PD-ABM-160

Annual Activity Report

September 1, 1994-August 31, 1995

Monitoring and Modeling of Saltwater Intrusion

Implemented to Gaza Strip and Morocco

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Address comments and inquiries to:

Dr. Alexander H-D. Cheng
U.S. Project Coordinator
Water Resources Program
Department of Civil Engineering
University of Delaware
Newark, Delaware 19716-3120
USA

Tel: (302)831-6787
Fax: (302)831-3640
E-mail: cheng@chaos.ce.udel.edu
WWW: http://www.ce.udel.edu/faculty/cheng/

Executive Summary

Major activities during the first year of the project include the following:

- During September 1994 the first planning/coordination meeting was held at the University of Delaware. All Principal Investigators were present.
- The second planning/coordination meeting took place during April, 1995, in Rabat/Marrakech, Morocco. All Principal Investigators were present.
- In addition to the project meeting, a number of offices and agencies were visited, including US AID Moroccan Mission, the Agricultural Ministry, Marrakech Division of Water Resources, AID sponsored agriculture project ORMVAT in Tadla, Office National Potable Water in Rabat, and AID sponsored Maghreb Agriculture project near Casablanca.
- Contract negotiation and international fund transfer were completed.
- Computers, field sampling and communication equipment were purchased.
- The Gaza and Israeli teams established bi-weekly meeting to coordinate and report the progress of the work.
- Both the Israeli team and the Moroccan team recruited new members.
- Water samples were collected and analyzed for Khan Younis City and the rest of Gaza Strip by the Gaza team.
- Geological and hydrogeological maps were prepared by the Israeli team and transferred to the Gaza team.
- The well location and water quality maps were updated by the Gaza team based on field survey.
- Relevant data in Israeli Hydrologic Service were prepared in computer data base and transferred to the Gaza team.
- The initial construction of the Eulerian-Lagragian program was completed by the Israeli team. Several benchmark problems were tested and the results were satisfactory.
- A new theory has been developed by the Israeli team for the characterization of Gaza/Israel coastal aquifers.
- Analytical solutions were compiled by the Moroccan team and computer software is being completed.
- The sharp interface boundary element programs problems has been completed by the Moroccan team. Optimization techniques based on

Nonlinear Programming, and the Genetic Algorithms are being developed to track down the salt-fresh water interface.

- Parallel work is being conducted for the utilization USGS model for sharp interface saltwater intrusion program SHARP.
- Field data in Morocco are being collected to feed the computer models.
- The software implementation is also underway.

The impact of the project is summarized as follows:

- The data that exist in Israeli agencies have been prepared and transferred to the Gaza team.
- USGS and UNDP computer programs have been transferred to the Gaza team. In particular, training on one program Groundwater Software for Windows has begun which will be used to organized the data base for Gaza Strip.
- Mr. Shaath of Gaza has been enrolled in the Ph.D. program of Ecole Mohammadia d'Ingenieurs, Morocco, for more advanced hydrogeological training.
- The spirit of cooperation between the Gaza and Israeli teams has been high. The two teams worked in harmony during the data and technology transfer phases.
- In Morocco, the USGS hydrogeological computer programs have been transferred.
- Links with other USAID sponsored program in Morocco have been made. Consultation was provided to these projects. Several national and provincial water agencies were visited. Consultation was provided.

The financial status is as follows:

- The expenditure during the first year is $145,089, or 34% of the total (two-year) budget.
- Including the committed amount (subcontract installments that are not yet realized), the expended and committed amount is $260,470, or 61% of the budget. These expenditure and commitment are within our expectation of the spending schedule.

Managerial Report

First Planning/Coordination Meeting

The project was launched in September 1994 by a planning/coordination meeting. The meeting was held during September 7-9, 1994, at the University of Delaware. Participants included the Principal Investigators:

- Dr. Alexander Cheng, University of Delaware, USA.
- Dr. Shaul Sorek, Ben-Gurion University, Israel.
- Dr. Abraham Melloul, Hydrological Service, Israel.
- Mr. Samir Shaath, Palestine Council of Health, Gaza Strip.
- Dr. Driss Ouazar, Ecole Mohammadia d'Ingenieurs, Morocco.
- Dr. Leonard Konikow, Geological Survey, USA.

sponsoring agency officers:

- Dr. Herbert Blank, Agency for International Development.
- Dr. Edward Rice, Winrock International.

observer from other organization:

- Mr. Andrew Macoun, the World Bank.

and several local participants.

During the meeting, introductions of hydrogeological conditions in the target areas were respectively given by:

- Dr. Melloul, Israeli Coastal Plain Aquifer, Gaza-Israel.
- Mr. Shaath, aquifer in Khan Yunis area, Gaza Strip.
- Dr. Ouazar, Agadir Aquifer, Morocco.

Other presentations included:

- Dr. Sorek, Eulerian-Lagrangian computer modeling of saltwater intrusion.
- Dr. Konikow, USGS computer modeling capabilities.

The division of work was discussed and coordinated. A detailed workplan was drafted and discussed with AID officers.

Contract Negotiation and Fund Transfer

Contract negotiation and international fund transfer has been time consuming. The primary contract between the AID and the University of Delaware was completed around the end of September, 1994. Negotiation of subcontracts with Gaza Strip, Israel, Morocco, and USGS began soon after that. Due to a variety of reasons such as ensuring the consistency of accounting methods, international fund transfer, authorization of advanced payment, permission for equipment purchase abroad, and administrative delays at the University, most of the subcontracts were finally in place around mid-December, 1994.

Preparatory Work

Despite the delay in subcontracts, preparatory work started during this period. A few meeting between the Israel and the Gaza teams were held. A new member Dr. Alex Yakirevich joined the Ben-Gurion University team. Student training for computer modeling started in Morocco. Once subcontracts were fully settled, and funds transferred to the designated banks, purchase of equipment and supplies could start. One microcomputer for Gaza Strip and one for Morocco were purchased. Office equipment to improve communication with the US were acquired in Gaza. Water sampling equipment and supplies were purchased.

Gaza/Israel Bi-Weekly Meetings

Regular bi-weekly meetings started between the Israel and the Gaza teams. The meeting places were either Jerusalem, or Beer Sheva. Meeting summaries were forwarded to the Project Coordinator at the University of Delaware. In addition to Dr. Yakirevich, two new members joined the Ben-Gurion University team:

- Dr. Anatoly Krupnik—A mathematician who would be involved in interpreting the field data.
- Dr. Viacheslav Borisov—A modeler who would be involved in programming the Modified Eulerian-Lagrangian computer code.

In the mean time, Mr. Samir attended several seminars and contacted several professional key persons in Gaza Strip. Information on the saltwater intrusion, and the dramatic increase in salinity at the present time was communicated to the public to gain publicity.

Second Planning/Coordination Meeting

The second planning/coordination meeting took place during April, 1995, in Rabat/Marrakech, Morocco. Members arrived in Morocco at different times. The official meeting time was 4/10/95-4/11/95 when all members were present. The Total time covered by all members was 4/5/95-4/20/95. The participants of the meeting were:

- Alexander Cheng (Univ. Delaware, US)
- Leonard Konikow (USGS, US)
- Shaul Sorek (Ben-Gurion Univ., Israel)
- Alex Yakirevich (Ben-Gurion Univ., Israel)
- Abraham Melloul (Israeli Hydrological Service)
- Samir Shaath (Palestinian Authority, Gaza Strip)
- Driss Ouazar (Ecole Mohammadia d'Ingenieurs, Morocco)
- Khalid EL Harrouni (EMI, Morocco)
- Ahmed Naji (EMI, Morocco)

A number of activities took place during this period. They are given here in the form of an itinerary.

- 4/6/95: The Israeli/Palestinian team (Sorek, Melloul, Yakirevich, Shaath) and Ouazar visited AID Mission in Rabat and discussed the project with Dr. Alan Hurdus.
- 4/7/95: The Israeli/Palestinian team and Ouazar visited Dr. Mohammed Ait Kadi, Director of the Administration for Rural Engineering of the Agricultural Ministry. Dr. Ait Kadi expressed his willingness to assist research aimed at agricultural issues from the aspect of water related problems.
- 4/10/95-4/11/95: The project meeting was held in Marrakech. All team members were present. The work of the previous two quarters were reviewed. Arrangement had been made to ensure the smooth transferring of data to Gaza team in the next phase. The Israeli team will try an exciting new technique of Map Theory to map out the hydrogeological characteristics of the Gaza Strip aquifer with focus on the Khan Yunis area.
- 4/11/95: The team visited Marrakech DRH (Division of Water Resources). Director Abdelmajid El Hebil and several of his engineers briefed the team about their effort in modeling the saltwater intrusion in Sahel aquifer near the Atlantic coast. They have completed USGS Modflow modeling and intended to continue on USGS SUTRA modeling. It was apparent that they ran into some technical difficulty. The team provided some advise and offered Dr.

Ouazar's researchers at EMI to help. The Director enthusiastically accepted the offer and stated that he would organize a workshop for his engineers. He invited the whole team to come back to lecture. Mr. El Hebil was also to provide the Marrakech hydrogeological data to the Israeli team to generate maps describing the characteristic of the aquifer.

- 4/12/95: Through Dr. Ouazar's arrangement, part of the team visited an AID sponsored agriculture project ORMVAT in Tadla, managed by Chemonics International. We discussed their water quality problem with Mr. Arthur Belsey, Irrigation Engineer, Mr. Ed Ross, Manager, and his Moroccan counter part, Mr. A. El Antaki. Due to the presence of salt formation in the region, their irrigation water was of poor quality. The agriculture return flow, further contaminated by fertilizer, pesticide, etc., flowed into a reservoir which was the major water supply for the city of Casablanca. They had purchased computer equipment and GIS software in preparation for organizing water quality data and initiating groundwater modeling. The actual work was not started. Dr. Konikow advised them not to carry out a formation capping project (covering with cement/clay) unless a groundwater study was conducted first, as the capping might not be effective. We had agreed that Dr. Ouazar would send one of his researcher to help them organizing their computer effort.
- 4/14/95: Ouazar, Konikow and Cheng visited AID mission in Rabat and met with Dr. Alan Hurdus and Dr. Mohammed Hanafi. We discussed in particular the possibility of studying the Sahel aquifer, rather than the Agadir aquifer. The reason is that the Sahel aquifer data were well organized by the Marrakech DRH such that our modeling effort will be more effective. The Agadir data was not yet organized. Dr. Hurdus stressed that the Agadir aquifer is of more interest, but gave us some flexibility if the data collection effort would turn out to be too difficult. The team later decided that we would adhere to the original plan of modeling the Agadir aquifer and would also model the Sahel aquifer as an extra effort.
- 4/18/95: Cheng gave a two-hour lecture on ``Saltwater intrusion in groundwater aquifers'' to about 20 engineers at ONEP (Office National de L'Eau Potable) in Rabat.
- 4/18/95: Cheng met with Mr. Driss Lahlou, President, Maghreb Agriculture, in charge of an AID agriculture project, in Casablanca. Mr. Lahlou described his problem of losing several fresh water wells in the farm to salt water. Some practical suggestion of using more wells, each pumping at a lower rate was given. He was asked to further contact Dr. Ouazar at EMI for follow-up.

Several other activities took place which were indirectly related to the project:

- 4/17/95: Ouazar and Cheng held a meeting with Dr. Gedeon Dagan, Univ. Tel-Aviv, Israel, to discuss about a separate project sponsored by AID/CDR on stochastic saltwater intrusion modeling in Israel/Morocco/US/Mexico.
- 4/17/95: Ouazar, Dagan and Cheng paid a courtesy call to Dr. Ben Sari, former Director of Moroccan National Research Council, expressing gratitude for his support. Dr. Ben Sari committed continuing support for water resources activities once his new post would be announced.
- 4/18/95: Ouazar and Cheng visited Dr. Mostafa Terrab, Charge de Mission, Cabinet Royal (King's Science Advisor). A preliminary proposal of forming a Water Consortium in the Middle East and North Africa to promote peace and economical development in the region was discussed with Dr. Terrab. Dr. Terrab expressed Morocco's interest in serving as mediator in the peace process. He also understood the vital importance of water resources in the region. He would help us promote the formation of such a scientific union.

Moroccan Team Members

In addition to the team leader, Dr. Ouazar, several researchers were assigned with primary duties as:

- Mr. Ahmed Naji—development of Boundary Element Method for sharp interface problems, Optimization Techniques, Genetic Algorithms.
- Mr. Hakim Nouioua—Three-dimensional Boundary Element programs.
- Mr. Najib Faraj—Software interfaces.
- Mr. Abdelghani Souhar—Menu driven Boundary Element Method, intelligent meshing.

Later on, Dr. Khalid El Harrouni joined the team. Dr. El Harrouni received his Ph.D. from Wessex Institute of Technology, at Southampton, UK in 1994. His specialty was in boundary element method and water resources. Dr. El Harrouni will share some responsibility of supervising the researchers.

Technical Report

Gaza Team Report

For the field work, water samples were collected and analyzed. Data was sorted into two parts: 1. Khan Younis City, and 2. the rest of Gaza Strip, which are reported below.

Khan Younis City

The work in Khan Younis City consisted of both office work and field work. From the office work, detailed maps were produced: one for the eastern Mediterranean sea coast, one for the Gaza Strip, and one for the Khan Younis City. The Khan Younis map showed the municipality, private water wells, and some other geographical information.

The field work included locating water wells (municipal and private), collecting water samples, recording pumpage intensity and frequency, and testing for chloride and nitrate concentration. The wells were selected with the intention to form a dense network for later numerical simulation purposes.

Some of these data were tabulated as shown below:

Well Name	Pumpage	Frequency	Chlorides	Nitrates
	m^3/hr	hrs	mg/ℓ	ppm
Al-Amal	90	24	374	203
Al-Saadah	100	24	876	275
Al-Ahraash	80	24	524	227
Al-Jadid	140	24	445	54
Ayah	80	24	624	228

All these wells were municipal wells in or near Khan Younis City, see map displayed in the next page.

Rest of Gaza Strip

General information and data related to water quantity and quality were searched and collected from various sources at different locations throughout Gaza Strip. Some of the data represented chemical tests conducted in recent years, while other data dated back 8 years. From the information, it was found:

Chlorides

WHO standard for chloride concentration was 250 mg/ℓ. We found a wide range of concentration in Gaza Strip. For example $C\ell$ was about 50 mg/ℓ to 60 mg/ℓ at Beit Lahia (North of Gaza Strip), and about 1,300 mg/ℓ at both Bani Suhaila and Abasan Al-Kabirah villages (in the vicinity of Khan Younis). In general, the salinity levels showed dramatic increase in recent years.

Nitrates

The nitrate levels were generally high. In fact there were relatively few wells showed nitrate levels below WHO standard. For example, in some private wells in Khan Younis, levels as high as 400 ppm were detected.

Extended Field Water Quality Data Collection

After reviewing the data base prepared from IHS data bank, it was found that some well concentration data was very old. The Gaza team also pointed out that many wells were no longer in use due to the poor water quality. The well data needed to be updated. It was decided to extend the scope of water quality data collection by the Gaza team. As originally planned, the data collection only served to support the validation of numerical modeling. The current scope would maintain an up to date data base. The Gaza team would continue send out the field team to locate and mark out abandoned wells. Water quality in existing wells would be updated. A computer data base would be maintained.

Israel Team Report

Thus far, the following had been accomplished:

- Compiled computer data set concerning pumpage, chlorine concentrations and hydraulic heads.
- Prepared four working maps with 1: 20000 scale to mark most of the existing wells.
- Prepared figures of hydrogeological cross-sections.
- Prepared a map of 1: 50000 scale on which we assembled information on the width of lithological layers, location of incoming chlorine fronts and typical hydrogeological sections.

- Prepared maps of lithological variations (sand, clay) which might suggest correlation to the spatial distribution of transmissivities. Later on, with prescribed transmissivities, one could build the correlation function with lithological data which could then be used to reconstruct the spatial distribution of transmissivities.
- Prepared maps showing zones of strong inhomogeneities which might suggest preferential flow paths. This was build on an assortment of different qualitative concepts.
- Prepared diagnostic map describing spatial distributions of local (phreatic and confined) aquifers.
- Prepared maps describing rate variations of chloride concentrations. Such maps might suggest domains with different aquifer recharge ,e.g., natural replenishment through the unsaturated zone or subsurface recharge.
- Prepared map pointing at possible principle axes of transmissivities.
- Developed the algorithm for the 2D concentration dependent flow and transport problem, based on Modified Eulerian-Lagrangian concepts.
- The initial stage of developing numerical scheme and the computer code had begun.

Map Preparation

During the last quarter, the following maps were collected from the map library and data bank of Israeli Hydrological Service (IHS) and prepared by Melloul: several figures of hydrogeological cross-sections; a map of 1: 50000 scale on which we assembled information on the width of lithological layers, location of incoming chlorine fronts and typical hydrogeological sections; maps of lithological variations (sand, clay) which might suggest correlation to the spatial distribution of transmissivities; maps showing zones of strong inhomogeneities which might suggest preferential flow paths; diagnostic map describing spatial distributions of local (phreatic and confined) aquifers; maps describing rate variations of chloride concentrations, which might suggest domains with different aquifer recharge ,e.g., natural replenishment through the unsaturated zone or subsurface recharge; a map pointing at possible principle axes of transmissivities. Those maps were originally prepared in Hebrew. To facilitate the use by Palestinians, all the map legends were tediously translated into English and the maps were redrawn. Those maps are transferred to Samir Shaath. A few of these maps were submitted as a part of the third quarterly report.

Computer Data Base Transfer

The water quality data for concentrations of Chloride and Nitrate for wells located in the Khan Younis area were stored in the form of computer data base in IHS. These data were carefully sorted out from IHS data bank. A commercial software QuattroPro was used to organize the data. The data file which contains the well coordinates, description of the well, concentration history, etc., was copied onto a diskette and transferred to the Gaza team leader Samir Shaath.

Computer Modeling

The computer modeling effort progressed as scheduled. The initial construction of the Eulerian-Lagragian program was completed. Several benchmark problems were tested and the results were largely satisfactory.

Gaza/Israel Coastal Aquifer Characterization

The lithologic sequence of the coastal aquifer of the Gaza Strip consists of calcareous sandstone of Pleistocene age, including silt and clay layers of continental and marine origin, and underlined by the so called Saqiye marl beds of marine origin. As usual, this type of aquifers is highly heterogeneous due to the various influences of the following factors:

- Lithologic (high spatial variability of thickness of the silt, clay and sandstones layers).
- Diagenesis (cement re-sedimentation, high spatial variability of the secondary porosity).
- Post sedimentation tectogenesis, that may be reflected as fractures of the cemented sandstones.

These processes form a system of two types of zones:

- High transmissivity latent drainage system characterized by preferential flow channels with local and regional recharge.
- Relatively stagnant separated zones with only local recharge.

Preferential flow paths may be presented as high thick sandstones channels, fractured zones, zones of low cement content or karst zones. Stagnant zones may be "sealed" by the system of clay layers or high cemented sandstones. On one hand, these preferential flow channels may be responsible for creation of inside lateral recharge system. Exhaustion of these recharge channels may be responsible for the possible degradation of water quality of the Gaza Strip coastal aquifers. Yet, these channels interconnections with salinization sources and the Mediterranean Sea in the West part of aquifer, may be responsible for the creation of inside vertical and lateral salinization system. Any action aimed at improving the control over the processes of groundwater flow and pollution, requires a better understanding of the system's structure, aquifers subdivision and heterogeneity distributions. Reconstruction of aquifers geological structure by existing geophysical, geochemical and hydrogeological methods, require heavy investments of capital under a high level of uncertainty considering the probability of success.

The objective of the methodologies described herein is, to define:

- Geological structure of the Gaza Strip coastal aquifer.
- Possible tracks of salinization.
- Preferential water flow channels.
- Heterogeneity distributions on the basis of the information derived from lithologic data, and applied as conventional methods in oil fields exploitation.

The above is depicted in maps describing spatial distribution of lithologic parameters

The basic advantage of these methods is in the fact that they employ a priori judgment based on scientific knowledge of processes, as well as produce information from already accumulated wells data with no need for any additional field work. This reduces the amount of investment and shortens the time for arriving at first level assessments.

Parameters for Hydrogeological Heterogeneity

In hydrogeology practice we usually refer to pumping tests to assess local heterogeneity characteristics. However, since such tests may show high local transmissivity even in sealed zones, this information may not be representative for sand aquifers. Due to lack of pumping tests data and high variability of their results in time and space, we suggest ,instead, to apply methods practiced in oil exploitation which are facing analogical situations. This on the basis of lithologic parameters may be correlated to hydrogeological macro heterogeneity.

Lithologic parameters

For sedimentation type heterogeneity, we refer to lithologic parameters which infer to hydrogeological macro heterogeneity and can be highly correlated with transmissivity values. These are:

- Parameters associated with clay:

- $T_1 = 1/(\text{Number of Clay Layers} + 1)$
- $T_2 = 1/\text{Total Clay Thickness}$

- Parameter associated with sand:
  - $T_3 = \text{Effective Thickness}$
- Relative parameters:
  - $T_4 = \text{Total Sand Thickness}/\text{Total Clay Thickness}$
  - $T_5 = \text{Total Sand Thickness}/\text{Number of Clay Layers}$
- Combined parameter:
  - $T_6 = \text{Sand Thickness}/(\text{Clay Thickness} \times \text{Number of Clay Layers})$

These parameters are used to characterize the heterogeneity of geological structures the location and the assessment of flow boundary conditions in saturated aquifers.

<u>Hydraulic parameters</u>

Wells Interconnection Parameter

In the process of aquifer exploitation, water pumpage rate data is collected. These may be used to define an hydraulic interconnection criterion for exploring geologic structure suggesting aquifer subdivisions. This method is well known in oil exploitation practice and enables the mapping of aquifer heterogeneity.

Wells interconnection analysis is based on examining a steady state equation describing the interaction between wells. This wells interference equation reads,

$$h_0^2 - h_{well}^2 = \sum_{i=1}^{n} A_i Q_i \qquad (1)$$

where h_0 denotes the unknown reference hydraulic head and A_i denotes the unknown coefficient referring to the influence of a battery of wells with Q_i pumpage on the hydraulic head h_{well} at a prescribed well. In general the pumpage of a well Q_{well} may be correlated to its hydraulic head h_{well}, namely

$$h_{well}^2 = \Psi(Q_{well}) \qquad (2)$$

We note that (1) may be interpreted as a balance equation in a liquid phase continuum and (2) as the boundary condition at the well.

By virtue of (1) and (2), we may ,in principle, express the pumpage of a prescribed well as a function of pumpage ,at the k time level, of wells surrounding it,

$$Q^k_{well} = F(h_0, A, Q^k) \qquad (3)$$

On the basis of wells pumpage information for all time instances together with an optimization procedure (e.g., nonlinear least squares), we may estimate the A coefficients and the h_0 hydraulic head. Note that (1) relies on the assumption that all wells reside within the same aquifer ,i.e., no inter impervious boundaries. We check this assumption by constructing maps of correlation ratios between Q_{well} and the F values. A low correlation ratio may serve as an indicator, between 0 to 1, for the extent of hydraulic interconnection.

The law of identical precondition

On the basis of the hydrogeologic analogous principle (i.e., two wells under identical hydrogeologic conditions must give the same pumpage yield), we can find the spatial distribution of the local stability $\frac{1}{Var(total - yield)}$ of the time integral of pumpage yield. This characterizes the aquifer macro heterogeneity.

Morocco Team Report

Work at the present stage concentrated on the construction of both analytical and numerical models.

Analytical Solution

Analytical solutions will be used for initial field assessment by field hydraulic engineers. The analytical solutions covering a variety of practical conditions have been compiled as summarized in the following. A computer software is being created. The major core of the program has been constructed. The graphics part is still under development by the Moroccan team.

Ghyben-Herzberg Solution

Assumptions:

- Static saltwater
- Static freshwater

Formula

$$z = \frac{\rho_f}{\rho_s - \rho_f} h_f$$

z = interface location

h_f = freshwater head above mean sea level (water table location for unconfined aquifer, or piezometric head for confined aquifer)

ρ_f = freshwater density

ρ_s = saltwater density

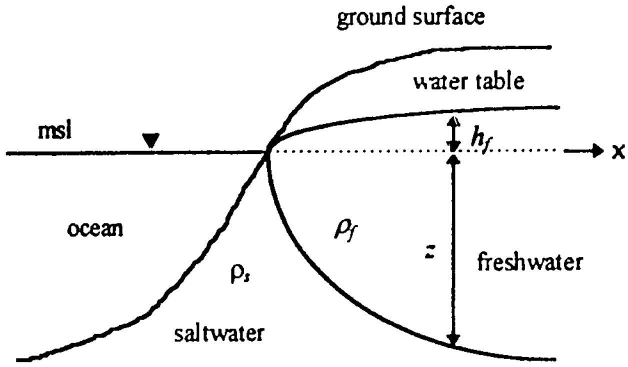


Figure 1: Unconfined aquifer.

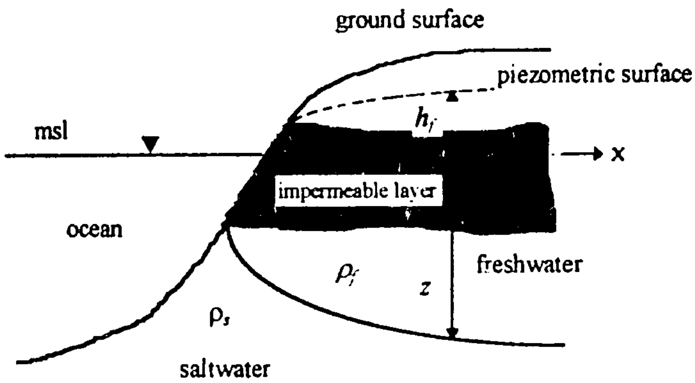


Figure 2: Confined aquifer.

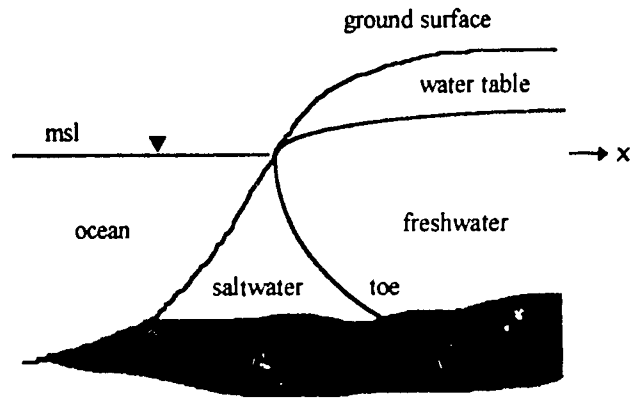


Figure 3: With aquifer bottom.

User Input

ρ_f, ρ_s

Default values can be set as

$$\rho_f = 1.000 \text{ g/cm}^3$$
$$\rho_s = 1.025 \text{ g/cm}^3$$

Such that

$$z = 40\, h_f$$

h_f

Water table or piezometric head elevation needs to be provided at a few location such that a profile $h_f\ (x)$ can be interpolated.

Toe

The location of toe is interpreted as where the interface meets the aquifer bottom.

<u>Modified Ghyben-Herzberg Solution</u>

Assumption

- Dynamic saltwater
- Static freshwater

Formula

$$z = \frac{\rho_f}{\rho_s - \rho_f}(h_f - h_s)$$

h_s = saltwater head below the mean sea level

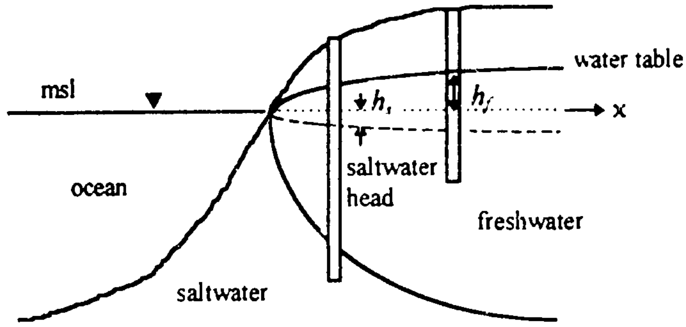


Figure 4: Modified for moving seawater.

User Input

In addition to the input in section 0, the saltwater head h_s , defined as the head below the mean sea level, needs to be provided. Such a head can be observed by using wells with screened section opening only in the saltwater region. An profile of h_s *(x)* is found from interpolation.

Glover Solution

Assumption

- Dynamic saltwater
- Dynamic freshwater
- Potential theory

Formula

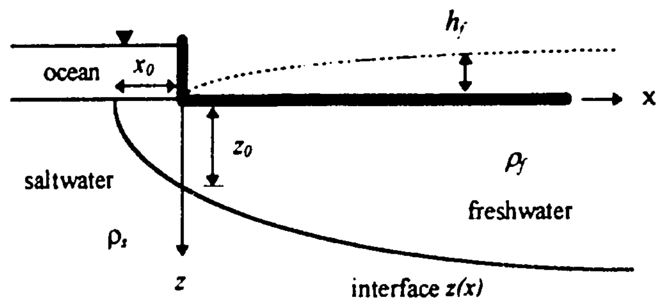
$$z = \sqrt{\frac{2qx}{\Delta\rho K} + \left(\frac{q}{\Delta\rho K}\right)^2}$$

$$h_f = \left(\frac{2\Delta\rho qx}{K}\right)^{1/2}$$

$$x_0 = -\frac{q}{2\Delta\rho K}$$

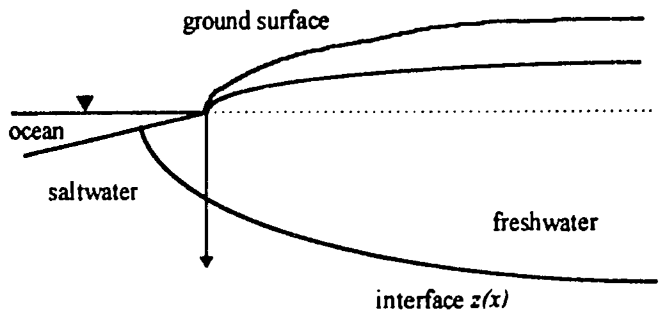
$$z_0 = \frac{q}{\Delta\rho K}$$

q = freshwater flow per unit length of shoreline
K = hydraulic conductivity of the aquifer



Interpretation

- h_f can be interpreted as the water table location for the unconfined aquifer case.
- An equipotential line can be chosen as the seabed.



Oceanic Island

Assumptions

- Ghyben-Herzberg assumption (static salt and fresh water)
- Dupuit assumption
- Circular island

Formula

$$z^2 = \frac{W(R^2 - r^2)}{2K\left(1 + \frac{\Delta\rho}{\rho_f}\right)\left(\frac{\Delta\rho}{\rho_f}\right)}$$

$$h = \frac{\Delta\rho}{\rho_f} z$$

W = surface recharge rate

R = radius of circular island

Numerical Modeling

Due to the diversity of the natural conditions encountered, saltwater intrusion problems were categorized according to the flow conditions. Dependent on the flow conditions, different hypotheses were made and governing equations were derived. Techniques such as the Boundary Element Method, Optimization Techniques based on Nonlinear Programming, and the Genetic Algorithms were being developed and to be applied to track down the salt-fresh water interface in islands and coastal aquifers. Parallel work is being conducted for the utilization of off-the-shelf, USGS model for sharp interface saltwater intrusion program SHARP. Field data are being collected to feed the computer models. The software implementation is also underway.

Impact Analysis

Gaza/Israel

Data Transfer

The Israeli hydrologic agencies hav^ accumulated over the years a significant amount of hydrogeological data in Gaza area. A major goal of the project is to ensure the smooth transfer of these data to the Palestinian Authority. The unprocessed data are not very useful to a field engineer. These data have been specially processed prepared. Under the collaborative agreement, the Israeli and the Gaza teams meet regularly. At the request of the Gaza team, these data are provided in the forms of traditional maps and in computer data base. In particular, data sets concerning pumpage, chlorine concentrations and hydraulic heads, and maps of well locations, hydrogeological cross-sections, width of lithological layers, location of incoming chlorine fronts, zones of strong inhomogeneities, etc. have been transferred. These data are begin utilized and updated as part of the project.

Technology Transfer and Training

A number of USGS computer programs have been provided to the Gaza team leader, Mr. Shaath. In addition, a UNDP program, Groundwater Software for Windows has been transferred. In collaboration with the Israeli and the US teams, the software is being used to maintain the Gaza Strip hydrogeological data base. To prepare Mr. Shaath for more advanced hydrological work, arrangement has been made to enroll Mr. Shaath in the Ph.D. program of Ecole Mohammadia d'Ingenieurs, Morocco.

Cooperation

The collaborative part of the project has been a success. Meeting between the Israeli and the Gaza teams were held regularly. The spirit of cooperation has been high. The two teams worked in harmony during the data and technology transfer phases.

Morocco

The USGS hydrogeological computer programs have been transferred. Links with other USAID sponsored program in Morocco have been made.

Consultation was provided to these projects. Several national and provincial water agencies were visited. Again, consultation was provided.

Financial Report

The total budget, expenditure of the first year (September 1, 1994-August 31,1995), and commitments are shown below.

Expense Category	Project Budget	Expenditures To Date	Expenditures Commitments	Expended and Committed	Balance Remaining
Faculty Salaries	14,708	7,621		7,621	7,087
Graduate Student Salaries	14,300	2,500		2,500	11,800
Staff Salaries	1,000	1,000		1,000	0
Fringe benefits	4,627	2,564		2,564	2,063
Travel	31,000	13,924		13,924	17,076
Supplies and Expenses	14,163	6,944	1,451	8,395	5,768
Occupancy and Maintenance	239,150	65,720	113,930	179,650	59,500
Equipment	15,000	3,163		3,163	11,837
Other Expenses	0	399		399	(399)
Total Direct Costs	333,948	103,835	115,381	219,216	114,732
Total Indirect Costs	88,909	41,254		41,254	47,655
Grand Totals	422,857	145,089	115,381	260,470	162,387

Analysis

The expenditure during the first year is $145,089, or 34% of the total (two-year) budget. Including the committed amount (subcontract installments that are not yet realized), the expended and committed amount is $260,470, or 61% of the budget. These expenditure and commitment are within our expectation of the spending schedule.