of this initial effort would comprise the Master's Degree work of Jehan Rihani at JUST over the next year, and that Reed Maxwell of LLNL and Khair Al-Hadidi of MWI would serve as members of her thesis committee. In this fashion, the interests of MWI would be served through coordination with Dr. Al-Hadidi, while the more technical aspects regarding the use and application of PARFLOW would be monitored and advanced by Dr. Maxwell of LLNL.

In February 2002, during an LLNL visit Jordan to deliver the first Groundwater Physical Model (see above), LLNL visited JUST and MWI to touch base with the PARFLOW simulation project. Figure 8 shows Jehan Rihani installing PARFLOW on an MWI computer, while Figure 9 shows Reed Maxwell giving a colloquium at JUST on PARFLOW and the kinds of problems that it has been successfully applied to at LLNL.

During the remainder of 2002, Dr. Maxwell, and Dr. Al-Hadidi, interacted (remotely and directly, respectively) with Ms. Rihani on her thesis work, along with her JUST advisor, Dr. Abu El Sha'r. During the year, Ms. Rihani expressed an interest to pursue a doctoral degree in the US following completion of her MS, and she was encouraged by other members of the team to apply for a Fulbright Fellowship to support this effort.

In January 2003, LLNL again traveled to Jordan, primarily to allow for Reed Maxwell to attend Ms. Rihani's thesis presentation and defense, but also to

deliver additional Physical Groundwater Models to RSCN and MWI (see above and Figure 4). Ms. Rihani's thesis, entitled, "Application of The High Performance Computing Techniques of PARFLOW Simulator to Model Groundwater Flow at Azraq Basin (Rihani, 2003) is described briefly in Appendix E. Her work now sets the stage for another phase of PARFLOW use in Jordan. Ms. Rihani completed her defense (and thesis) successfully. Later in the year, she learned that she was to be awarded a Fulbright Fellowship for doctoral study in Environmental Engineering at the University of California, Berkeley, where she will begin her work in earnest in August 2003. During her studies in Berkeley, Jehan's proximity to LLNL would allow her to continue interactions with the LLNL team as part of her doctoral studies.

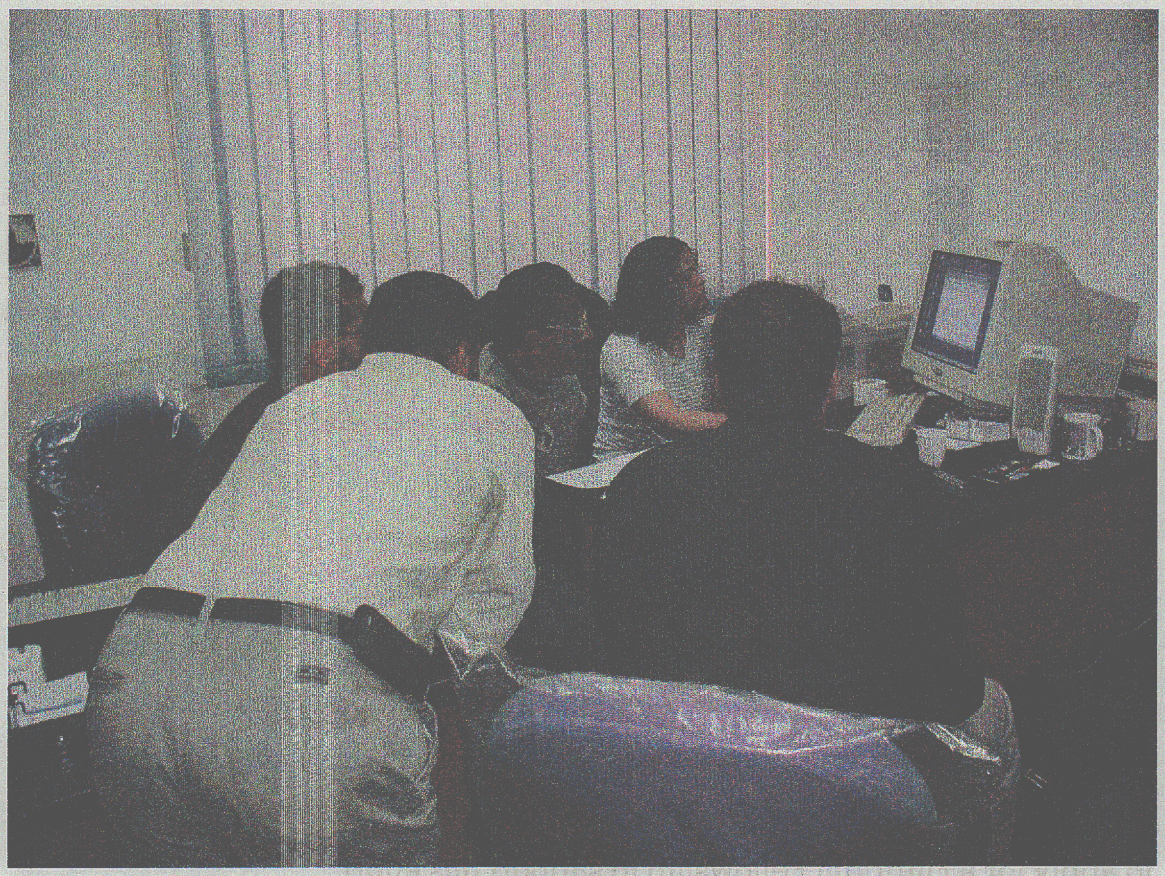

Figure 8. Jehan Rihani (seated at computer) working with PARFLOW at the Jordanian MWI in April 2002.

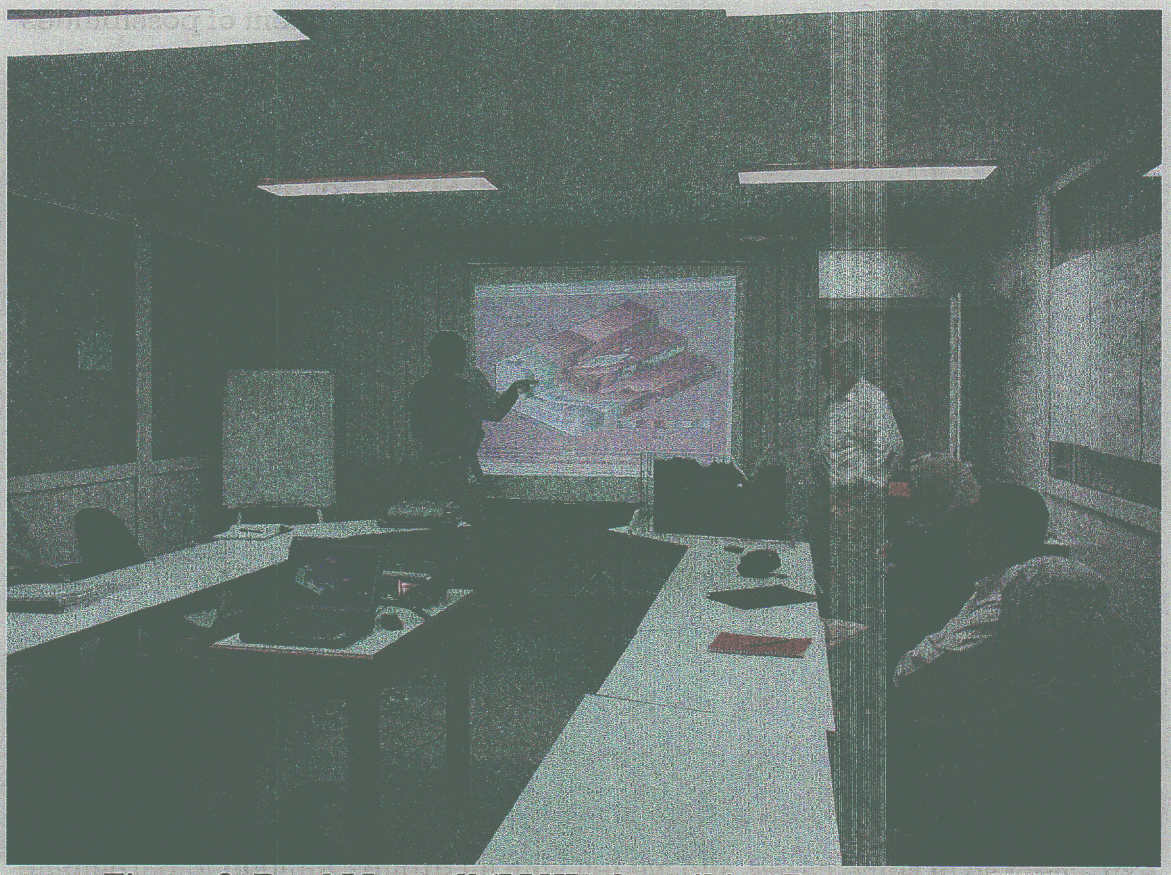

Figure 8. Reed Maxwell (LLNL) describing PARFLOW at a JUST colloquium, April 2002.

During the last LLNL visit to Jordan in January 2003, both the LLNL and JUST teams also traveled to Damascus, Syria for a series of meetings with various Ministry and Educational officials regarding the possible expansion of this project (via a new and separate proposal) into Syria. Further details on this visit are provided in the next section.

4. Project Expansion into Syria

A final aspect of the current project involved the development of possibilities and contacts for expanding our educational program to other parts of the Middle East, and in particular, Syria. In January 2003, Andrew Tompson and Reed Maxwell of LLNL traveled with Wa'il Abu El Sh'ar of JUST and Paul Malik of the US Embassy in Amman to Damascus to attend four meetings set up by the US Embassy in Damascus on our behalf. The (separate) meetings took place at the Ministries of Education, Irrigation, and Environment, and the last was conducted at the University of Damascus with a newly founded NGO group called the Syrian Environmental Association at the University of Damascus (Figure 10). Peter Schroeder of the US Embassy in Damascus helped set up the meetings (Appendix F) and accompanied us on all visits.

In each visit, we discussed our interest in developing a new project along the lines of our Jordanian one; we reviewed our work and accomplishments in Jordan, and we showed each group the Physical Groundwater Model (but did not demonstrate it because of time limitations). All meetings went very well, extremely so in some cases, and we left with all groups wanting to participate and all write letters of support.

There were some differences in the people we met and the overall kind of interest we received. At the Ministry of Education, we met the Director of Cultural Relations and a number of ministerial employees who are in charge of environmental, science, sociology, and geography education in the secondary school system and also higher education system in Syria (see Appendix F). We also met Adel Awad, a professor of environmental engineering at Tishreen University in Latakia. Prof. Awad was invited at our request because he was recommended by Wa'il Abu El Sha'r, and has had a previous introduction to our project. He expressed a strong interest in participating in our new project.

Figure 10: Visits and discussions at the Syrian Ministry of Education (upper L), Ministry of Irrigation (upper R), Ministry of Environment (lower L), and Syrian Environmental Association at the University of Damascus (lower R) in January 2003, with Physical Groundwater Model being shown.

At the Ministry of Irrigation, we met the Deputy Minister of Technical Affairs (who is also on the Faculty of Science at the University of Damascus). We also met the Directors of Technical Affairs and Planning. As we were told, this ministry is in charge of all water in Syria, although it seemed that they referred primarily to large infrastructure projects, surface water distribution systems, and agriculture. There seemed to be less emphasis on groundwater (although some simple modeling work was discussed), and little emphasis on water quality problems. Although the Ministry did not seem to foster significant outreach programs, they were intrigued and interested in our proposed work and wanted to remain in contact.

The Ministry of the Environment seems to be a newer agency, staffed by younger and more recently educated people. We specifically met with Reem Abed-Rabboh, Director of the Water Resources Management Department, and Sawsan Arafeh, Rania Shamseen, and Leen Abed Rabo, who are all environmental engineers. Dr. Adel Awad of Tishreen University also attended this meeting. Ms. Abed-Rabboh emphasized the importance of their ministry's mission to interface with all other ministries in matters environmental, and discussed the importance of outreach and public awareness programs in their work. There was specific interest in groundwater quality and contamination problems, especially with respect to modeling and prediction of hydrodynamic dispersion phenomena, and the problems of Damascus groundwater were again discussed. Notably, Ms. Abed-Rabboh was a former student of Dr. Awad. As in previous meetings, interest in our proposed project was very strong.

The meeting at the University of Damascus was led by Dr. Warka Barmada of the Directorate of International and Cultural Relations. Also in attendance were Dr. Ihab Jnad of the Faculty of Agriculture, and Dr. M. Fawaz Azmeh of the Faculty of Agriculture and Vice Dean for Scientific Affairs. Dr. Barmada also heads up the Syrian Environmental Association, and was, again, extremely interested in our proposed project. Upon hearing of the other ministries that we visited that day, she was extremely concerned about who locally will be coordinating the work, if funded, and stressed how funding may now be sent directly to the University of Damascus. We were also pleased by her quick interest in moving forward and her recognition of project coordination over the long haul.

Ultimately, what needs to be done is for the groups to assimilate more precisely what we want to do (e.g., Appendix G), suggest in writing what they are interested in (among what we discussed), and for us to craft a more exacting proposal tuned to specifics we heard there. We kept all groups informed as to whom we met with; Dr. Abu El Sha'r was very helpful in

expressing the importance of a team approach and for the groups to possibly confer together and with the Jordan team. The importance of education as a goal of this project was reemphasized - knowing that US aid to Syria is very restricted - and the need to grow the new project out of our Jordan work through continued regional cooperation. More communications were promised to follow.

Prior to the Ministerial meetings, LLNL and JUST also had an informal meeting with another water specialist, Dr. Jean Khouri, whose name was provided a contact provided to A. Tompson by a colleague back in the US. Dr. Khouri spent the last 30 years in ACSAD (the Arab Center for the Study of Arid and Dry Lands, part of the Arab League), most recently as director of the water resources division. Prior to that, he was head of the Syrian groundwater bureau for 10 years, and prior to that, he established the first hydrogeology program at the University of Damascus. He liked our project very much; thought it was a great idea, and was very supportive. He suggested that, among other things, water data was poorly organized, not fully developed or nonexistent in many parts of Syria (e.g., hydrogeologic data, water quality data, stream flow data, etc.) and that work in this area could lead to longer term improvements in the water sector in Syria. Moreover, he noted that concern for groundwater pollution and mass transport was not well developed, appreciated, or understood in much of Syria, and that improvements in education and public awareness of these issues would go a long way. By way of example, Dr. Khouri reviewed the water supply story of Damascus. Most water has traditionally been developed from karst springs in the nearby Anti Lebanon Mountains that have been in use for centuries. Increased population and drought have forced the development of several well fields in Damascus and the plains to the east of Damascus, and these have revealed significant pollution from sewage and wastewater discharges as well as chemicals from local textile industries. Much of the sewage in Damascus has only recently been connected to wastewater treatment plants and some

portions of the city still discharge raw sewage into nearby watercourses, including the well-known Barada River.

Dr. Khouri wanted to stay in the loop or our efforts, so we will keep him abreast of our work as it progresses.

5. Summary

This project involved two main activities that were coordinated among four principal partners: the Lawrence Livermore National Laboratory, University of California (LLNL), the Jordan University of Science and Technology (JUST), the Royal Society for the Conservation of Nature (RSCN) and the Jordanian Ministry of Water and Irrigation (MWI).

The first activity involves a series of educational activities with all partners to educate primary-aged children, laypersons, academic, government, other technical professionals, and farming communities on basic groundwater issues – its production, depletion, movement, and pollution, using a simple Physical Groundwater Model. The second activity involved technical exchanges, primarily with JUST and MWI, regarding the use of new LLNL groundwater computer models in Jordan. A small third activity involved developing an approach to establish these kinds of interactions in other countries of the region.

In all senses of the word, the project was a success. New Physical Groundwater Models were designed, developed, and brought to Jordan for demonstrations, and further curricula development is underway between JUST, LLNL, and RSCN. The models were welcomed not only by RSCN – as the principal 'NGO' on the project – but also by JUST and MWI. The cooperative use of LLNL PARFLOW model in Jordan between LLNL, JUST, and MWI was successfully initiated through the training of a new graduate student at JUST. Her work was well received and she was ultimately awarded a Fulbright Fellowship for further graduate study at the University of California. LLNL and JUST were energized by a fruitful exploratory visit to Syria where a future phase of this work may begin soon.

There is a broader purpose for this work, of course, and that is to begin forge important and lasting relationships with our new colleagues in the Middle East, making meaningful scientific contributions along the way,

especially in troubled regions where such relationships and contributions albeit small, can make a big difference. We were all struck by a positive cooperative team spirit that developed in this project (Figure 11) and the fact this spirit was markedly reinforced during the LLNL modeling workshop – held, coincidently, during the week of the 9/11 terrorist attacks.

Figure 11: Project team lunch in April 2003 (L to R): A Tompson (LLNL), J. Richardson (LLNL), A. Al Zoubi (RSCN), R. Maxwell (LLNL), K. Al Hadidi (MWI), J. Rihani (JUST), O. Abu-Eid (RSCN), W. Abu El Sha'r (JUST), A. Subah (MWI) and R. Hayyaneh (RSCN).

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Appendix A. Operation of the Physical Groundwater Model

This Appendix provides a brief review of the purpose and operation of the Physical Groundwater Model shown in Figure A1 and follows some of the basic lessons demonstrated with the model during visits in Jordan. Further details will be provided in a future document, "Teaching with Physical Groundwater Models".

Figure A1. One of the new Physical Groundwater Models and associated operating equipment developed for this project.

This small model illustrates how water occurs and moves through the earth beneath the ground surface. Many features and characteristics of real systems described below can be seen here.

A1. What is Groundwater?

Water that occupies the pore spaces of underground soils and rocks is called groundwater. Groundwater occurs as part of the natural hydrologic cycle (Figure A2). We are all familiar how rainfall or melting snow can runoff over the ground surface and collect into lakes and flowing streams – but, it can also infiltrate into the ground and collect in deeper saturated zones where the openings, fractures and pore spaces soils or rocks are completely filled with water. The water "surface" beneath which the soil or rock is saturated is called the water table. The region between the ground surface and the water table, through which percolating rainwater travels, is called the unsaturated zone. In dryer areas, such as in the desert areas of Jordan or the American southwest, the water table is generally located at deeper locations. In wetter areas, the water table is generally found at shallower locations.

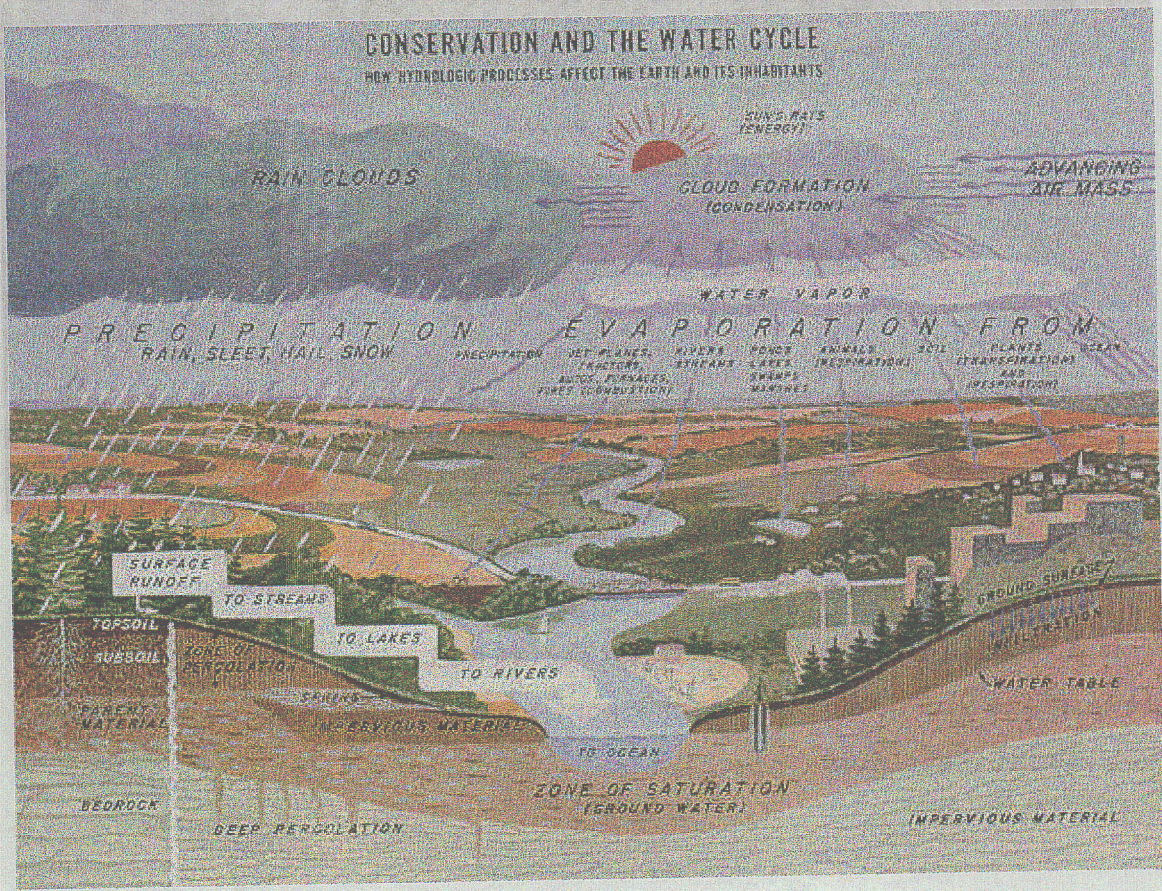

Figure A2. Natural hydrologic cycle.

Even in dry areas, the water table may be found close to the ground surface, especially in low-lying valleys or basins. In some cases, the water table may actually "cross" the ground surface at locations where there are surface lakes or rivers (see Figure 2). This was historically the case in Jordan's Azraq basin, where these ponds and lakes assembled to form the Azraq Oasis, a large area of surface wetlands, with a rich diversity of plants and animals that came to grow or rely on this water.

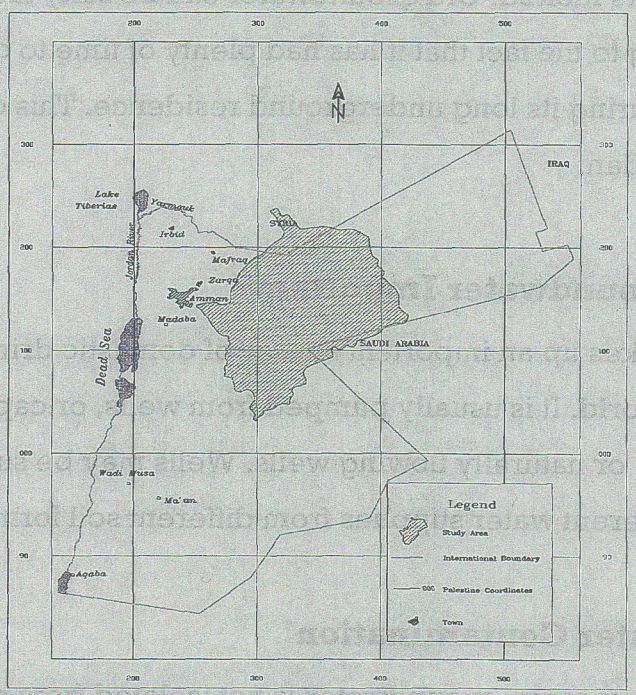

Figure A3: Location of the Azraq Groundwater Basin in Jordan. The Oasis is located in the central part of the shaded area.

Groundwater will actually flow or seep underground from areas where the water table is high to areas where it is low. Groundwater typically moves at about 10 to 100 meters per year. In the Azraq Basin of Jordan, Syria, and Saudi

Arabia, for example, groundwater flows from the higher areas at the perimeter of the basin near Syria and Saudi Arabia (Figure A3), where it is has been recharged from precipitation, to the basin center, where it may move into the wetlands, evaporate, or be transpired by the roots of plants and trees. Shallower groundwater is usually "younger" than deeper groundwater. By this, we mean that it has only been underground for a relatively short period of time (say less than 100 years) during is movement through the hydrologic cycle. Some deep groundwater is very old, often more that a 1,000 years, and has been "locked" underground, away from the hydrologic cycle, for this entire time. In the United States, some deep groundwater dates back to the time when glaciers melted. Old groundwater can be salty and taste bad, in some case, owing to the fact that it has had plenty of time to dissolve salts and other minerals during its long underground residence. This can be the case in some parts of Jordan.

A2. Why is Groundwater Important?

Groundwater makes up an important source of domestic drinking water throughout the world. It is usually pumped from wells, or captured in so-called "Artesian" or naturally flowing wells. Wells may be sunk to different depths to tap different water supplies from different soil formations.

A3. Groundwater Contamination

As remote as it may seem, groundwater is not isolated from what happens on the earth's surface. Groundwater may flow into or out of rivers and lakes. Groundwater is replenished from rain and melting snow via seepage through soil.

Unfortunately, any kind of hazardous liquids or materials poured on the ground, buried beneath the ground surface in leaky containers, or introduced down a well may find their way into groundwater, just as the rain and snowmelt do. Hence, groundwater may become contaminated in some places.

This can even apply to agricultural fertilizers that slowly dissolve into percolating rainfall, or to salty seawater that is drawn towards huge pumping wells in coastal cities like Miami or Hong Kong.

Since groundwater moves, it will carry contaminants along with it. This may threaten drinking water supplies in wells, or even the clarity and quality of water in lakes and streams.

A4. Cleanup of Groundwater Contamination

Groundwater is easy to contaminate, but really hard to clean up. Why is this so?

The extent of contamination is usually difficult to ascertain from the surface. So are the properties of the soils that control how fast the water moves, or how fast chemicals react or degrade. Plus, many contamination events may go unnoticed for years before they are discovered. By this time, that may have spread far and wide.

One approach to clean up is to remove the "dirty" water by pumping. Pumping draws contaminated water towards wells from which the water may be removed and treated. This can take a long time, a lot of energy, and a lot of money, and it assumes we know where all the contamination is!

Another way is to chemically manipulate the contaminated water by introducing bacteria or other chemicals to degrade the contaminants into harmless compounds.

A third way involves the introduction of heat, say, through the injection of steam, to degrade the contaminants into harmless compounds.

These techniques may be cheaper and faster, but must be carefully tailored for specific contaminants in specific groundwater environments. Physically exposing or mixing contaminated groundwater with bacteria, other chemicals, or heat can be a tough job.

The best way clean-up groundwater is to never let it get polluted in the first place. This is an important message that can be demonstrated with a Physical Groundwater Model.

A5. Some Simple Examples

The following figures illustrate how a Physical Groundwater Model can be presented and demonstrated. These figures pertain to an older model (different from that in Figure A1) that was taken to Jordan for initial demonstration and project organization purposes (as in Figure 1 of the main text).

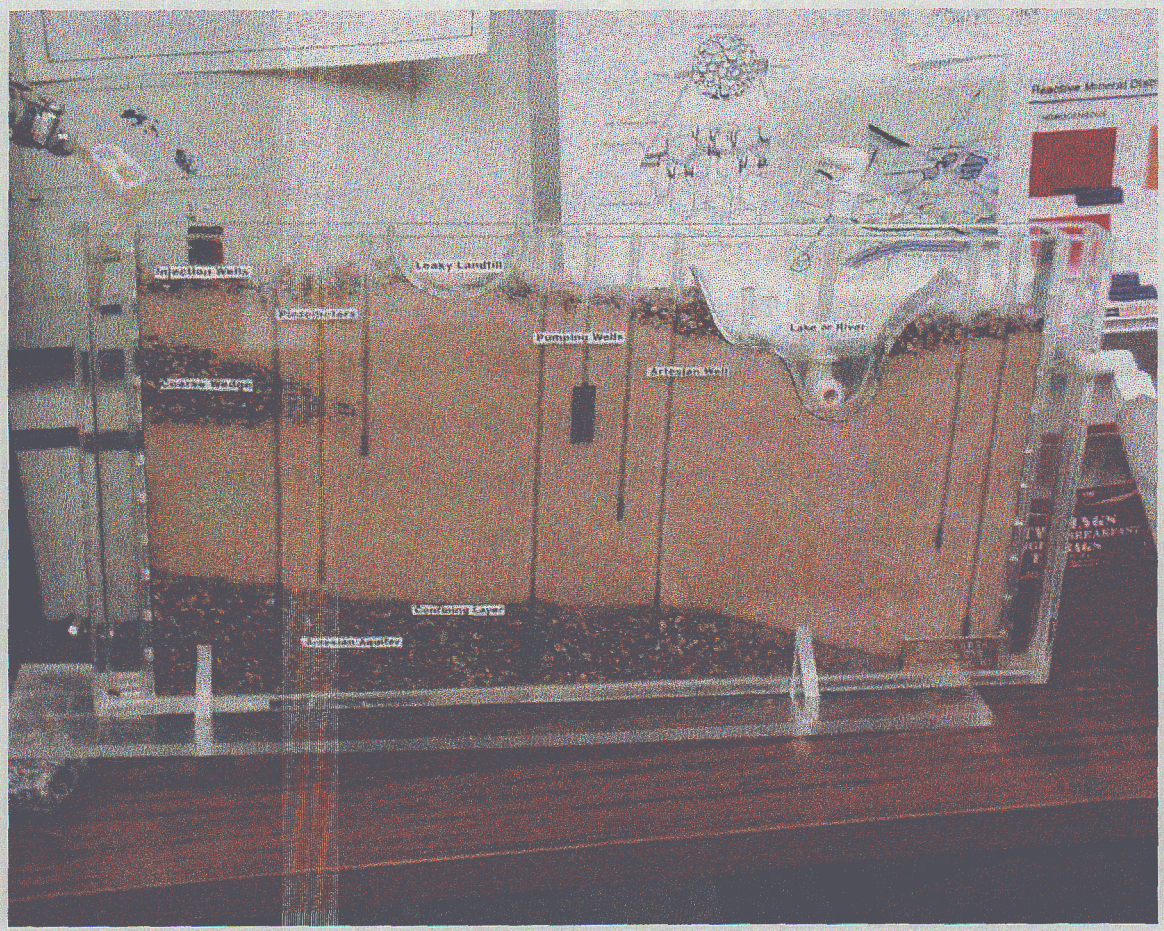

Figure A4. A generic picture of an older Physical Groundwater Model that was taken to Jordan for demonstrations.

Figure A4 shows is a generic photograph of a Physical Groundwater Model, showing a deep artesian aquifer, a confining layer, a sandy aquifer, various wells, a lake, and a "landfill". Water can be introduced on the left, in a vertical reservoir to simulate the infiltration of "snowmelt" or "rain" in high elevation areas, and induced to move underground towards a drain reservoir on the right, where the water level is lower. At lower elevations, groundwater may intersect the ground surface, as it did at the Azraq wetlands in Jordan. The vertical tubes in the system represent water wells that can be pumped to extract water (see below). The water table can be inferred by connecting the water levels observed in the well tubes. The water table can be lowered by significant extraction of water; this can also reduce the water level in the lake, or even dry it out completely, as happened at the Azraq wetlands.

In Figure A5, a pulse of blue dye was injected into a hidden well on the left side of the picture (using a syringe as an injection pump). This dye be used to monitor the flow of groundwater in time, from the left to the right, or be considered as a pollutant that will move through the system and possibly contaminate other wells.

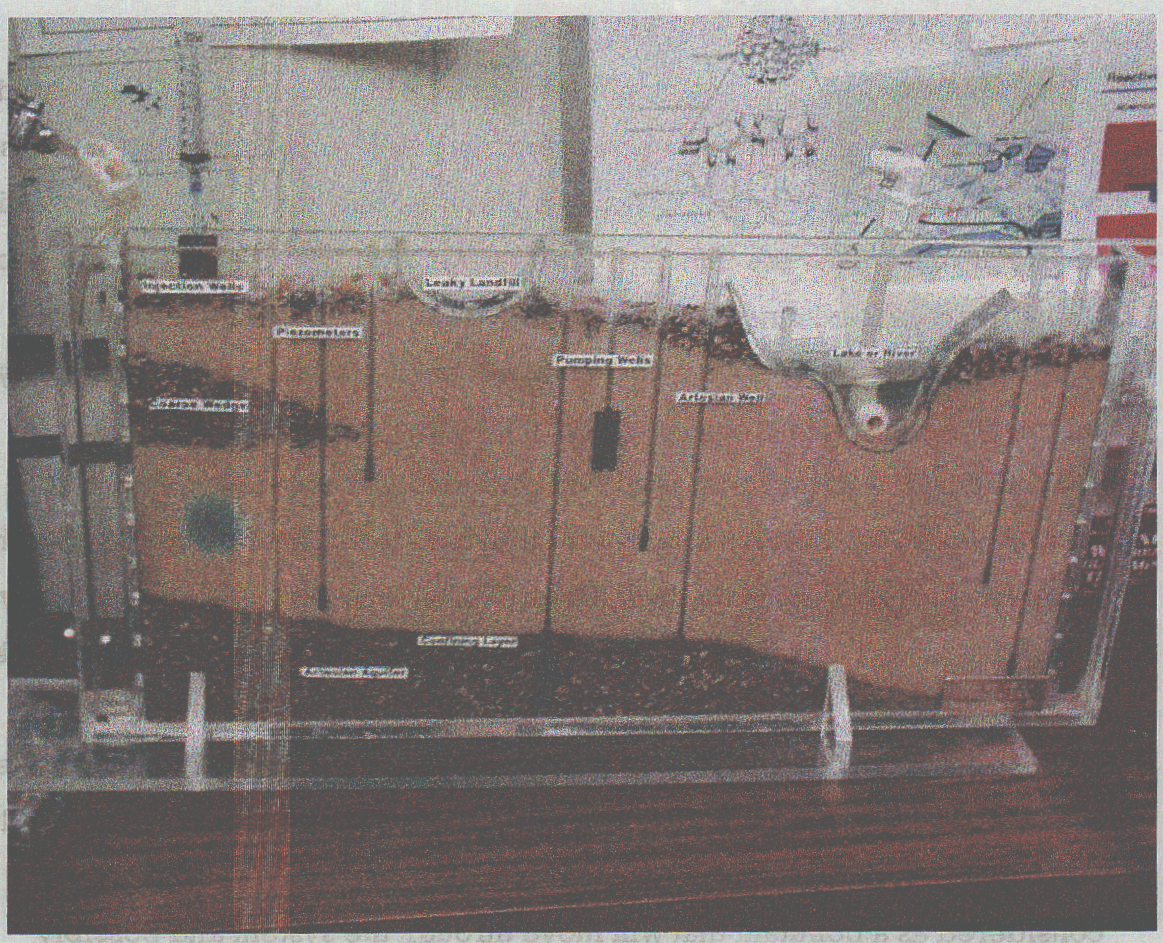

Figure A5. Injection of a pulse of blue dye through a hidden injection well on the left side of the model.

In Figure A6, the blue dye has moved a bit. In addition, some red dye is now introduced into the "landfill", just above the water table. This can be used to demonstrate the discharge of sewage, wastewater or pollutants on the ground surface or the over-application of pesticides or fertilizers in agriculture.

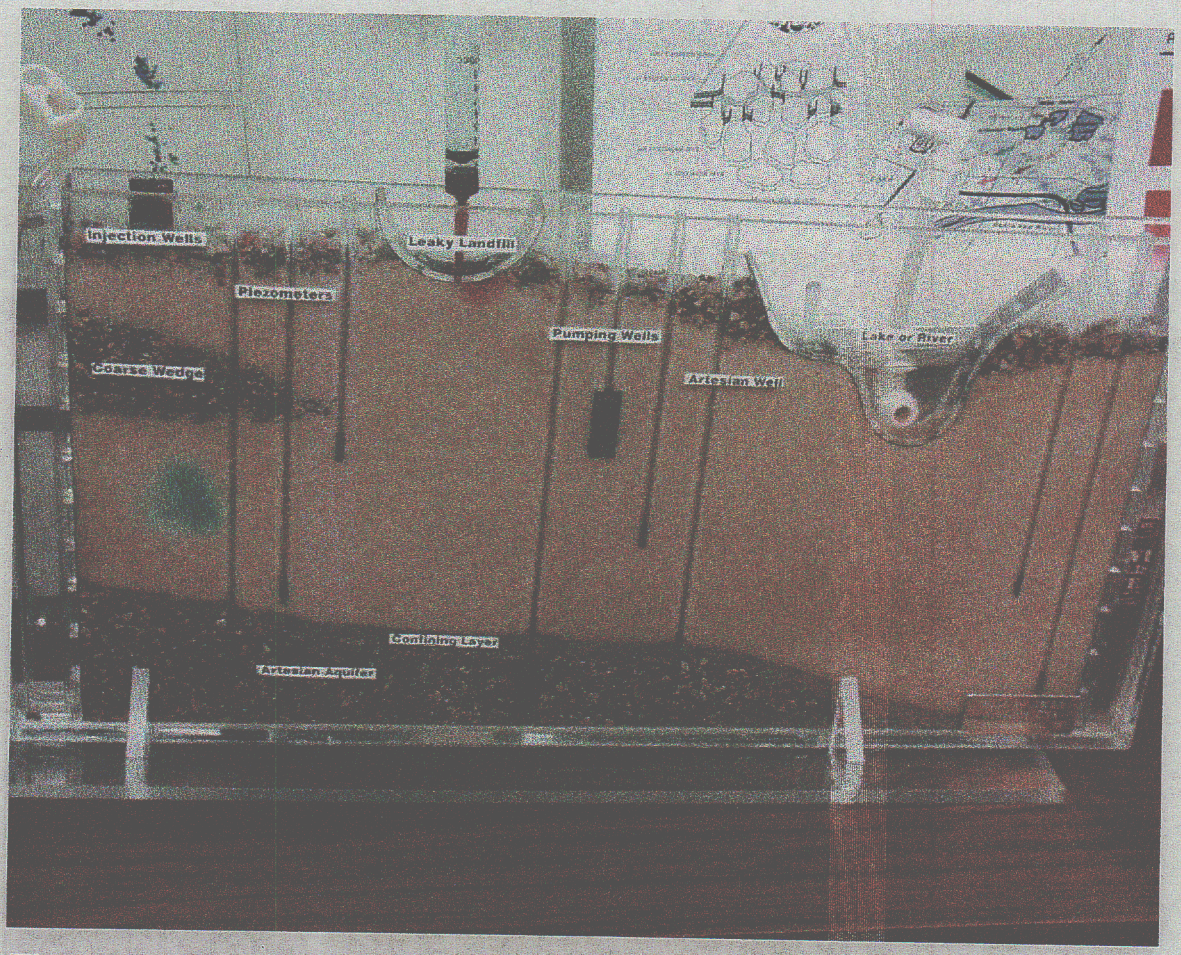

Figure A6. The blue dye has moved a bit. Some red dye is introduced into the landfill, just above the water table.

In Figure A7, the blue dye has moved more and the red dye tracks along the interface between the gravel and sand, towards the lake, along the edge of the water table.

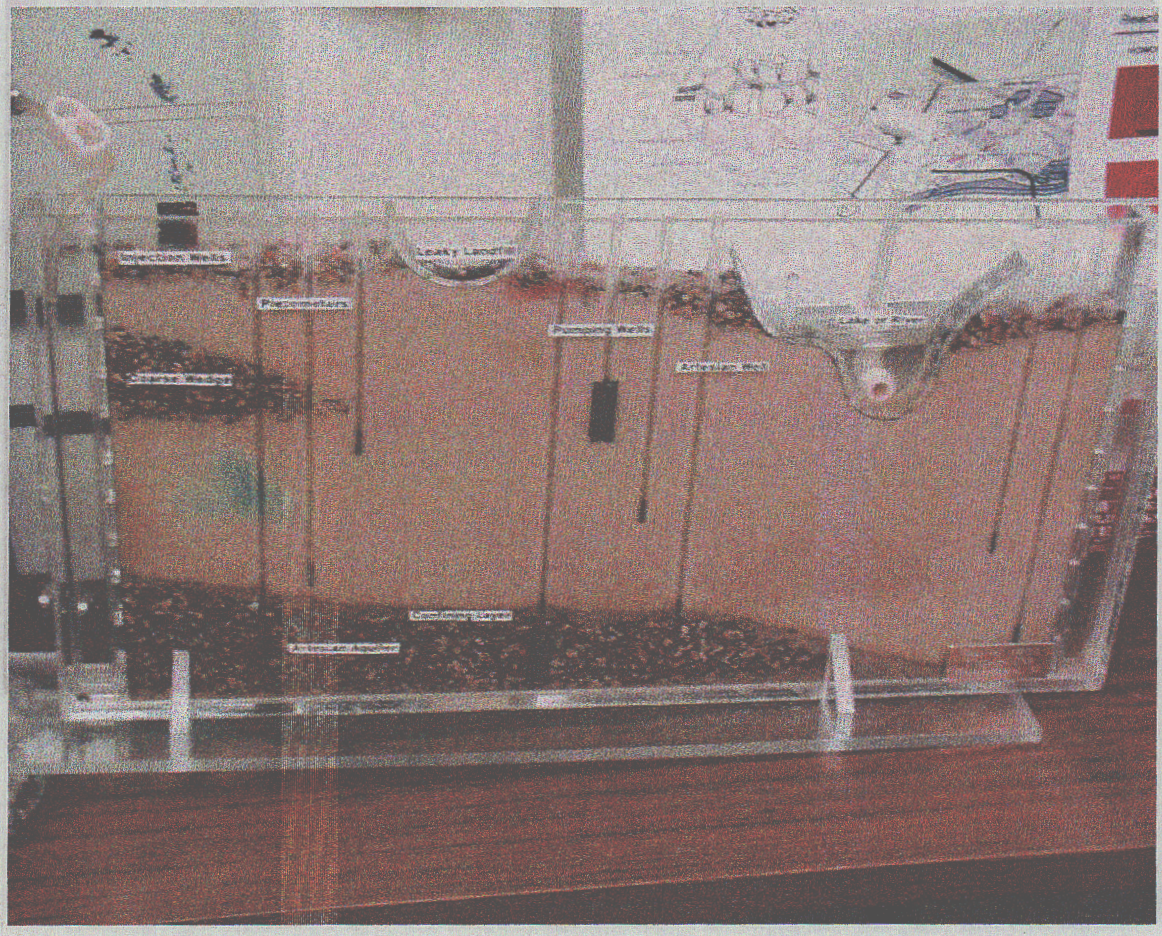

Figure A7. The blue dye has moved more and the red dye tracks along the interface between the gravel and sand, towards the lake, along the edge of the water table.

In Figure A8, the blue dye has moved to the well, in response to pumping. The well is now contaminated. The concentration of dye in the pumping syringe is lower than that of the dye originally injected because of diffusion phenomena and the fact that clean water is mixed with the dye in the well. Alternatively, the well may be considered as a remediation well that attempts to extract contaminants from the system.

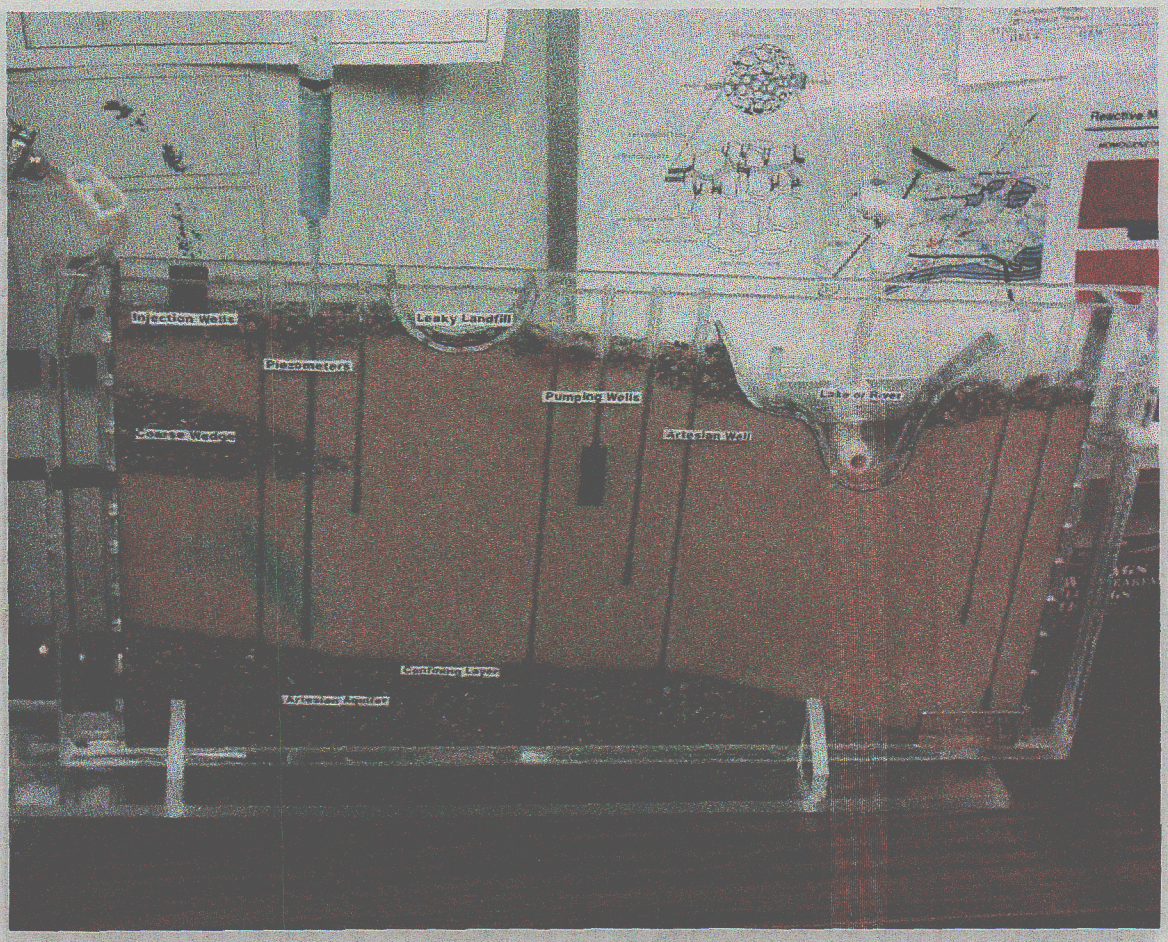

Figure A8. The blue dye has moved to the well, in response to pumping. The well is now contaminated.

In Figure A9, the red dye has reached the lake in this close up. Surprise, where did that come from? Note, also, the bubble in the small "funnel" placed in the Artesian well, neat the "shore" of the lake. This indicates water wanting to flow upwards under pressure from the gravel at the bottom of the tank (Figure A8) through a hidden well. We would call this an Artesian well since it flows under its own pressure (after Artois in France, where many such wells were originally exploited). If the hidden well were a natural fissure instead, we would call this flowing water a "spring".

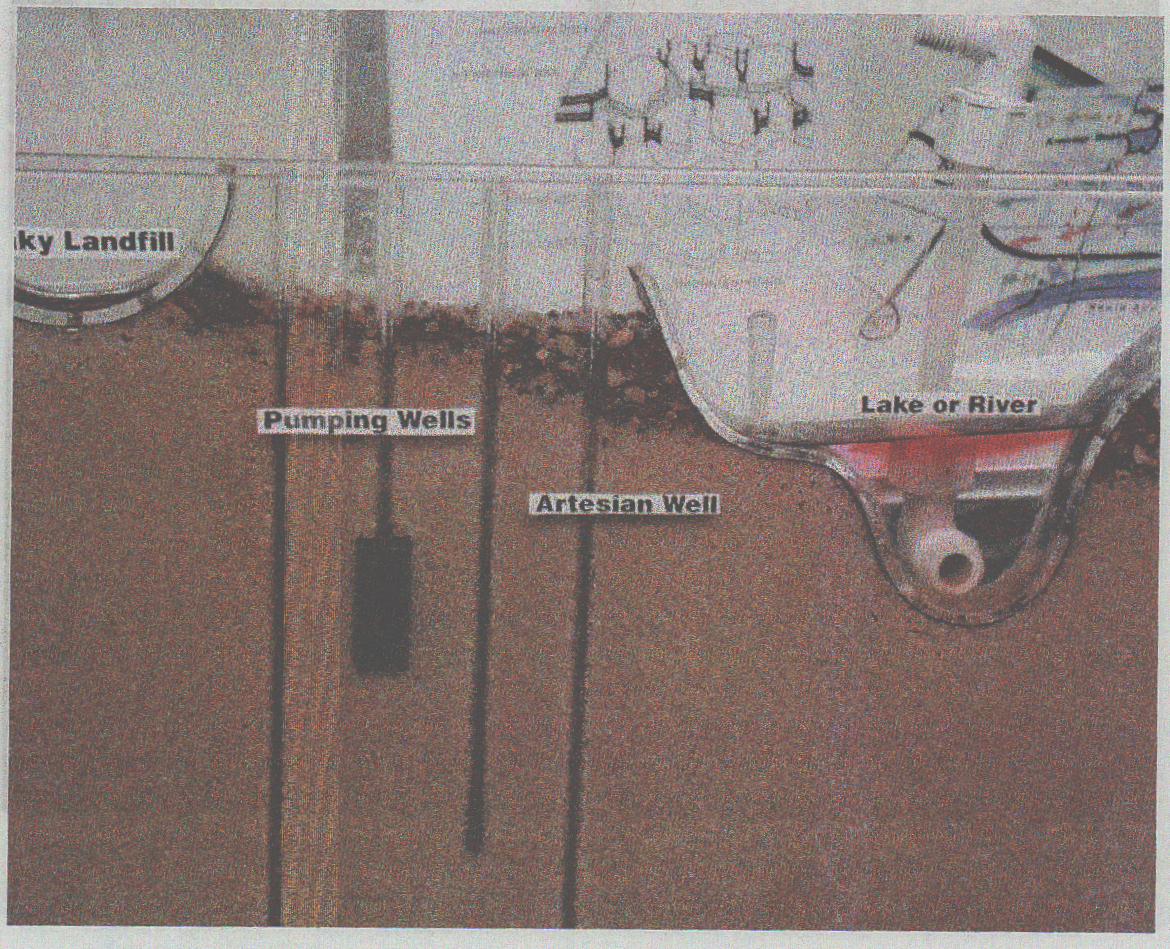

Figure A9. The red dye has reached the lake in this close up.

In Figure A10, the blue dye has moved well away from the source and has an elongated, dispersed profile. Note the red dye has moved out of the lake, under natural conditions.

Figure A10. The blue dye has moved well away from the source and has an elongated, dispersed profile.

Appendix B. Parts and Related Design Criteria for the Physical Groundwater Model

B1. Basic Plan

The basic framing plan of the new physical model is shown in Figure B1. The model has dual input and drainage reservoirs on both ends so that pressure and flow conditions in upper and lower aquifer regions can be controlled more independently. There is also a drain on the backside to allow for the "pond" (not shown here, see Ponds and Lake Plan below) to act as a "river".

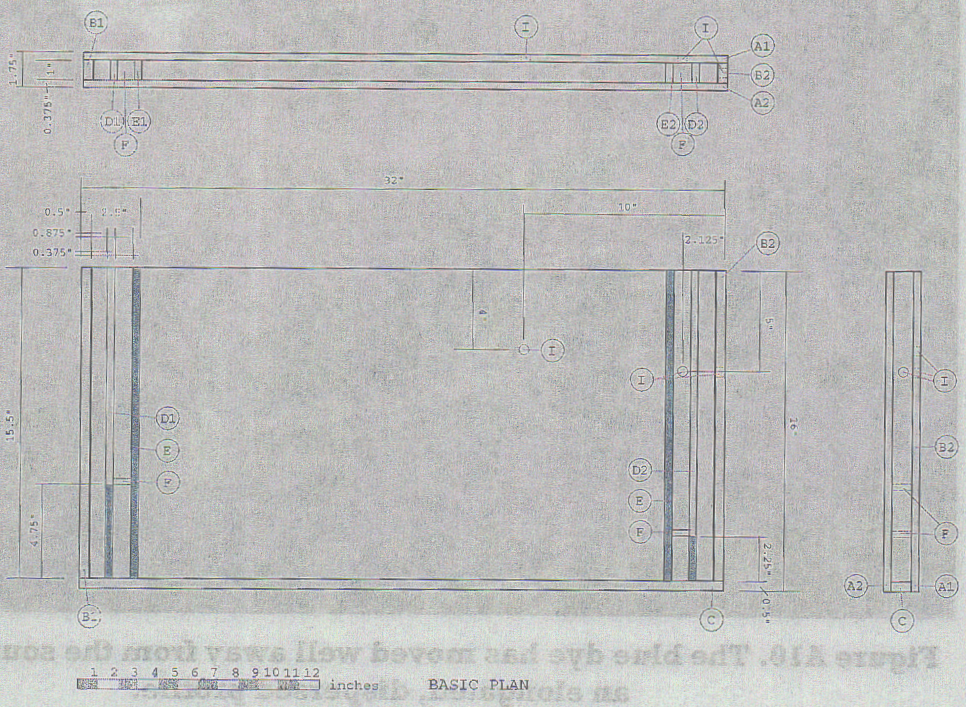

Figure B1: Basic framing plan for the Physical Groundwater Model

Parts List

A1 and A2. Front and rear panels, PMMA acrylic, 32" x 16" x 3/8", beveled outside edges. Rear panel has two 1/2" threaded holes for screw-in drain tubes (1 piece each).

B1 and B2. Left and right side walls, PMMA acrylic, 15 1/2" x 1" x 1/2", beveled top edges. Right side wall has a 1/2" threaded hole for an additional screw-in drain tube (1 piece each).

C. Bottom element, PMMA acrylic, 32" x 1" x 1/2", beveled bottom edges (1 piece).

D1 and D2. Left and right side middle internal reservoir boundaries, PMMA acrylic, 15 1/2" x 1" x 3/8", perforated for flow on bottom 4 3/4" (left) or 2 1/4" (right) (1 piece each). *Perforation technique discussed below.*

E. Inside internal reservoir boundaries, PMMA acrylic, 15 1/2" x 1" x 3/8", perforated for flow over entire length (2 pieces). *Perforation technique discussed below.*

F. Reservoir bridge for separating internal and middle internal reservoir boundaries, PMMA acrylic, 1" x 7/8" x 3/8", non-perforated (2 pieces).

I. 1/2" grooved holes for screw-in drain tubes (3 instances).

Comments:

A. Parts to be glued or fused together with additional screw connections at joints for increased durability.

B. Perforation technique to be used on D and E to include drilled holes or slots and water permeable tape or related material slots.

B2. Ponds and Well Plan

The Ponds and Well Plan of the new physical model is shown in Figure B2. From left to right are an "agricultural basin", a "landfill", and a "lake", which may also be operated as a river if the drain on the backside is engaged. The wells may either be attached to the front panel (blue) or in the center of the model (yellow), where they will not be visible when the geologic materials are inserted. The well entering the bottom of the lake is to be operated as an artesian well or spring.

Parts List

J1 to J7 1/4" outer diameter (OD) tubes to be used as internally- or wall-mounted wells, various lengths and numbers. The bottom 1" of each tube will be replaced by a porous, 1/4" OD fritted nickel tube, fused shut at the bottom, which will act as a "well screen".

J1, 4" long (2 pieces)

J2, 8" long (1 piece)

J3, 13" long (1 piece)

J4, 9" long (2 pieces)

J5, 5 1/2" long (2 pieces)

J6, 14" long (2 pieces)

J7, 12 1/2" long (1 piece)

K1 to K3 1/8" perforated barriers, PMMA acrylic, for lining the bottoms of the lake and recharge basins (1 basin, 1 lake. 1 lake/river). The barriers will be covered by water permeable tape.

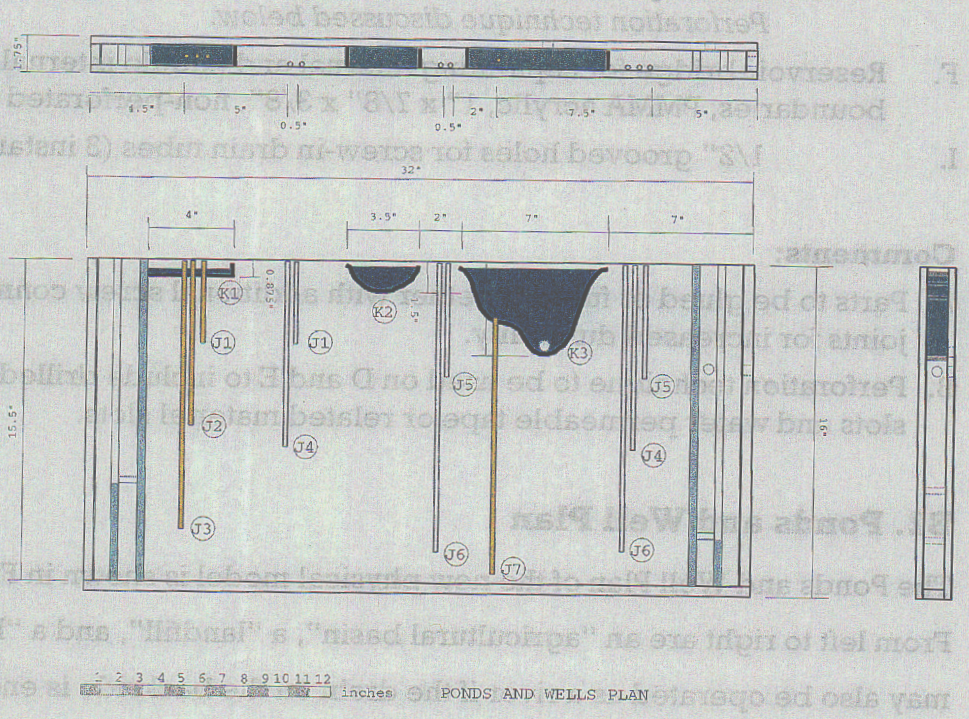

Figure B2: Ponds and well plan for the Physical Groundwater Model.

Comments:

A. Wall-mounted wells to be glued into place *before model has been loaded with geologic materials.*

B. Internally mounted wells to be inserted into place *with the loading of the geologic materials.* Glue carefully the three internal wells passing through the agricultural basin (on the left) to the basin frame.

C. Lake and pond barriers to be glued into place between face and rear plates *during or immediately after has been loaded with geologic materials.*

D. Protection of the top and bottom (exposed) portion of the well tubes may include covering with permeable tape and / or strengthening with thin metal cap or cylinder.

B3. Geology Plan

The Geology Plan of the new physical model is shown in Figure B3. Three principal types of geologic materials will be used. The dark brown areas correspond to low permeability clays that will be used to separate the three more permeable aquifer units in white. The upper yellow area corresponds to a very permeable layer of pea gravel. Pea gravel might also be used in the lower-most aquifer unit. The clays that define the boundaries of the aquifer units must be placed carefully. It is envisioned that the lower-most aquifer unit can be operated as a "fossil" or "saline" aquifer whose water (colored, for example) may be drawn into the upper aquifers (through a small gap in the clays) if the pumping stresses are sufficiently large or if the system is drained only through the right-most drain reservoir. A completed model, partially unpacked from its case, is shown in Figure A1 in Appendix A.

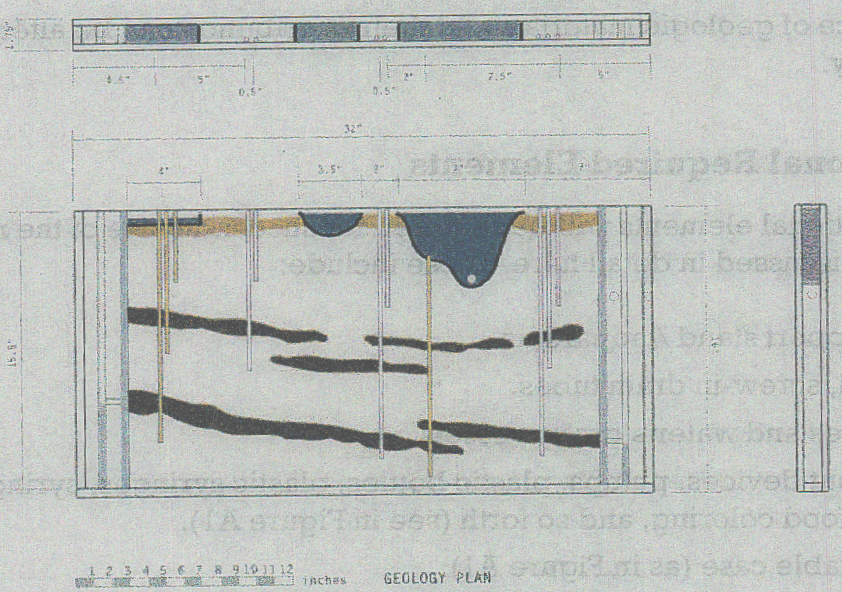

Figure B3: Geology plan for the Physical Groundwater Model

Parts List

Clay	Mix a small amount of dry Bentonite clay (available at ceramics stores) with moist fine-grained sand or soil using a loose 1:5 or 1:10 volume ratio. Mix well and keep moist during emplacement into the model. Keep well packed during emplacement.
Sand	Use a clean, white silica sand (e.g., ASTM 20-30 uniform white silica sand conforming to ASTM C778).
Pea Gravel	Use a 1/8" to 1/4" pea gravel (available at landscape supply stores).

Packing tools, such as a small tamping block, bent shirt hanger, and various funnels.

Comments:

A. Packing the model can be tricky, especially when burying internally mounted wells. Only add and distribute small amounts at a time. Carefully tamp the clay layers before proceeding, and moisten if necessary. Try to not bury well screens in clay.

B. Distribution of clay materials (as the locations shown) is critical for defining the leaky three-aquifer system and for hydraulically separating the pairs of input and drainage reservoirs.

C. The choice of geologic materials and their distribution can be altered if necessary.

B4. Additional Required Elements

Several additional elements will be required for successful use of the model, but are not discussed in detail here. These include:

A. Model support stand / apparatus.

B. Threaded, screw-in drain tubes.

C. Drain hoses and water storage vessels

D. Water input devices, pumps, plastic bottles, plastic syringes, syringe needles, food coloring, and so forth (see in Figure A1).

E. Transportable case (as in Figure A1).

F. A more detailed Instruction and operation manual.

Appendix C: Physical Model Demonstration Workshop, RSCN Azraq Wetlands Visitors Center, Azraq, Jordan, April 10, 2002

The Royal Society for the Conservation of Nature
Reserves Section + Public Awareness Section

Work Shop
Demonstration of Azraq Water Model

Wednesday 10th April 2002
Azraq Wet Land V.c

Time	Activities
8,00 – 8,30	Short meeting At the Hotel
8,30	Leaving to Azraq
10,00	Arrival to Azraq
10,00-10,15	Coffee Break
10,15-10,30	Welcoming
10,30-11,30	Presentation about Azraq Water Model + Demonstration for the model
11,30-12,00	Discussion with the Educators+ Students +RSCN project team
12,00-1.00	Meeting with the team project
1,00- 2,00	Site seeing in Azraq Wet Land Reserve
2,00- 3,00	Lunch Break

RSCN team project:
Omar Abu- Eid / Reserves Section Manager
Leena Al –Faiz / Azraq Wet Land Reserve Manager
Manal Al- Foqaha / Public Awareness Section
Rani Haiook / Azraq Visitor Center
Ahmad Al Zoubi / Educational Officer
Anwar Al Halah / Educational Officer

Appendix D: LLNL Groundwater Modeling Workshop, September 2001

The workshop agenda and photos are included below.

Lawrence Livermore National Laboratory

AGENDA

Groundwater Modeling Workshop

"Experiential Education in Groundwater Hydrology: Bridging the Technical - Policy - Populace Gap"

U.S. Information Agency, Department of State
Lawrence Livermore National Laboratory
Jeffery Richardson
Andrew Tompson
Reed Maxwell

Jordan Ministry of Water and Irrigation
Engr. Ali Mohammed Ali Subah
Moh'd Hasan Mousa Al-Awamleh
Dr. Khair Hasan Yousef Al Hadidi

Jordan University of Science and Technology
Prof. Dr. Wa'il ABu-El-Sha'r
Ms. Jehan F. Rihani

Sunday, September 9, 2001

Arrival, San Francisco Airport (14:05 and 14:25 (Wa'il)). Transfer to hotel

Evening: Free, dinner on own, rest time.

Monday, September 10

7:45	Transport to Laboratory from Hotel and badging	
9:15	Welcome and Introduction (B132, R1781)	J. Richardson A. Tompson
10:00	"Water Resources Management in Jordan" Eng. Ali Subah and Dr. Khair Al Hadidi	(Open to all)
11:00	"Groundwater Management in Azraq Bazin" Eng. Ali Subah and Dr. Khair Al Hadidi	(Open to all)

12:00	Lunch at West Cafeteria	
1:00	Brief overviews of LLNL groundwater projects	A. Tompson R. Maxwell S. Carle D. Smith
3:00	Discussion and organization of next days work	A. Tompson et al.
4:00	Transfer to hotel	
5:00	Dinner with J. Richardson/A. Tompson	

Tuesday, September 11

7:45	Transport from Hotel to Laboratory (B1478, Franciscan Room)	
9:00	Working meetings	A. Tompson et al.
12:00	Lunch at West Cafeteria	(Open to all)
1:00	Working meetings	A. Tompson et al.
5:00	Transfer to hotel	

Evening: Free, dinner on own

Wednesday, September 12

7:45	Transport from Hotel to Laboratory (B1478, Franciscan Room)	
9:00	Working meetings	A. Tompson et al.
12:00	Lunch at West Cafeteria	(Open to all)
1:00	Working meetings	A. Tompson et al.
5:00	Transfer to hotel	

Evening: Free, dinner on own

Thursday, September 13

7:45	Transport from Hotel to Laboratory (B1478, Franciscan Room)	

9:00	Working meetings	A. Tompson et al.
12:00	Lunch at West Cafeteria	(Open to all)
1:00	Working meetings	A. Tompson et al.
3:00	Wa'il to meet with Paul Dickinson; Return to hotel separately	Paul Dickinson
5:00	Transfer to hotel	

Evening: Free, dinner on own

Friday, September 14

PLAN A:

7:45	Transport from Hotel to Laboratory (B1478, Franciscan Room)	
9:00	Working meetings	A. Tompson et al.
12:00	Lunch at West Cafeteria	(Open to all)
1:00	Working meetings	A. Tompson et al.

PLAN B:

8:00	Transport from hotel to UC Offices in Oakland	
9:00	Meetings with UC/Lab Staff	
	Meetings on Campus (to be arranged)	
	Lunch (to be arranged)	

3:30	BBQ dinner at A Tompson's home	(By invitation)
8:00	Transfer to hotel	

Lawrence Livermore National Laboratory

Saturday, September 15

Tour of San Francisco area sights (to be determined) — J. Richardson, A. Tompson

Sunday, September 16

Free day

Monday, September 17

7:45 Transport from Hotel to Laboratory (B1478, Franciscan Room)

9:30 Tour of California Water Project Pumping Plant, Tracy

12:00 Lunch

1:00 Close-out meeting (B132, R1781)

5:00 Transfer to hotel

6:00 Dinner with J. Richardson/A. Tompson

Tuesday, September 18 (Departure day)

Morning: Free

12:30 Transfer to San Francisco Airport for return

Figures D1 (top) and D2 (bottom). Participants at the LLNL Groundwater Modeling Workshop, held September 2001. Top (L to R): Khair Al Hadidi (MWI), Steve Carle (LLNL), Mohammad Al-Awamleh (MWI), Ali Subah (MWI), Jehan Rihani (JUST), Andrew Tompson (LLNL), Wa'il Abu-El-Sha'r (JUST), and Reed Maxwell (LLNL). Bottom (L to R): Khair Al Hadidi (MWI), Ali Subah (MWI), Jehan Rihani (JUST), Jeffery Richardson (LLNL), Mohammad Al-Awamleh (MWI), and Wa'il Abu-El-Sha'r (JUST).

Appendix E: Abstract of Master's Thesis of J. Rihani (Rihani, 2003)

Application of The High Performance Computing Techniques of Parflow Simulator to Model Groundwater Flow at Azraq Basin

By: Eng. Jehan Fouad Farhan Rihani

Supervised by: Dr. Wail Y. Abu-El-Sha'r

ABSTRACT

Being one of the largest groundwater basins in Jordan, the Azraq basin has been considered by many investigative, assessment, and modeling studies ever since the early 1960s. The basin's current situation can be summed up as being highly exploited with serious salinity problems at some of its parts. This is where assessment studies equipped with the proper modeling tools come into the picture. The highly advanced groundwater model, ParFlow, was utilized in this thesis in order to model groundwater flow in the basin. ParFlow employs the latest numerical techniques along with the massive power of parallel computing to utilize three-dimensional heterogeneity in groundwater flow modeling. This was tested against the homogeneous assumptions employed in more commonly used models such as Processing Modflow. Modeling results were compared to similar results

produced by the PM5 modeling study conducted by the water group of the Higher Council for Science and Technology project, namely "Jordan Badia Research and Development Program: Integrated Studies of Azraq Basin for Optimum Utilization of the Natural Resources" (Al-Hadidi and Subah, 2001). Groundwater flow in the Upper and Middle aquifer systems was modeled via ParFlow. The model parameters were calibrated within an unstressed (steady state) modeling process. The calibrated head was matched to the initial head of the basin. The calibrated hydraulic conductivities ranged between 1.2 and 75 m/day for the upper aquifer, and between 0.35 and 70 m/day for the middle aquifer. The confining layer between them (aquitard) had a conductivity value of 0.01 m/day. The system's water balance for the year 1998 showed that the total inflow into the basin was 34.3 MCM/year while the total outflow added up to 59.1 MCM/year, which is way above the aquifer's safe yield. The calibrated flow model was used to predict the aquifer system's response to a pumpage scheme of 55.5 MCM/year. The results showed that the maximum drawdown predicted by ParFlow (35.8 meters) was greater than the amount predicted by Modflow for the same pumping scheme. One of the causes of this difference in predictions may be attributed to the fact that ParFlow gives a general, more comprehensive picture of the system at hand, as opposed to the point dependent results obtained via Modflow. Such comprehensiveness in modeling results is of great importance when it comes to the role of decision-makers in maintaining our water resources from pollution and overexploitation. In the end, only proper management of the basin's groundwater extraction will revive the basin's water situation into the beautiful Oasis that once existed in the heart of the desert.

Appendix F: Agenda for Ministry Visits, Damascus, January 23, 2003

Schedule for Environmental Specialists
Andrew Thompson and Reed Maxwell
Lawrence Livermore National Laboratories
Damascus: January 22-23, 2003

Openmet: Doc# schedEnvTeam
Raouf: 01/22/03

Wednesday, January 22, 2003
Arrive Damascus

Thursday, January 23

09:00	Peter and Raouf proceeds to the Motorpool to take a van to the Sheraton Hotel
09:15	Pick us the team and proceed to the Directorate of Cultural Relation of the Ministry of Education in Adawi
09:30	Meet with Isam Diab, Director of Cultural Affairs. Following inspectors will attend: - Mr. Muhammad Adnan Al-Mahdi, Senior Inspector of Environment and Science Educa - Dr. Omar Abu Own, Senior Inspector of Environment Education - Mr. Walid Shbeeb, Head of Environment Education Sector - Mr. Safwat Qabaqibi, Deputy of Environment Education Sector - Ms. Tahani Makhloof, Deputy of Environment Education Sector - Mr. Ahmad Al-Ghadhban, Senior Inspector of Sociology and Geography Education.
10:40	Proceed to the Ministry of Irrigation
11:00	Meet with Dr. Solaiman Rammah, Deputy Minister and the following water specialists: - Engineer Taher Hajj Hasan, Director of Technical Affairs - Mr. Atef Deeb, Director of Planning
12:45	Proceed to the Ministry of Environment
13:00	Meet with Ms. Reem Abed Rabo, Director of Water Protection Affairs and the following water specialists: - Ms. Sawsan Arafeh, Environmental Engineer - Ms. Rania Shamseen, Environmental Engineer - Ms. Leen Abed Rabo, Environmental Engineer
14:15	Lunch
15:15	Proceed to Directorate of Cultural Relations, Damascus University
15:30	Meet with the Director of Cultural Relations at Damascus University

Departing Damascus for....

Appendix G: Proposed Project Program in Syria

As a result of our visit to Syria in January 2003, we are now proposing to involve six organizations in the US, Jordan, and Syria in a new, yet expanded project, entitled, loosely, "Regional Cooperation on Water Resource Education in the Middle East: Syria and Jordan". In no particular order, these organizations (with particular points of contact) are:

- Lawrence Livermore National Laboratory (LLNL), University of California, Livermore, California USA (Dr. Andrew F. B. Tompson)
- Jordan University of Science and Technology (JUST), Irbid, Jordan (Prof. Wa'il Abu El Sha'r)
- Syrian Ministry of Education (SME), Damascus, Syria (Mr. Issam Diab)
- Syrian Ministry of Irrigation (SMI), Damascus, Syria (Dr. Sleman Rammah)
- Syrian Ministry of the Environment (SMEnv), Damascus, Syria (Ms. Reem Abed-Rabboh)
- Tishreen University (TU), Lattakia, Syria (Prof. Adel Awad)
- Syrian Environmental Association (SEA) at Damascus University, Damascus, Syria (Dr. Warka Barmada)

During a return visit to Damascus in June 2003,Wa'il Abu El Sha'r and Paul Malik presented and proposed the following tasks to these organizations for discussion:

(1) Develop criteria for the design and fabrication of approximately 5 prototype physical groundwater models to be delivered to Syria (SME, SMI, MEnv, TU, and SEA). These criteria will be developed from a mutual assessment of important groundwater issues in Syria by all Syrian partner organizations (possibly focusing on Damascus where groundwater is becoming important and where groundwater contamination is becoming recognized as a problem). The criteria will be eventually be used to formulate a teaching curriculum for use and demonstration of the physical models by all Syrian partner organizations.

(2) Identify and train a group of educators as an intermediary between the

water resource professionals and the general community. These educators may include (a) teachers in primary or secondary schools, (b) professors or instructors in the university system, or (c) other interested professionals associated with important ministries, museums, or other non-government organizations. LLNL and JUST will first train and demonstrate the physical models to members of the Syrian partners (SME, SMI, SMEnv, TU, and SEA) using the preliminary curriculum. The Syrian partners will then modify the curriculum, as needed, and identify and train other educators in the use of the models. Particular schools, universities, museums, or outreach organizations of the Syrian ministries will be identified for continued, sustained demonstrations. JUST and the Syrian partner organizations will develop a plan to fabricate additional physical models in Jordan or Syria to support this endeavor over the long term. These future water resource educators will be fully incorporated into all aspects of the project. In addition, we suggest that physical models be permanently placed within selected Syrian organizations to optimize their use and accessibility to reach the widest audience.

(3) Identify a professor and one or more undergraduate or graduate students (at TU, for example) to define one or more critical groundwater problems in Syria as a basis for an extended scientific study, in collaboration with LLNL and JUST, and in collaboration with one or more of the other Syrian partners (SME, SMI, SMEnv, and/or SEA). The scientific study will involve training of students and/or professors on the use and application of computer-based groundwater simulation models (which are an analog to the physical models) as a means to develop insights in to the behavior of a real and important groundwater problem in Syria (as identified in Task 1) and as a means to develop technical solutions or new policies related to management of groundwater in Syria. This task may involve travel to Jordan or the US for a short period as part of this training. It is expected that a link will be developed between this

phase of the project and the broader educational outreach programs under Task 2.

(4) The fourth phase of the project will be is to jointly compile the lessons learned from these efforts, modify the approach as needed, and then expand the consortium to other regional states. These may include Lebanon, for example, which shares common problems in water resource management. In this way, we can both achieve sustainable progress in each country while slowly building a regional network of special water educators. Water knows no political boundaries and our special educators can facilitate solution of these regional problems on a regional scale.