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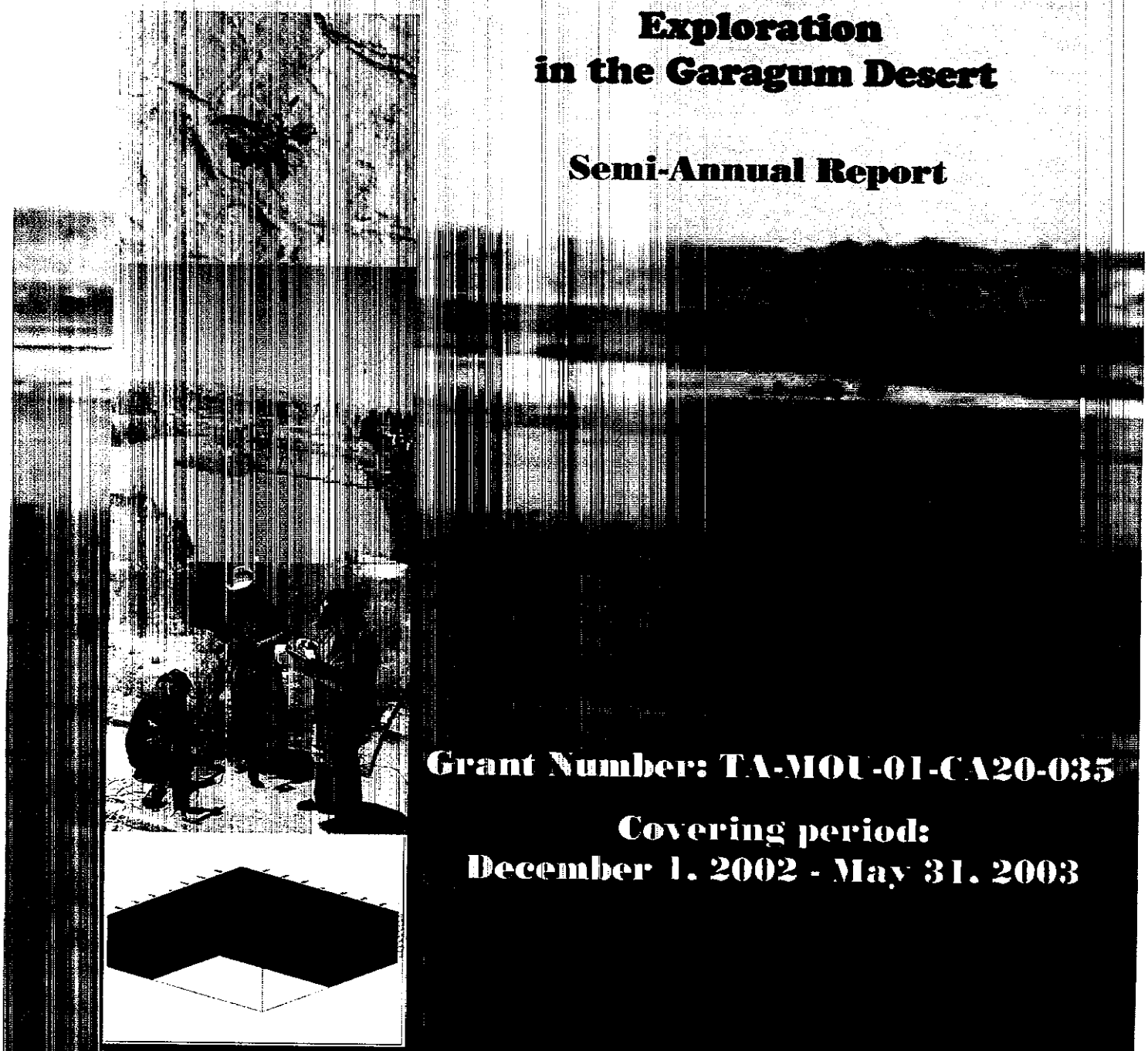
Formation of Artificial Lenses of Freshwater and Their Sustainable Exploration in the Garagum Desert

Semi-Annual Report



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Covering period:
December 1, 2002 - May 31, 2003

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Formation of Artificial Lenses of Freshwater and Their Sustainable Exploration in the Garagum Desert

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Principal Investigators: Dr. A. Yakirevich, Prof. S. Sorek
Grantee Institution: J. Blaustein Institute for Desert Research,
Dept. of Environmental Hydrology & Microbiology
The Institute For Water Sciences & Technologies (IWST)
Ben-Gurion University of the Negev (BGU),
Address: Sede Boqer Campus, 84990, Israel
Telephone Number: 972 8 6596869
FAX Number: 972 8 6596909
E-mail address: alexy@bgumail.bgu.ac.il, sorek@bgumail.bgu.ac.il

Co-Principal Investigators: Dr. I. Mamiyeva
Institution: National Institute of Deserts, Flora and Fauna, Turkmenistan
Address: Bitarap Turkmenistan str., 15, Ashkhabat, 744000, Turkmenistan
Telephone Number: 99 312 398596
FAX Number: 99 312 390586
E-mail address: sic@online.tm

Administrative Official: Sharona Rittberg
Institutional Affiliation: Research Liason Section, Head
Address: P.O. Box 653, Beer-Sheva, 84105 Israel
Telephone Number: 972 8 6472443
FAX Number: 972 8 6472930
E-mail address: sharona@bgumail.bgu.ac.il

Administrative Official: Paltamet Esenov
Institutional Affiliation: Director

Address: Bitarap Turkmenistan str., 15
Ashkhabat, 744000, Turkmenistan
Telephone Number: 99 312 395427
FAX Number: 99 312 353716
E-mail address: desert@online.tm

1) Executive Summary

Storing rainwater gathered at the 'takyr' watershed (clay soil with very low permeability, typical of desert conditions) on top of the saline groundwater table, allows the establishment of Artificial Lens Fresh Ground Water (ALFGW). Such lenses in the desert are often the only source of fresh water for small agricultural farms and livestock for most of the year. The purpose of this project is to explore the complex processes of lens formation in the takyr soil of the Garagum desert, and to produce recommendations for their sustainable exploitation. Research is based on field investigations at the Karrykul ALFGW pilot system complemented by computer simulations. During the period covered in this report, the Turkmenistan team continued their field activity, attempting to restore the infiltration basin that was partly destroyed during catastrophic floods of 2002, resumed functioning of the observation wells network, gathered data from previous experiments at the 'takyr' Karrykul watershed and conducted observations and water sampling. The BGU team executed computer simulations aimed at the improvement and adaptation of a mathematical model on the basis of the collected field data.

Collaborative activities include: (1) mutual discussions of collected data and interpretation of the results of numerical simulations; (2) a meeting in Israel where teams discussed field experiments, equipment for the hydrochemical measurements, the mathematical model and simulation results; and (3) designing of scientific activities for the near future.

Section I: Technical Progress

A) Research Objectives

The main goal of the research is to study the formation of Artificial Lenses of Fresh Ground Water (ALFGW) in the 'takyr' soil of the Garagum desert, and to produce recommendations for their sustainable exploitation.

The specific objectives during the reported period were:

- Experimental study to assess the dynamics of water storage and its quality during infiltration through the unsaturated zone and formation of ALFGW.
- Application of a comprehensive mathematical model to simulate processes of flow and transport in the unsaturated-saturated zones during ALFGW formation.

B) Research Accomplishments

1) *Field activity*

During the rainy seasons of 2001-2002, the dam between the takyr watershed and the infiltration basin, as well as the hydrometrical station, were destroyed by floods (Figure 1). Therefore, some of the initially planned field observations (water levels in the infiltration basin, changes of groundwater level and groundwater concentration during infiltration) were not accomplished.

Inspection of the observation wells revealed that most were clogged or totally destroyed. Only eight out of 44 wells could be used. Therefore, considerable efforts were directed towards recuperation of the observation networks. Currently, 26 wells have been cleaned and large volumes of water were bailed. Some of the wells were not recovered, as the only valid possibility was to utilize the costly method of airlifting. Some of the other remaining wells cannot be restored and so the possibility of drilling new observation wells was considered, but has not yet been implemented.

During past six months, the Turkmenistan team has been carrying out a retrieval program at the experimental site. This included the rebuilding of a dam guiding the surface water at takyr towards the infiltration basin, repairing "protectors" at the lower part of the watershed near the infiltration basin, agro-technical works at a small oasis farm, restoring the irrigation system at the experimental site in Karrykul, and partially cleaning the takyr watershed. Simultaneously, field data was collected regarding rain amount, chemical composition, and groundwater levels, and sampling and analysis of runoff water and groundwater were performed.

The ALFGW pilot system had not been used for observations for several years. As a result, uncontrolled breakthrough of water into the infiltration basin occurred sporadically.The primary task was therefore to determine spatial distribution of groundwater concentration in order to define the spatial extent of the ALFGW. The results of the chemical analysis indicated that groundwater has higher salinity (8-13 g/l) at the center of the infiltration basin (under the observation island, see Figure 1) than in the surrounding vicinity (3-5 g/l). The precise delineation of the ALFGW is still not possible due to the limited number of groundwater samples.

The design and construction of the ALFGW pilot system was carried out by the Turkmenistan Department of Geology during the early 1960s. This included drilling boreholes, construction of the infiltration basin, conducting the first infiltration experiments, etc. One of the tasks, therefore, was to collect field data (in addition to information collected during first six months) and to prepare it for simulation of these initial stages of the ALFGW formation. The Turkmenistan team executed this activity (following the instructions of the Israeli team) using reports of the Turkmenistan Geology Department. This data referred to:

- geometrical parameters of the infiltration system,
- particle size distribution and hydraulic parameters of different lithological layers composing the aquifer,
- hydrogeological cross-sections,
- coordinates and parameters of the observation well network,
- salinity of the unsaturated zone and groundwater prior to the ALFGW experiments and post several infiltration cycles;
- turbidity and chemical composition of runoff water entering the infiltration basin;
- temporal rate and volume of infiltration, water balance, and water levels in the infiltration basin;
- temporal and spatial variations in groundwater level and salinity.

Most of this data was transferred into electronic form and used as input to run the mathematical model and to achieve its calibration.

2) *Modeling*

The process of the ALFGW formation was simulated using the FEFLOW 5.0 numerical code (Diersch, 2002). The FEFLOW is a user-friendly computer code for simulating 3-D density dependent flow and transport in the unsaturated and saturated zones using the finite element method.

Simulation procedure includes the following steps: schematization of the modeling domain, discretizing the domain into a finite element mesh, specifying initial and boundary conditions, defining model parameters, numerical simulations, comparing with existing experimental data, and analysis of the result.

At this stage we simulated the configuration of the pilot system for the formation corresponding to the years 1965 to 1967 (the ALFGW pilot system was altered during the renovation phase from the years 1982 to 1986) and experimental results obtained during that time period. The modeling domain was chosen to be a rectangular area of 1000 x 1000 m, 30 m thick. An infiltration basin was situated at the domain center, sized 40 x 40 m at the bottom, 50 x 50 m at the top, and 3.3 m in depth (Figure 2). The geological structure is composed of sand with lenses of sandy loam, loam and clay. A non-uniform finite element mesh was composed of 33432 nodes. The horizontal mesh dimension was finer (2 m) near the basin and increased to the extent of 80 m at the boundaries of the modeling domain. The vertical size of the mesh varied from 0.5 m at the top to 2 m at the bottom.

Initial conditions prescribe the hydraulic head distribution, at equilibrium, corresponding to a groundwater depth of 15 m and uniform concentration of 20 g/l. Flow boundary conditions of the first type (Dirichlet) were assigned at the area borders. Distribution of the hydraulic head was determined by assuming steady flow conditions and using observed values of groundwater

level. Hydraulic heads along these boundaries were calculated based on the Boussinesq approach and known flow direction (North-West). First type boundary conditions for the groundwater salt concentration were equal to 20 g/l. The bottom of the aquifer was considered an impermeable boundary.

At the soil surface, water flux (resulting from rain and evaporation) was prescribed everywhere excluding the basin where mixed (third type) boundary conditions were prescribed. A mathematical model was developed to simulate infiltration processes through the basin's bottom and its embankments. The hydraulic head in the basin was calculated using a differential mass balance equation accounting for infiltration and evaporation rates. The infiltration rate was assumed to be dependent on the hydraulic properties of the sediment layer on the bottom and along the embankments of the basin. The thickness of this layer was calculated depending on turbidity and size of clay particles in the water, and using Stoke's law. Some additional parameters were determined during numerical experiments using observed water levels in the infiltration basin. The boundary condition of solute concentration in the basin water was equal to 0.2 g/l. The developed model and its numerical code concerning basin water infiltration were coupled with the FEFLOW model using the C++ language and programming interface.

Figure 3 demonstrates a comparison between simulated and observed concentrations in groundwater under the infiltration basin. We note that the observed concentration is higher than the simulated one, especially for depths greater than 20 m as the model does not account for the solute in the solid phase. This solute is dissolved during infiltration of fresh water, after which it leaches to even deeper extents, thus increasing groundwater concentration. Figure 4 shows an areal distribution of concentration in the modeling domain at the groundwater level, after which a water volume of about 15000 m^3 was infiltrated during three rainy seasons. The ALFGW with concentration less than 5 g/l has a maximum radius of about 25 m and 4 m depth containing water volume of about 900 m^3. This corresponds to the observed data.

C) Scientific Impact of Collaboration

On top of the semi-annual meeting held in Israel (April-May 2003), the teams collaborate regularly by exchanging ideas and transferring data via e-mail. Some urgent questions were solved by multi-participant telephone conferences. During the Turkmenistan researchers' visit to Israel, they were introduced to the mathematical modeling techniques used to solve the problem of density driven flow and transport in unsaturated/saturated soils. Simulations with the FEFLOW code were performed. The modern laboratory equipment for the chemical analysis of water samples was demonstrated, discussed and ordered for the Turkmenistan team. The exchange of information and dialog between Israeli and Turkmenistan participants of the project significantly enriched the scientific capacity of both teams.

D) Description of Project Impact

The pilot system for ALFGW formation constructed by the National Institute of Deserts, Flora and Fauna of Turkmenistan was designed for underground storage of rainwater, and for subsequent use of this water for small agricultural farms (pasture irrigation and livestock). Due to unforeseen reasons (destroyed dam), however, the runoff water was not used for controlled

replenishment of the ALFGW but rather largely for irrigation of pistachio and other trees around the Karrykul experimental site, during the winter and spring seasons.

E) Strengthening of Developing Country Institution

During the past six months the Turkmenistan team has purchased a computer, two printers, fax-machine, xerox machine, telephone, rain gauge, sounding devices for measuring groundwater level, bailers for sampling groundwater, specific PC software, CD's, diskettes, facilities for printing, etc. During the visit of the Turkmenistan partners to Israel both teams discussed methods for fast and reliable determination of groundwater salinity in field conditions. The Israeli team suggested using the hand-held Conductivity/TDS/Temperature Meter "CyberScan CON 100/200/300 and demonstrated work with this device. The teams agreed that two such meters for the Turkmenistan partners will be purchased from their budget and through BGU. The Israeli team also demonstrated the FEFLOW software as a tool for simulation processes of density driven flow and transport, which can be used also for modeling the ALFGW formation.

F) Future Work

As was mentioned above, during the rainy seasons of 2001-2002, the dam between the takyr watershed and the infiltration basin, as well as the hydrometrical station, were destroyed by floods. The swampy conditions at the field site did not allow the bringing of machinery to perform recuperation works. Thus the work plan was modified. We expect to carry out system restoration during the summer of 2003 in order to be prepared for the experimental observations through winter to spring of 2004. The restoration works will include: renovation of the infiltration basin and its destroyed right-side embankment; construction of the hydrometric station; cleaning the lower part of the takyr watershed (total surface area 100,000 m^2) from shrubs; continued cleaning of the observation wells and drilling of new ones. At the same time, field and/or lab experiments will be carried out to determine hydraulic parameters of the unsaturated zone. We anticipate that completing these tasks by September-October 2003 will allow us to perform controlled water filling of the infiltration basin and to carry out observations originally planned for the winter – spring season of 2002 to 2003.

We will also continue simulation of the water flow and solute transport using the mathematical models. Preliminary results show the importance of salinity of the unsaturated zone in affecting the concentration of groundwater. Therefore, we will adapt a 1-D model of flow and multi-component solute transport in the zone under the infiltration basin in order to estimate the effect of the physico-chemical reaction (mainly, ion exchange and dissolution-precipitation processes) on leaching salts into groundwater. The results will be analyzed and transformed into a simple relation of a linear sorption isotherm, which can be introduced to a complex 3-D model of density dependent flow and transport.

Section II: Project Management and Cooperation

A) Managerial Issues

The original work plan did not include restoration of the basin embankment and the hydrometric station that were destroyed during floods of 2001-2002. This restoration will lead to necessary changes in the timetable. However, we hope to conduct this activity within the total budget of the project.

B) Special Concerns

As of now, there are no protocols addressing any special concerns.

C) Collaboration, Travel, Training and Publications

Collaborative activities include discussion of technical issues concerning restoration works at the field site, experiments and observations to be performed, preparation of data for simulations with the mathematical model, and analysis of the obtained results.

1) *List of participants.*

Israeli team: Dr. Alexander Yakirevich – PI, Prof. Shaul Sorek – co-PI, Dr. Mikhail Kouznetsov – researcher, Nimrod Gafni – M.Sc. student, Shai Arnon – Ph.D. student.

Turkmenistan team: Dr. Irina Mamiyeva – co-PI, Dr. Mukhamet Nepesov – researcher, Mr. Serdar Tashliyev – Ph. D. student, technicians

2) *Travel.*

Dr. Mamiyeva and Mr. Tashliyev visited Israel where a second meeting of both teams took place. The purpose of this meeting was to discuss project achievements, plan field activity, discuss requirements associated with the equipment to be purchased, and prepare existing data for simulations with the mathematical model. During this visit, the researchers from Turkmenistan were acquainted with some field and lab devices for determining conductivity and TDS of soil solutions. The Israeli team presented the developed mathematical model and its numerical code for simulating processes of the ALFGW formation.

3) *List of publications.*

So far no publications were prepared.

4) *Anticipated activities in the next six months.*

Teams will continue their efforts to prepare the field site for observations during the rainy season of 2003-2004. We will also further apply the mathematical model for simulating the ALFGW, and sensitivity analyses will be performed.

D) Summary of Requests for CDR Program Actions

There are no requests for CDR Program actions.

Appendix

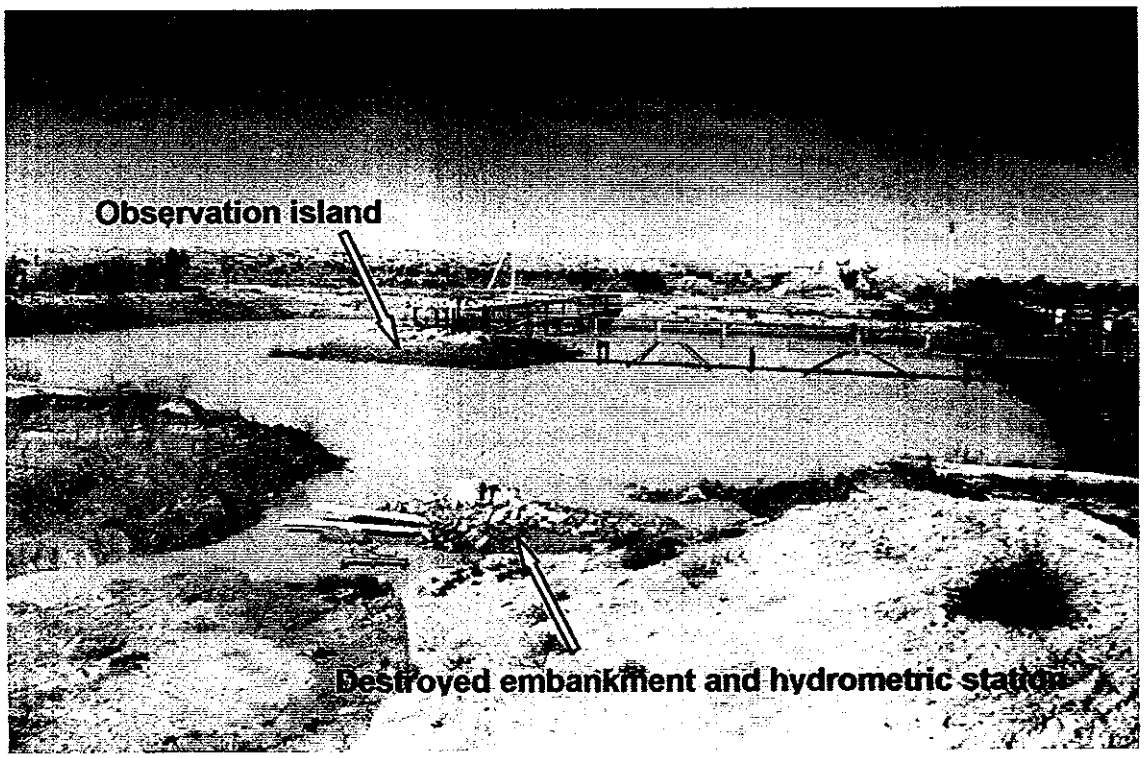

Figure 1. A general view of the infiltration basin during the flood of spring 2002.

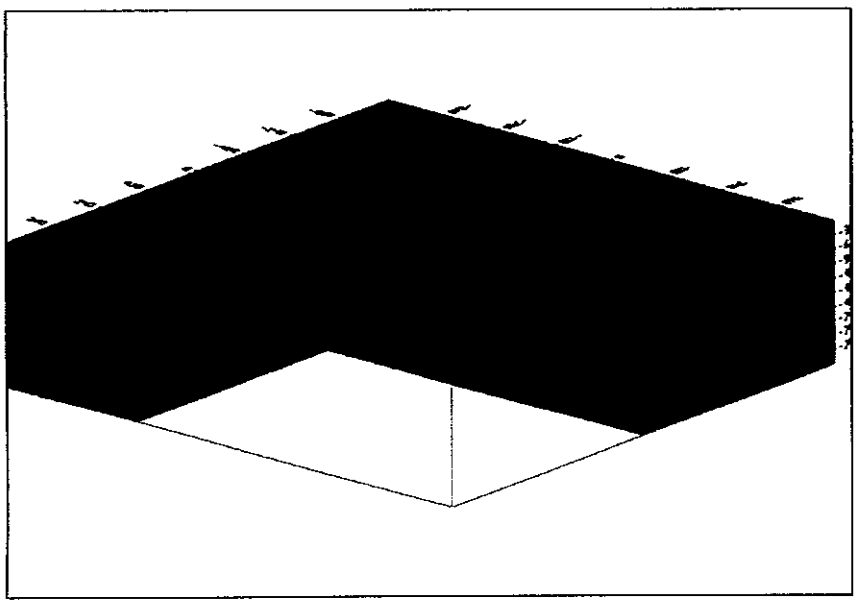

Figure 2. Finite-element mesh discretizing the flow domain and visualization of the simulated ALFGW for the year 1967.

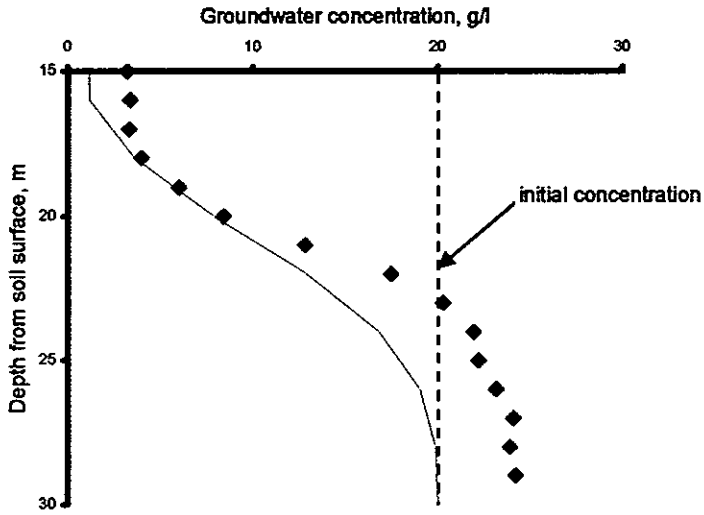

Figure 3. Comparison between simulated (solid line) and observed (dots) solute concentrations under the infiltration basin (June 10, 1966).

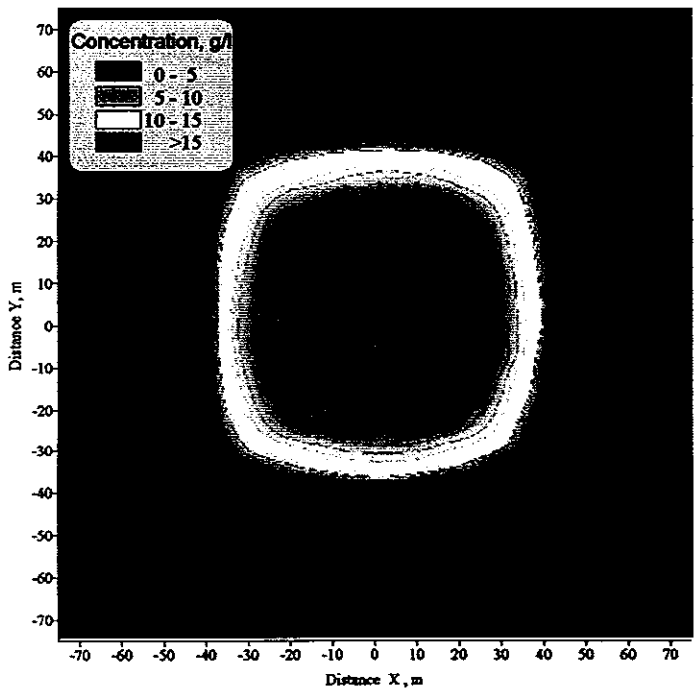

Figure 4. Areal distribution of groundwater solute concentration at a depth of 15 m.