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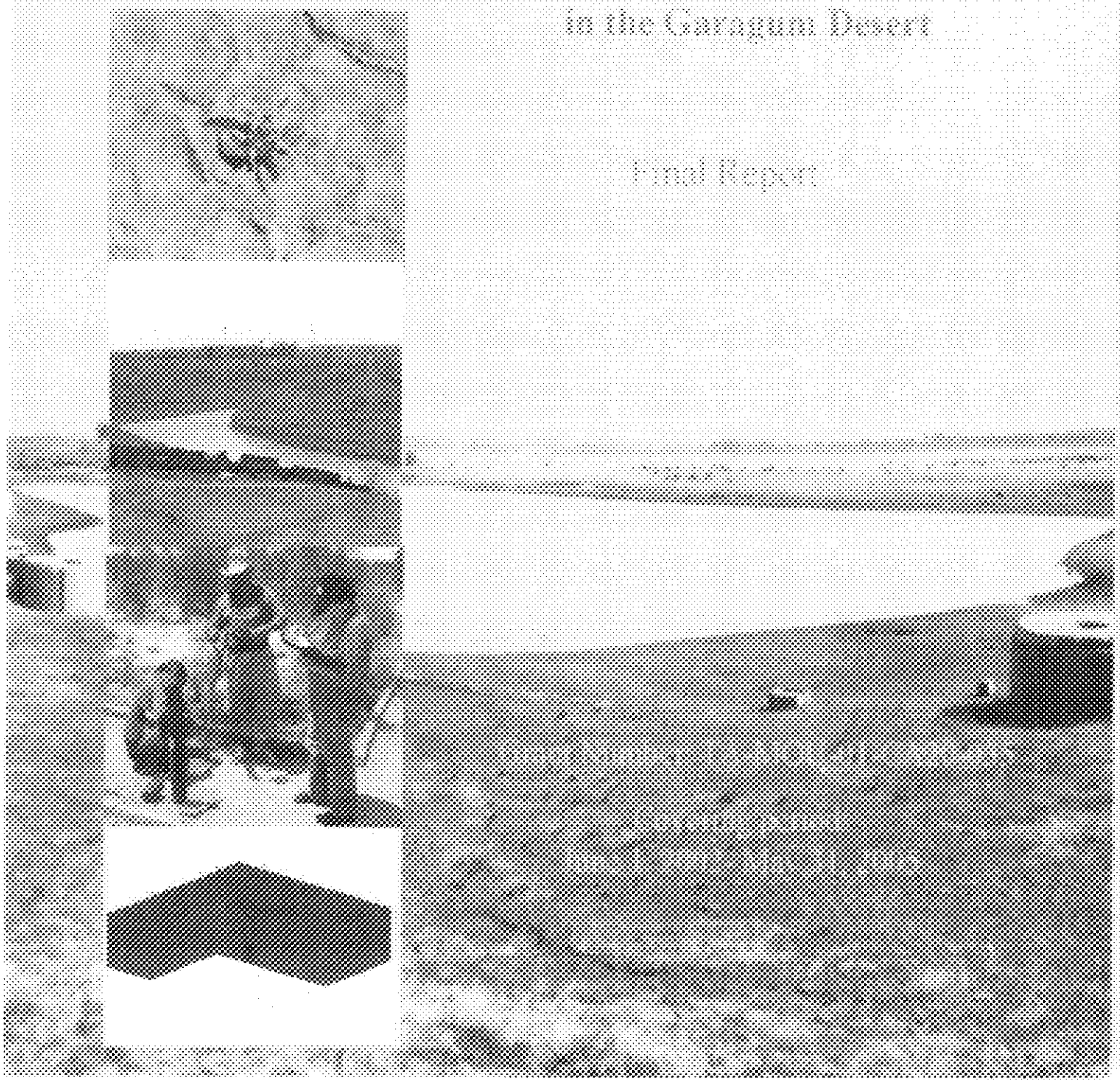
# Formation of Artificial Lenses of Freshwater and Their Sustainable Exploration in the Garagum Desert

Final Report



# FINAL REPORT

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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: Dept. of Environmental Hydrology & Microbiology,
Zuckerberg Institute for Water Research (ZIWR),
J. Blaustein Institutes for Desert Research (BIDR),
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: Office of Sponsored Research, Director
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: Dr 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

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## Executive Summary

This project deals with some of most acute problems in desert areas, namely: harvesting, storage and proper use of freshwater resources. Collecting seasonal runoff water and storing it underground on top of a highly saline groundwater table enables creation of Artificial Lenses of Fresh Groundwater (ALFGW). Due to difference in densities of fresh and saltwater, ALFGW are relatively stable and can serve as storage for significant volumes of fresh and brackish water. The project aimed to investigate factors affecting the creation, evolution and pumping of ALFGW. The investigation was based on field observations and numerical simulations of an established ALFGW, using the pilot system at the takyr (clayey watershed) Karrykul in the Garagum Desert. The system was repaired and field experiments to replenish and pump the lens were carried out. The simplicity of the system, which does not require significant investment in construction, and the possibility of storing and using large volumes of good quality water, demonstrate that the ALFGW technology is economically promising. An ALFGW with an average volume of 3000-6000 $m^3$ can provide 1500-3000 animals with fresh and brackish water and can be created and utilized to serve small agricultural farms, pasture irrigation and watering livestock. A numerical model was adapted to validate observations and simulate different scenarios of lens pumping. Modeling can be applied to assess lens parameters, to choose rational schemes for ALFGW creation and exploitation at any specific site. Based on analyses of hydrogeological, hydrochemical and climatic conditions of Turkmenistan, a map of potential areas and technology for ALFGW establishment was recommended, geared at planning and design of storage for freshwater resources in Turkmenistan.

This project also strengthened the computing facilities and research capabilities of the National Institute of Deserts, Flora and Fauna of Turkmenistan. Transfer of theoretical expertise from Israel to Turkmenistan focused on using modern methods to simulate processes of highly saline groundwater flow and solute transport in the subsurface. Researchers from Turkmenistan were trained in Israel to simulate these problems numerically. The related software, two computers, equipment to conduct hydrological investigations and hydrochemical analyses were also purchased for the Turkmenistan team.

## Research Objectives

This project addressed some of most acute problems in desert areas, namely: harvesting, storage and proper use of fresh water resources. Deserts occupy 80% of the area of Turkmenistan. In the plain part of the country, groundwater mostly has a high level of salinity (15-35 g L), and the quality of the surface water has been significantly deteriorating as a result of non-sustainable agricultural practices. Although the average annual precipitation in the Garagum desert is quite small (130 mm), the total amount of water received in the form of precipitation is up to 50 $km^3$. However, most of this water is lost through spatially scattered infiltration and evaporation. Therefore, finding and using alternative sources of fresh water is of high importance. Takyr watersheds are being used to collect runoff water during seasonal precipitation. Takyr (from Uzbek *takyr*, barren land) soil is composed mainly of clay particles; it has a low hydraulic conductivity and a high runoff coefficient. Volumes of collected runoff water can be very large, requiring proper storage. The collected runoff water can be infiltrated underground and stored on top of the saline water table. Thus, an artificial lens of fresh groundwater (ALFGW) can be created and used afterwards for water supply. This method was actually implemented by ancient societies in Turkmenistan for centuries. However, the technology of lens formation and its exploitation was very inefficient: about 90% of runoff water was lost due to spatially scattered infiltration and evaporation, while only 10% of water replenished the ALFGW.

Natural lenses of fresh water were studied by Wentworth (1948), Lebbe (1983) and van Dam (1999); however, these were mainly under coastal dunes. In desert conditions, ALFGW formation was investigated by Kunin (1959), Leshinsky (1970), Rogovskaya *et al.* (1986), Ganus and Kuznetsov (1992), and Mamieva (1999). It was found that ALFGW are quite thin (3-10 m) and that the transition zone between salt and fresh water is narrow (1-3 m). Conditions of ALFGW recharge and formation are very different from those of natural lenses. The ALFGW parameters (volume, thickness, and surface area) depend on characteristics of the aquifer, recharging system and on the infiltration regime. Another important task is to assess sustainable pumping regimes in ALFGW. It was recognized that a groundwater well discharged from the freshwater zone causes the saltwater to move upwards towards the well (saltwater upconing). Several methods to calculate upconing were developed using models of different complexities (Bear and Dagan, 1964; Reilly and Goodman, 1985; Huyakorn *et al.*, 1996; Aliewi and Mackay, 1999; Bakker, 1999; Zhou *et al.*, 2005). However, the ALFGW is very sensitive to pumping because of its relatively small size. Therefore, it was important to study the process of the ALFGW formation and the dynamics of its water quality during lens exploitation.

The main goal of the research was to study the formation of ALFGW in the takyr soils of the Garagum desert, and to compile recommendations for their sustainable exploitation. The specific objectives were:

- To perform an experimental study to assess the dynamics of water storage and quality during the following stages: infiltration through the unsaturated zone, formation of the ALFGW, and exploitation by pumping.
- To apply a comprehensive mathematical model to simulate processes of flow and transport in the unsaturated and saturated zones during ALFGW formation and exploitation.
- To assess rational parameters and pumping system regimes to ensure sustainable exploitation of the ALFGW.
- To assess potential ALFGW sites, along with areas with high demand for resources in Turkmenistan.

The major innovations of the present study were aimed at improving the technology for ALFGW formation and exploitation, to solve the problem of harvesting and storing freshwater in the takyr watersheds, and the development and application of a mathematical model. The scientific benefits of the research are a detailed consideration of the complex problem concerning density-driven flow and transport for the specific conditions of the Garagum Desert.

The project was supported by several Turkmenistan organizations. The Ministry of Water Resources of Turkmenistan helped to carry out the renovation of the experimental system at the takyr Karrykul. The Center for Ecological Monitoring assisted in conducting soil and groundwater analyses. The Scientific Information Center of the Interstate Commission for Sustainable Development helped construct a map of potential ALFGW sites by using GIS to analyze different maps of Turkmenistan.

## Methods and Results

*Karrykul experimental site and field investigations*

A pilot system for ALFGW formation was constructed in 1965 by the National Institute of Deserts, Flora and Fauna of Turkmenistan. The system is located at the Karrykul takyr in the southern part of the Garagum desert, 60 km to the north of Ashkhabad (Figure 1a). Mean annual precipitation is 150 mm and rains occur mainly during the winter-spring seasons. The catchment surface area is 1.75 km$^2$, which allows an annual collection of 20,000-25,000 m$^3$ of run-off water. The experimental pilot system consists of an infiltration pond 40 x 40 m at the bottom, 50 x 50 m at the top, and 3.3 m deep (Figure 1b and c).

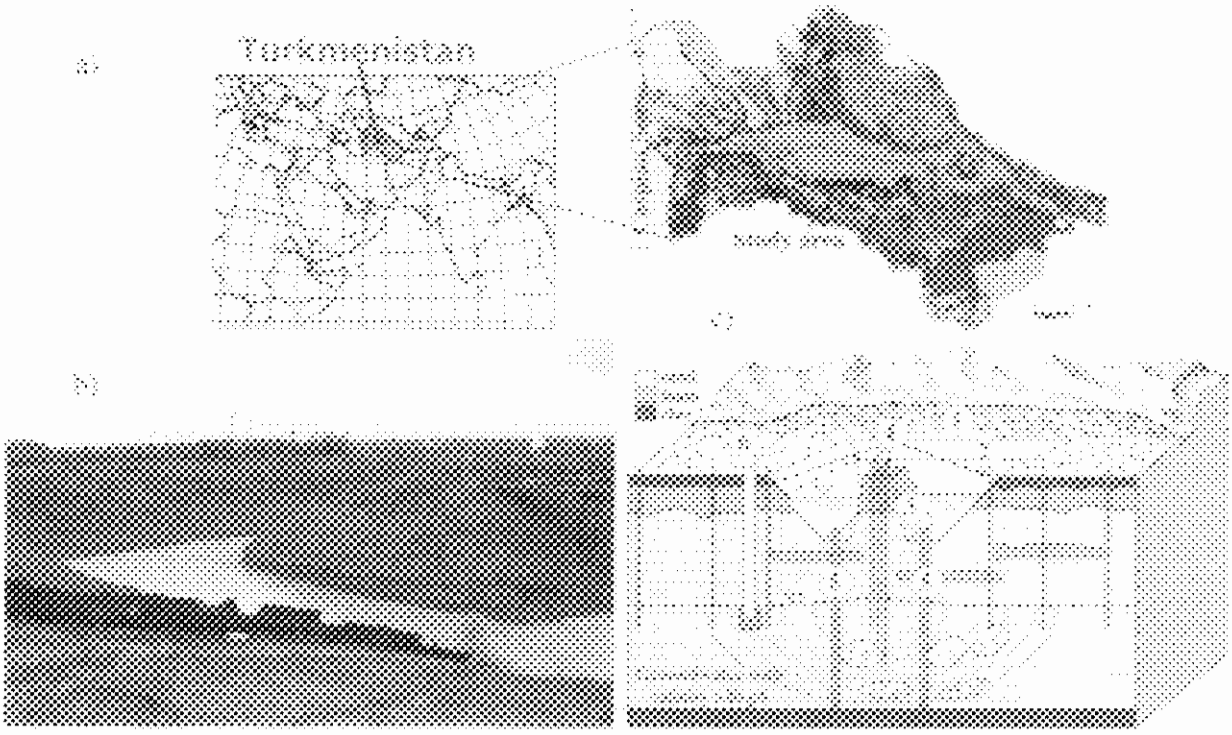



Figure 1. Experimental system for ALFGW formation at the takyr Karrykul:
a) location of the site, b) refilling infiltration basin (April 2004), c) schematic set-up

The middle of the infiltration pond is occupied by an island (20 x 20 m at the bottom and 10 x 10 m at the top), on which a cluster of boreholes was installed and used for observations of water levels and sampling groundwater from different depths. A number of monitoring boreholes were also drilled around the infiltration pond. In 1982, four recharging wells were constructed to enforce water infiltration, and a settling pond was excavated to decrease turbidity of runoff by sedimentation.

The upper 12 m of the unsaturated zone is built of fine- and medium-grained sand with lenses of sandy loam, loam and clay. Underneath this zone the aquifer is composed of well-sorted coarse sand of the Kara Kum suite. Content of salts in the unsaturated zone varied within the range

of 1-10 g/kg in the sand and 10-20 g/kg in the loam and clay layers. The aquifer base, at the depth of 30 m, is composed of clay deposits. Groundwater of sodium-chloride type has a salinity of more than 20 g/L TDS, and the depth of the water table is at about 15 m. Hydraulic conductivity of the sand in the saturated zone is 3.7-10.5 m/day. The groundwater flows towards the northwest driven by a gradient of 0.0002-0.0003.

During the years 1965 to 1968, the volume of surface water 25,000 $m^3$ with salinity of 0.2 g/L was infiltrated into the underground. This created a lens of a maximum thickness of 6 m and a radius of 38 m with concentration increasing from less than 2 g/L at the central part of the lens to 10 g/L at its periphery (Leshinsky 1970, Rogovskaya *et al.*, 1986). During 1980-1984, the system was renovated (additional wells were drilled, the infiltration basin was cleaned and deepened by 2 m, 4 recharging wells were installed at the bottom of the infiltration basin. The ALFGW recharge was in 1981, 1985 and 1987 (2000 $m^3$ each time). In May 1988 the volume of water 124000 $m^3$ was infiltrated to refill the ALFGW. There were no observations conducted during these years. 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 2a). Therefore, renovation works at the experimental site were carried out during autumn 2002 and 2003.

a) b)

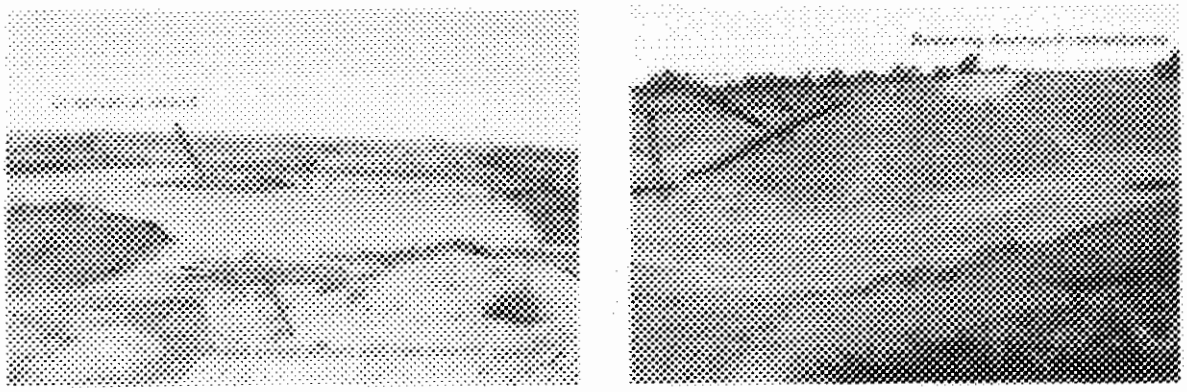


Figure 2. A general view of the infiltration basin: a) during the flood of spring 2002, b) during renovation works in 2003

As a result, the system (infiltration basin with recharge wells, Figure 2b) was prepared for conducting field experiments during spring 2004. Simultaneously, field and laboratory experiments were carried out to determine hydraulic parameters of the unsaturated zone. The coreholes were drilled at different locations of the infiltration basin. Soil cores were sampled from the unsaturated zone to a depth of 15 m and analyzed to determine particle size distribution, water content and salinity (Tables 1-4, Appendix). The results indicated that salinity of the unsaturated zone drastically decreased in comparison to its initial state (before construction of the infiltration basin). The Total Dissolved Solids (TDS) in the soil profile vary within the range of 0.2-0.6 g/L. Regular sampling of groundwater was also performed. The groundwater has higher salinity (8-13 g/l) at the center of the infiltration basin (as it is a zone beneath an island situated at the middle of the basin where saline water is stagnant), in comparison with the surrounding vicinity (3-5 g/l) (Table 5, Appendix).

The 18 mm of rain precipitated during April 5, 2004. This induced an approximate volume runoff of 17,000-20,000 $m^3$, which was partly used to fill in the infiltration pond at the

experimental site (Figure 1b). The remaining runoff water had flown downstream filling in a "kak" (locally stands for pond like depression) at the takyr border near the Karrykul village.

Runoff water had TDS concentration of 0.37 g/l and a turbidity of 3.2 g/l with 61% clay particle content. Maximum water level in the infiltration pond was 237 cm in April 6. After one month, approximately 4000 $m^3$ of water infiltrated through the pond bottom and its embankments and the water level dropped to 8 cm. Thickness of the clayey crust in the pond after infiltration varied from 0.8 to 1.5 cm. The measurements of groundwater salinity were carried out using a hand-held Conductivity/TDS/Temperature Meter "CyberScan CON 200". Distribution of the measured TDS concentration is depicted in Figure 3, for four time periods. We note a consistent decrease of groundwater salinity under the infiltration pond and nearby.

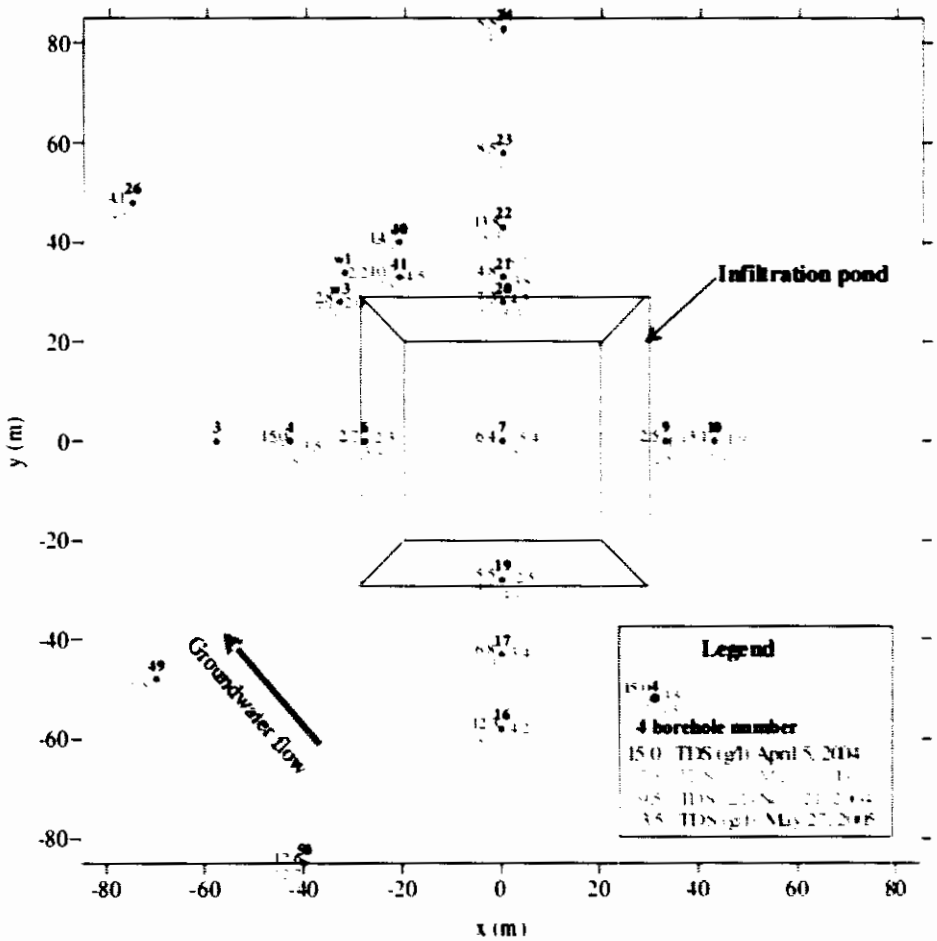



Figure 3. Measured distribution of TDS concentration in groundwater during April, 2004 –May 2005.

Refilling the infiltration pond with runoff water during April-May 2004 revealed several problems regarding the hydrometric station design and measurements of water flux through it. A significant portion of the water bypassed the hydrometric station and flowed into the pond through several cracks, which had developed due to erosion processes. The fissure developed between the hydrometric station and boreholes 8, 9 and 10 had a length of 50 m, a width of 1-2.5 m and a depth up to 2 m. This fissure started at the takyr border and ended at the pond embankment. Water

flowing through this fissure infiltrated underground and induced a decrease in groundwater concentration near boreholes 9 and 10 (2.8 and 2.3 g/L, respectively). A portion of this water flowed into the pond and was not accounted for by water balance calculations. Development of this fissure also subjected the hydrometric device to be destroyed again.

***Modeling the ALFGW formation and sensitivity analysis***

The process of the ALFGW formation was simulated using the FEFLOW numerical code (Diersch, 2002) for two spatial dimensions (2-D) or three dimensions (3-D) density driven flow and transport in the unsaturated and saturated zones. The non-linear Richards equation and advection-dispersion equation are coupled through the liquid density, which is assumed as a function of solute concentration. The balance equations of water flow and solute transport are solved using the finite-element method.

Infiltration of fresh water through the unsaturated zone is modeled by assigning water level varying with time at the infiltration pond surface. The runoff water on the takyr soil has significant concentration of clay particles (3-8 g/L), sedimentation of which caused sealing of the base and embankments in the infiltration pond, during water percolation. This sealing causing a decrease in hydraulic conductivity was accounted for when simulating the processes associated with the ALFGW formation. To account for the effect of water turbidity on infiltration rate through the pond bottom and its embankments, we developed a sub-model of soil particles sedimentation in the pond creating a layer ("cake") impeding water infiltration. The sub-model equations were solved numerically at each time step by a computer code that was developed and coupled with the FEFLOW code, using the C++ language and the FEFLOW programming interface.

To simulate the ALFGW formation for a 3-D configuration, together with field observation data at the takyr Karrykul, the modeling domain was chosen to be a square area of 1000 x 1000 m and 30 m thickness. An infiltration basin was situated at the domain center, sizes of 40 x 40 m at the bottom, 50 x 50 m at the top, and 3.3 m in depth. A non-uniform finite element mesh was composed of 48887 nodes. The horizontal mesh dimension was finer (1 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 1 m at the bottom.

Initial piezometric head distribution was calculated by assuming vertical equilibrium conditions, and using observed values of groundwater level (15 m at the middle of the infiltration pond), known gradient of water table (0.0002), and groundwater flow direction (northwest). Calculations were based on the Boussinesq approach. Initial salinity of groundwater was prescribed as constant and equal to 22.5 g/L. In the unsaturated zone we assigned measured distribution of salt concentration varying with depth. The Dirichlet boundary conditions for the flow and transport problems were assigned at the area borders. At the soil surface, water flux (resulting from rain and evaporation) was prescribed everywhere excluding the pond where the Cauchy boundary condition was prescribed. This condition accounts for the changing water level in the pond as a function of inflow, evaporation and infiltration through the impeding layer as described previously. The pond water salinity was equal to 0.2 g/L. To account for the effect of the observation island as a flow obstacle, a no flow boundary condition was assigned at a square of 10x10 m located at the pond center.

The unsaturated zone parameters (retention curves and the unsaturated hydraulic conductivity) were estimated using an indirect method based on particle size distribution data (Arya and Paris, 1981; Mishra *et al*, 1989) and the van Genuchten relations (1980). The saturated hydraulic conductivity ($K_s$) and porosity ($n$) of the different lithological units were estimated from

data of field and laboratory experiments. Values of $K_s$ were 7.0, 0.8, 0.4 and 0.1 m day for coarse sand, fine sand, loam and clay, respectively, and the $n$ values were 0.31, 0.41, 0.43 and 0.36, respectively. The longitudinal and transversal dispersivities of 0.5 and 0.05 m, respectively, were assessed by trial and error using limited data of groundwater salinity. Porosity and hydraulic conductivity of the cake were 0.96 and 1 mm/day, respectively. These values were adopted by fitting the observed and simulated water levels in the pond. Volume ratio of soil particles in runoff was 0.002 $cm^3$/mL, a mean radius was 0.005 mm.

Simulation period, following field experiments, from May 1965 to April 1970 was subdivided into several time intervals (infiltration cycles). At the beginning of each cycle, the pond was cleaned from sediments and filled with water collected at the watershed during rainstorms. The total water volume of 26,000 $m^3$ was infiltrated. An approximate of 5,000 $m^3$ of water was needed to saturate the vadose zone under the pond. During the first year, groundwater salinity slightly increased due to leaching of salts from the unsaturated zone. Continuing infiltration resulted in a decrease of groundwater salinity under the pond. Figures 2 to 4 show simulated distribution of groundwater salinity and the point values at the observation boreholes, for June 1967 and April 1970. Figures 4 demonstrates the areal distribution of concentrations at different depths, starting from z = -15 m (water table) in June 1967 and in April 1970, respectively. The ALFGW (area contoured by the iso-concentration 5 g/L) has the maximum extent at this depth increasing the radius from 21 m in 1967 to 36 m in 1970. The maximum thickness of the ALFGW was about 4.0 m in 1967 and it did not change in 1970 (Figure 5). We note (Figures 4 and 5) that concentration of salts at the ALFRW center is higher than at its vicinity because of the observation island, which prevents infiltration at the middle of the pond. Consistent agreement was obtained between the simulated and observed concentrations. However, at some locations (e.g. under the eastern side of the pond) the observed groundwater salinity is somewhat higher than what was simulated. This may be due to actual heterogeneity of geological structure and distribution of concentrations that were not introduced into the model. By 1970 the ALFGW slightly moved northwest in the direction of ambient groundwater flow (Figure 4b). The ALFGW with concentration less than 10 g/L contains water volumes of about 2800 and 5200 $m^3$ in 1967 and 1970, respectively. Simulated 3-D distribution of concentrations and velocity-vector patterns at different depths are shown in Figure 6. We note countercurrent directions when comparing the flow at 20m depth to that of 25m depth.

To test the model predictions for a long time period (1965-2004) we used historical data regarding ALFGW replenishment and the results of field experiment conducted within the project framework. About 60000 $m^3$ of water was infiltrated during 40 years to create and replenish the lens. The areal distribution of groundwater concentration in November 2004 is presented in Figure 7. Although consistent agreement was obtained between simulated and observed concentrations, we note significant deviations at several locations, which can be explained by uncertainties in lithological structure and boundary conditions that were not accounted by the model. The ALFGW (area contoured by the iso-concentration 5 g/L) has the maximum extent of about 30 m and the maximum thickness of about 10 m, and estimated volume of water of 10000 $m^3$.

To estimate the effect of water-rock interaction resulting from physico-chemical reactions during leaching salts from the unsaturated zone into groundwater, we adopted a 1-D model of flow and multi-component transport. This model considers water flow and major ions transport in the unsaturated-saturated zones accounting for the cation exchange and dissolution-precipitation of gypsum and calcite (Yakirevich et al., 1997). Simulations with that model indicated that cation exchange processes have minor effects on soil and groundwater quality because the cation exchange capacity of sand and clay layers (composing the unsaturated zone) is small (10-30

maybe for sand, and up to 120 mg/kg for clay). The dissolution precipitation of gypsum may increase groundwater salinity at the initial stages of infiltration. However, after several water infiltration cycles, this effect decreases due to almost complete leaching of salts from the unsaturated zone.

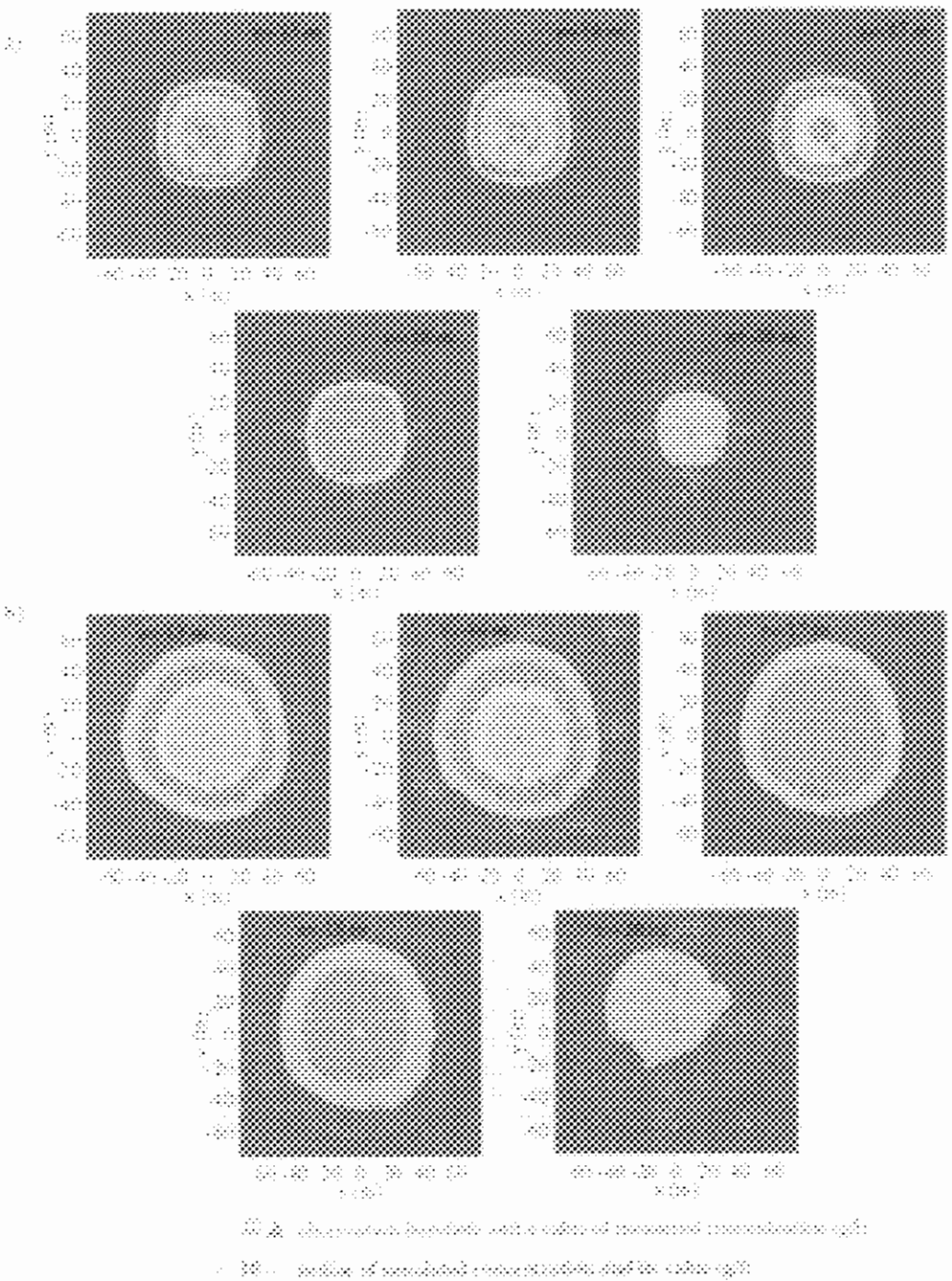


Figure 4. Measured and simulated spatial distribution of concentrations at different depths: a) June 1967, b) April 1970

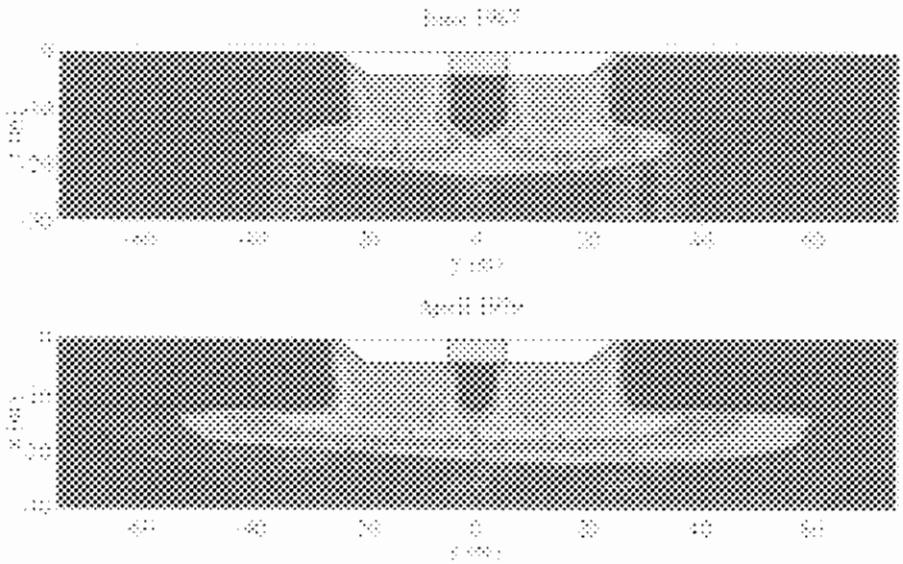


Figure 9. Measured and simulated spatial distribution of concentrations through a vertical cross-section at x=0

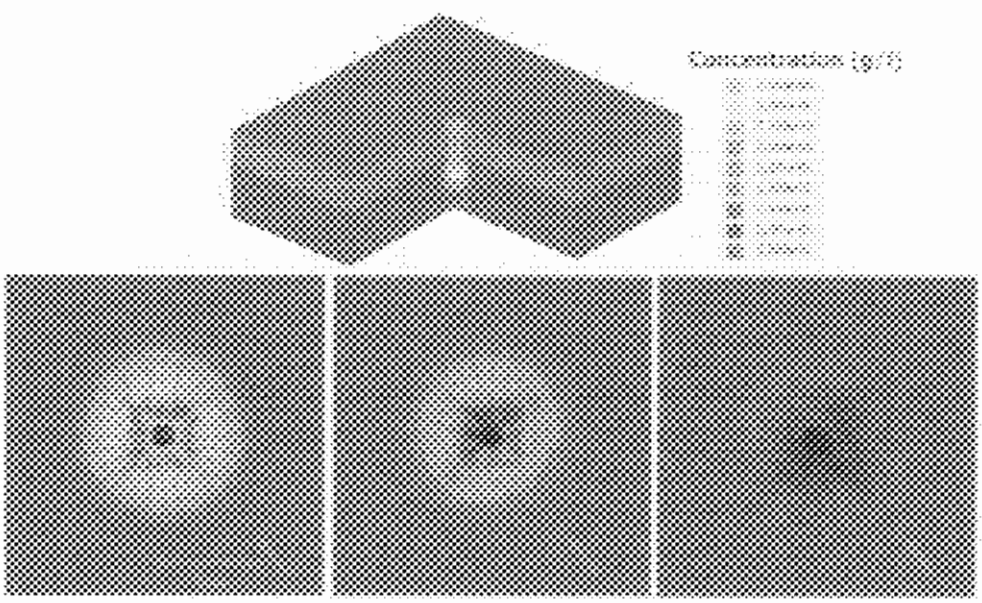



Figure 6. Simulated 3-d distribution of concentrations and flow velocities at different depths.

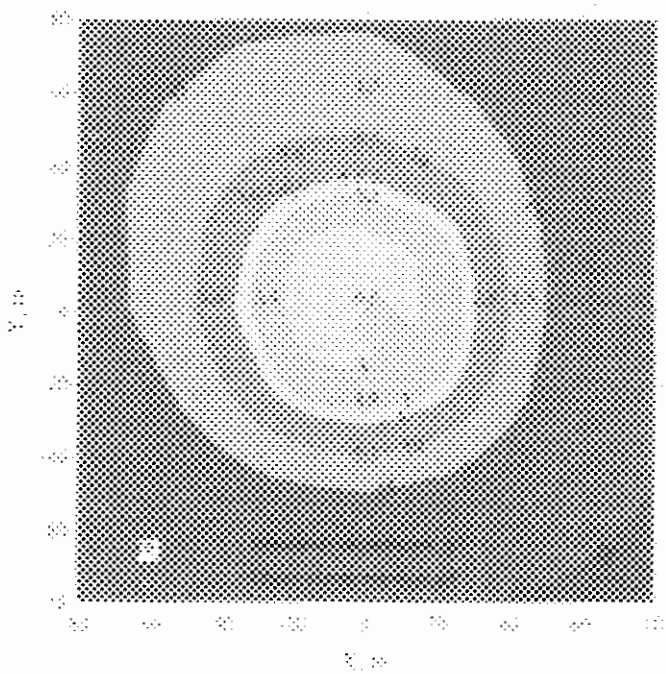


Figure 7. Measured and simulated spatial distribution of concentrations in November 1994.

To investigate processes of the ALFGW formation and to assess the effect of different parameters on lens extent, a series of simulations for 2-D axisymmetrical space were carried out. A homogeneous sand profile (radius of 500 m and 50 m depth) was modeled. Saturated hydraulic conductivity, longitudinal and transversal dispersivities were 5 m/day, 1 m and 0.1 m, respectively. Initial groundwater level of 15 m and uniform salt concentration of 30 g/L was prescribed. The sedimentation of particles was not accounted for. A period of 10 years was analyzed, assuming that throughout the first 5 years, 5000 $m^3$ of water was infiltrated through the pond (radius of 25 and 20 m at the top and at the bottom, respectively, and of 3 m depth) during the first month of each year. The second 5 years period was simulated subject to the conditions that the ALFGW was not replenished. Figure 8 depicts the distribution of concentration, flow velocity vectors and streamline patterns. We note that at the lens edges, the water flow has a vortex pattern (fresh soil is being desalinated). This behavior is due to differences in densities of fresh and saline water.

The ALFGW that is not replenished decreases in thickness with a rate of about 90 cm/year, while increases into a lateral extent by 1.5 m/year. After 5 years, the thickness of the transition zone between fresh and saline water (a zone between two concentrations of 1 and 10 g/L) in vertical direction decreases from 5 to 4 m. While horizontally this zone increased from 10 to 11 m. The reason of such behavior is vortex flow below the lens. Close to the middle of the ALFGW, the flow velocities directed upward and saline dispersive flux use the same direction, reducing the lens thickness. Away from the center of the lens, flow in the transition zone is mainly horizontal and opposite to the direction of the dispersive flux, increasing lens width. With time, the vortex center moves in a horizontal direction to the lens edges.

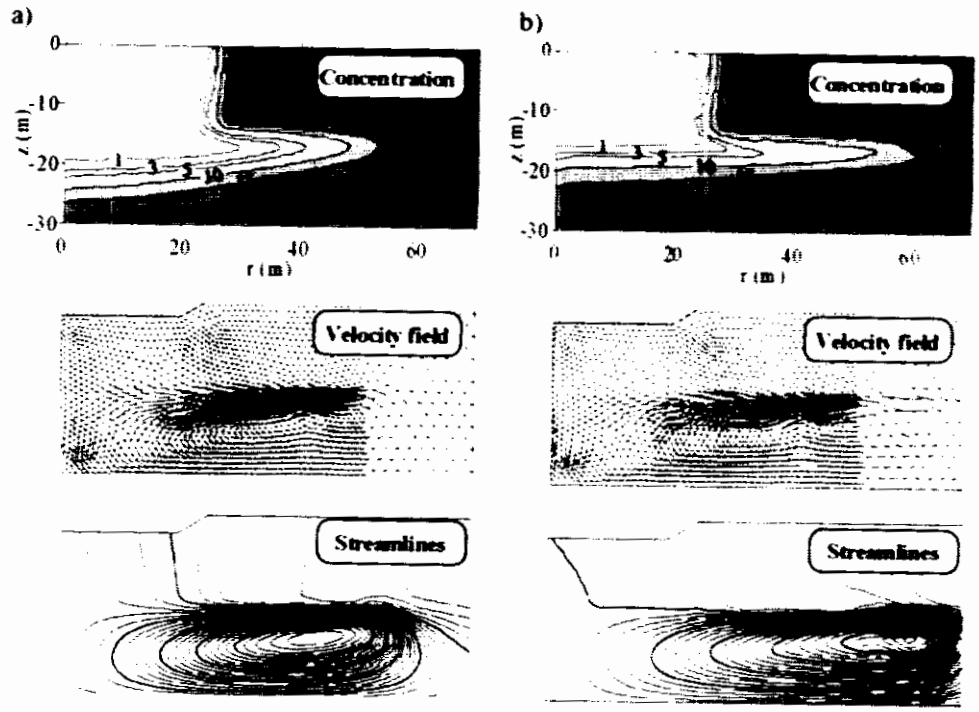



Figure 8. Simulated distributions of concentration (g/L), velocity field and streamlines:
a) after 5 years of 5000 $m^3$ ALFGW replenishment per year;
b) after additional 5 years without the ALFGW replenishment.

Sensitivity analysis was performed to assess the effect of physical parameters on the ALFGW extension. The following parameters were changed during simulations: saturated hydraulic conductivity; longitudinal and transversal dispersivities; initial groundwater salinity; infiltration basin configuration; and groundwater depth. A water volume of 25,000 $m^3$ was infiltrated through the pond boundary surface during 5 years (5,000 $m^3$/year).

It was found that increasing aquifer hydraulic conductivity from 0.5 to 10 m/day lead to a decrease of the ALFGW maximal radius with concentration less than 3 g/l from 34.5 to 29.4 m, while for a concentration less than 10 g/L this radius increases from 40.6 to 45.6 m. For $K_s$ =0.5 m/day the maximal lens thickness was 9.5 and 12.5 m with water salinity of less than 3 to 10 g/L, respectively; while for $K_s$=10 m/day this thickness was 5.5 and 8.5 m with the same salinity levels.

Increasing longitudinal dispersivity from 0.1 to 2.5 m and transversal dispersivity from 0.01 to 0.1 m, resulted in a decrease of the ALFGW maximal radius from 39.1 to 26.9 m with concentration less than 3 g/L. This radius decreases from 46.9 to 39.2 m for concentration less than 10 g/L. Maximal lens thickness bounded by isoline 3 g/L decreases from 8.5 and 5.6 m with the increase of dispersivities. Changing dispersivities does not affect ALFGW thickness with salinity less than 10 g/L.

Simulation with increasing initial groundwater salinity from 20 to 30 g/L indicated that maximum ALFGW radius and thickness decrease by about 3.5 m and 2 m, respectively. Simulations for different configurations of the infiltration pond (radius and depth) demonstrated that the ALFGW volume significantly decreases with an increase of the pond radius. When equal water volume infiltrated over larger area, more water was required for flashing out salts from the unsaturated zone and the developed lens thickness is much smaller. Increasing groundwater depth leads to the same effect of the lens decrease.

Additional simulations were carried out to estimate the effect of infiltration time on the volume of water stored in the ALFGW. Altogether 25,000 $m^3$ was infiltrated through the pond during 5 years (5000 $m^3$/year) assuming that the time interval of an infiltration cycle varies for different scenarios. Results indicated that increasing infiltration interval from 5 to 80 days lead to an increase of water volume in the ALFGW with concentrations less than 3 and 10 g/L by about 20% and 30%, respectively. We account this to the flow velocities that decrease in the unsaturated zone with the increase of the infiltration period. Consequently, changes of water table under the pond are much lower, and groundwater velocities are smaller in comparison to the scenario with the short infiltration period. The velocities of the vortex flow, induced by the differences in density of fresh and saline water, are also minor and, therefore, cause a less dispersive flux and a narrower ALFGW mixing zone.

***ALFGW pumping***

Experimental pumping of the ALFGW was conducted from well **w1** (diameter of 0.5 m) located northwest near the infiltration pond, downstream to ambient groundwater flow (Figure 2). Pumping was performed in June 2, 2005 during 5 hours with a discharge of 1.5 $m^3$/h. Concentration of the pumped water was measured every hour. During the first two hours water salinity decreased from 1.9 to 1.8 g/l, and water level in the well dropped by 1.3 m. During next three hours, concentration decreased to 1.4 g/l, while water level increased by 36 cm. This means that more fresh water flows from the ALFGW center towards the pumping well. When pumping was stopped, water level was recovered and concentration increased to 2 g/l after 5 hours. This indicates that more water comes from the lens edges than from its center. We did not simulate this experimental data because of large deviation between observed and simulated groundwater concentrations for the time corresponding to the pumping, and it was difficult to prescribe initial conditions for complex 3-D configurations using very limited number of observations.

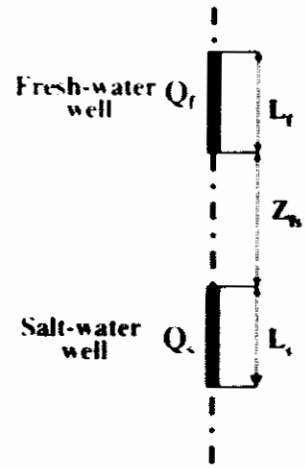
Therefore, we performed synthetic simulations of different pumping scenarios of the ALFGW. Usually, pumping is modeled by introducing sinks with prescribed rates at specific nodal locations. However, such procedures sometimes cause numerical instability due to lowering of the simulated water table below the sink specified depth. Another problem, the actual mixing of water in the well during pumping and the effect of seepage face are not accounted for. To improve simulations, we developed a sub-model of pumping from a well of prescribed geometry and coupled this model with the FEFLOW code.

First, we simulated an axi-symmetric case for a pumping well located at the center of the modeling domain. Two pumping schemes were considered: 1) a skimming well with a screen initially at the freshwater zone; 2) a scavenger well system with one well screened in the freshwater zone and another well screened in the saltwater zone. The initial distribution of salt in the domain was adopted from previous simulations assuming a 5-year period of lens formation (with replenishment of 5000 $m^3$ of freshwater each year). The radius of the pumping well was 0.5 m. It was assumed that the prescribed volume of water (25 or 50 $m^3$) was pumped during one pumping cycle, which varied from 1 to 5 days. Pumping continued as long as the concentration of pumped water did not exceed 5 g/l. Several pumping scenarios of the ALFGW were simulated (Table 1). These varied in their pumping rates, well screen length and location, duration of pumping cycle and the distance between freshwater and saltwater well screens. The results of simulations are depicted in Figures 9 and 10.

Table 1. Simulated pumping scenarios for the axy-simmetrical problem

| N | $L_f$ (m) | $Q_f$ ($m^3$/day) | $L_s$ (m) | $Q_s$ ($m^3$/day) | $Z_{fs}$ (m) | $T_p$ (day) |
|---|---|---|---|---|---|---|
| 1 | 2 | 25 | - | - | | 1 |
| 2 | 4 | 25 | - | - | | 1 |
| 3 | 4 | 25 | 4 | 25 | 2 | 1 |
| 4 | 4 | 25 | 4 | 5 | 2 | 5 |
| 5 | 4 | 25 | 4 | 25 | 6 | 1 |
| 6 | 4 | 25 | 4 | 50 | 2 | 1 |
| 7 | 4 | 50 | 4 | 50 | 2 | 1 |

$L_f$ – lenth of freshwater well filter, $Q_f$ – pumping rate from freshwater well.
$L_s$ – lenth of saltwater well filter, $Q_s$ – pumping rate from saltwater well.
$Z_{fs}$ – vertical distance between filters of freshwater and saltwater wells.
$T_p$ – length of a pumping period.



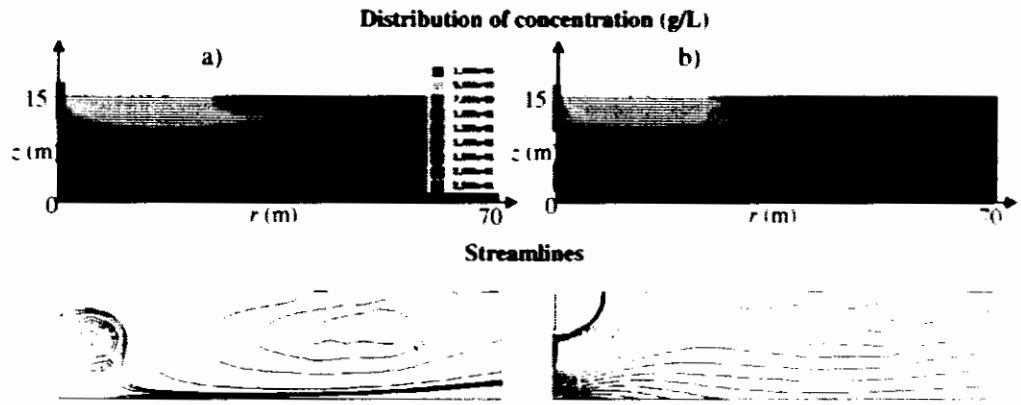




Figure 9. Simulated distribution of concentration and streamlines during pumping from (a) skimming well, and (b) scavenger well.

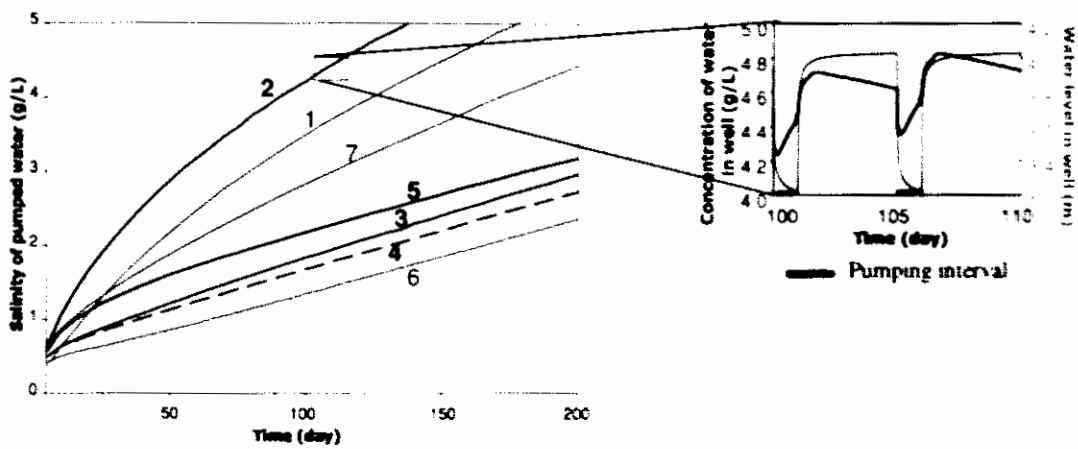



Figure 10. Simulated dynamics of TDS in pumped water for different parameters of a pumping system (Table 1).

It was found that increasing pumping cycle time and decreasing its rate have little effect on concentration of the pumped water. Simulations suggested that pumping from a shallow well produces water of better quality than from a deep well. However, the former case limits the rate of production by lowering the water level in the well up to full depletion. Using scavenger wells, which are screened in both the fresh and saline water zones, considerably decreases the up-coning effect and the risk of salinization of the freshwater zone. Decreasing the distance between screens of freshwater and saltwater wells results in a decrease in salinity of water pumped from the freshwater well. However, in this case a significant volume of freshwater can be pumped by the saltwater well.

Pumping from a well at the pond center allows effective use of stored freshwater because the ALFGW thickness is usually maximal at that point. However, in Turkmenistan the pumping wells are constructed at the pond borders positioned downstream to ambient groundwater flow. Usually water is pumped from 3 to 5 wells that belong to different local families. In order to check the effect of well position relative to the infiltration pond, we conducted synthetic simulations of pumping for a 3-D problem. Initial conditions correspond to a lens with volume of freshwater (with concentration less than 3 g/l) equal to about 16000 $m^3$. Several pumping scenarios regarding well type (skimming or Ranney) and position were considered (Figure 10e): (a) pumping from a single skimming well (w1/w6/w7); (b) simultaneous pumping from three skimming wells located at the pond borders (w1, w2 and w5); (c) simultaneous pumping from five skimming wells located at the pond border (w1, w2, w3, w4 and w5); (d) pumping from a Ranney well located either in the pond center (R1) or at the pond border (R2). Simulations were for a period of 300 day with a total pumping discharge of 5 $m^3$/day. Results presented in Figures 10a-d. For scenario (a), most effective pumping is from well w7 situated at the vicinity of the recharging wells (Figure 11a). For scenario (b) when 3 wells pump simultaneously, the highest concentration is observed for well w1 (located at the pond northwest corner), compare to wells w2 and w5 pumping water at the northern and western pond borders, respectively (Figure 11b). This is also similar to scenario (c) for simultaneous pumping from 5 wells. However, in this case the worse effective pumping is for wells w3 and w4, located upstream ambient flow relative to ALFGW (Figure 11c). We note that in this case, changes of water salinity pumped from well w1 are less significant in comparison to scenarios (a) and (b). The most effective pumping was obtained for a Ranney® Collector Well or Radial Horizontal Collector Well (scenario (d), Figure 11d). In this case we considered lateral well screens installed 1 m below water table (simulated as sinks distributed along relevant nodes of the finite element mesh). Since these well screens are horizontally positioned, much longer screen lengths can be installed, reducing the velocity of the water entering the screen slots and maximizing well efficiency. We note (Figure 11d) that salinity of the pumped water is initially reduced and then increased with time. The rate of this increase is higher for the case of a Ranney well located at the pond center in comparison with that located near the northwest corner. Concentration of the pumped water did not exceed 1 g/l and the up-coning saltwater was minimal because of lower specific discharge per unit area and reduced velocities.

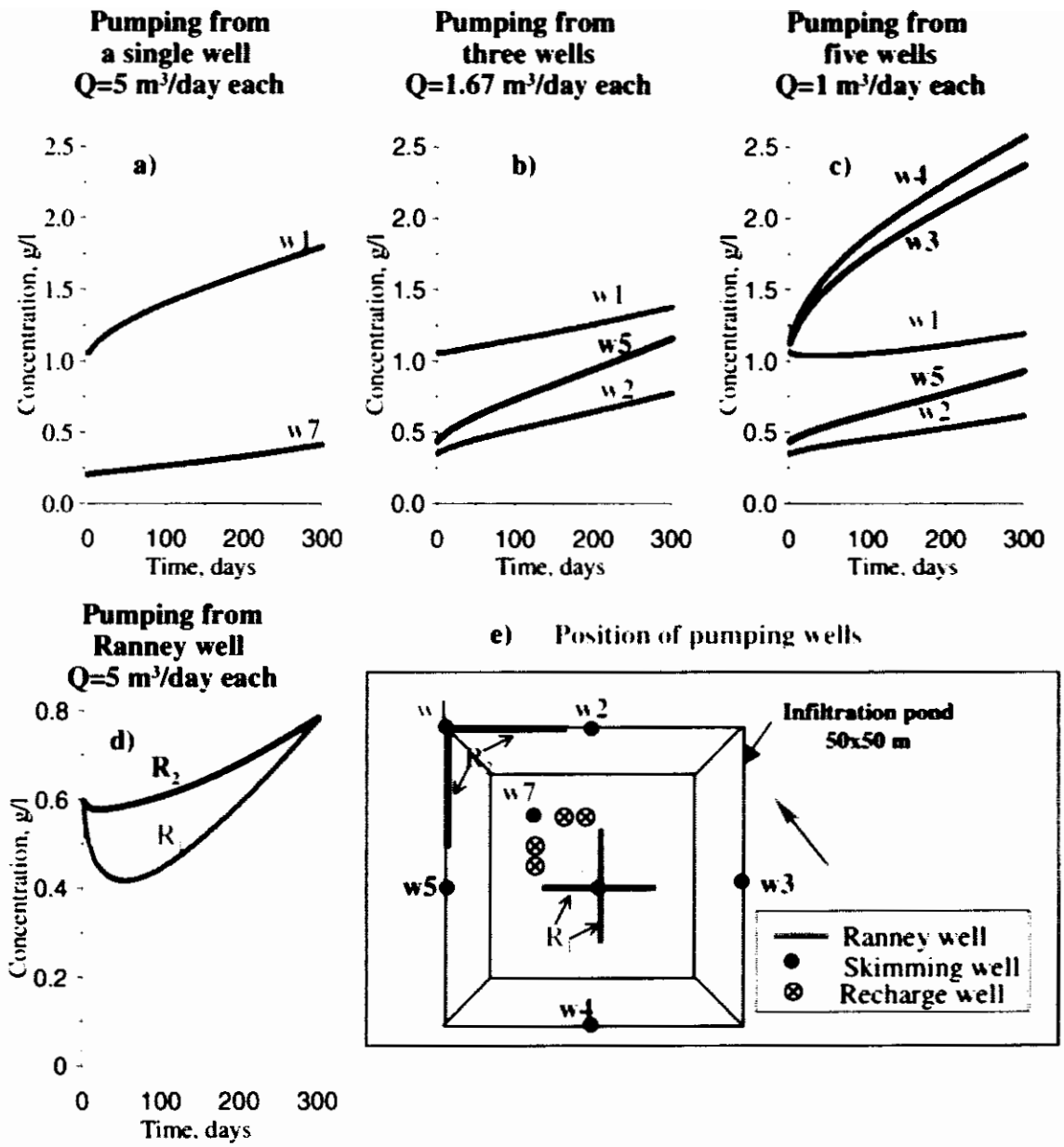



Figure 11. Simulated dynamics of TDS in pumped water for different scenarios of a pumping system

***Mapping the potential ALFGW sites in Turkmenistan***

To prepare recommendations for a wide range of applications of the ALFGW technology in Turkmenistan, we collected data regarding the locations of potential ALFGW sites and their parameters, accounting for different hydrogeological, hydrochemical and climatic conditions. The new collected data refers to the takyr watersheds spreading over a minimum area of 1 $km^2$ and with an unsaturated zone characterized by high hydraulic conductivity. Following maps were used: the map of 39% likelihood of maximum daily precipitation, the map of maximal runoff of 39% likelihood, the map of takyr areas in Turkmenistan (by A.P. Lavrov), the map of the vadose zone characteristics (lithology and salinity), the map of groundwater salinity (by N.G. Shevchenko), the map describing the potential ALFGW sites along with areas of demand for resources in Turkmenistan (Rogovskaya et al. 1986). We also used some results of the research project "Indigenous Water Harvesting" (USAID CA21-031) that is being carried out at part of the takyr Karrykul. Specifically, to calculate runoff volume we used the relation between rain characteristics (intensity and volume) and watershed parameters (length and slope). Simulations of the ALFGW creation were carried for selected sites accounting for different technology of runoff water infiltration. As a result, a map of potential ALFGW areas was composed (Figure 12).

Following is the explanations to the legend of the Figure 12:

**Area 1** – conditions are favorable for ALFGW creation: vadose zone is composed of sand with thin lenses (occupying less than 3% of the vadose zone volume) of loamy sand, loam and clay; salt concentration in soil profile does not exceed 5g/kg.

**Area 2** – conditions are relatively favorable for ALFGW creation: vadose zone is composed of sand with lenses (occupying 3-5% of the vadose zone volume) of loamy sand, loam and clay; salt concentration in soil profile is 5-10 g/kg.

**Area 3** – conditions are relatively difficult for ALFGW creation: vadose zone is composed of loamy sand and with intercalations of loam (occupying till 10% of the vadose zone volume); salt concentration in soil profile is 10-20 g/kg.

**Area 4** – conditions are not favorable for ALFGW creation: vadose zone is composed of loamy sand and loam with layers of clay (thickness 0.3-0.5 m); salt concentration in soil profile is more than20 g/kg.

Characteristic **a** – vadose zone is composed of mainly sand with a total thickness more than 15.

Characteristic **b** – sand layer of a thickness at least 5 m over layers loamy sand, loam and clay.

Characteristic **c** – intercalating layers of loam and clay of significant thickness over the whole vadose zone.

**Area 5** – natural lenses of fresh and brackish water;

**Area 6** – solontchaks;

**Area 7** – sanctuaries and rest zone;

**Area 8** – mountains.

**Technical Recommendation I** – open infiltration basin with maximum depth up to 3 m, designed for filling with runoff gathered from takyr watershed and accounting for 39% likelihood of annual rain;

**Technical Recommendation II** – combined system consisting of open infiltration basin and 1 to 3 recharging wells;

**Technical Recommendation III** – a bundle of 3 to 5 recharging wells of large diameter (up to 1m). Well characteristics (location, number, diameter, depth, filling material, perforation) depend on watershed area, lithological conditions of the vadose zone, planned ALFGW parameters

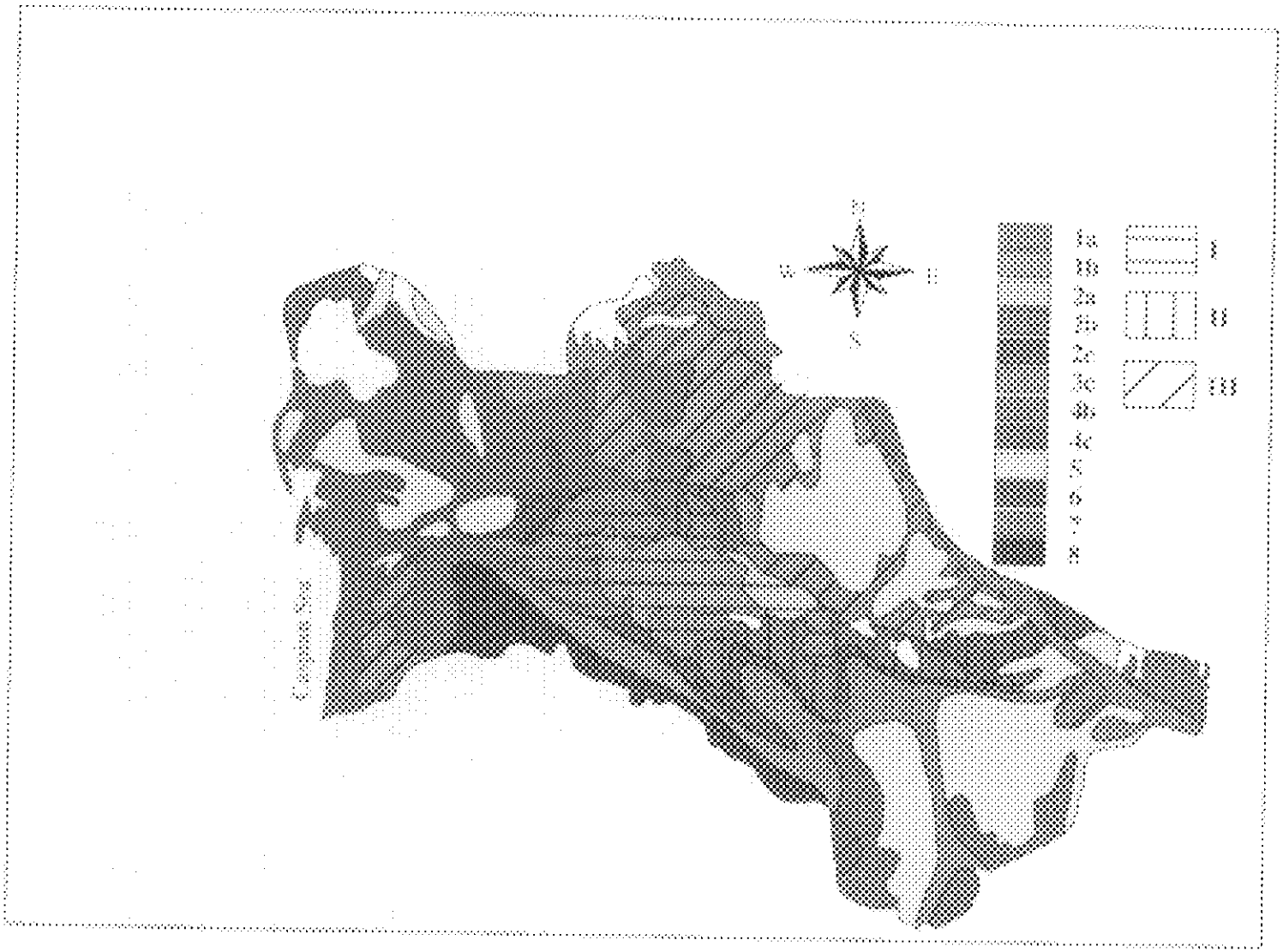



Figure 12. A map of potential ALFDW areas in Turkmenistan

## Impact, Relevance, and Technology Transfer

Harvesting and storage of seasonal runoff water percolated underground, for the formation of fresh water artificial lenses is a promising method to solve the problem of water supply in desert conditions. The project results yield the technology improvement in terms of erecting and exploiting of ALFRW. The National Program of social and economic development of Turkmenistan up to the year 2010 considers development methods of harvesting and using water in the desert as one of the utmost important tasks. Implementing the developed model and technology will help in planning and design of storage for freshwater resources in Turkmenistan. Similar conditions exist in other countries of Central Asia (Uzbekistan, Kazakhstan, Tadjikistan) as well as in many countries worldwide where highly saline groundwater exist in desert regions. The simplicity of the system that does not require significant investments for its constructions, and the possibility to store and use large volumes of good quality water, leads to the expectation that the method of ALFGW formation is economically promising. The ALFGW can be erected and utilized for small agricultural farms, pastures irrigation and livestock. An artificial lens with the average volume of 3000-6000 $m^3$ can supply 1500-3000 animals by fresh and brackish water.

This project also strengthened the research capacity of the National Institute of Desert, Flora and Fauna of Turkmenistan. The FEFLOW 5.1 computer code and two hand-held Conductivity/TDS/Temperature Meter "CyberScan CON 200 were purchased and transferred to the Turkmenistan team. They were trained in Israel during December 2004 to use this code for simulation of related problems and the meter as a tool for fast chemical analyses of water samples. The Turkmenistan researchers purchased two computer, two printers, fax-machine, Xerox machine, telephone, rain gauge, sounding devices for measuring groundwater level, bailers for sampling groundwater etc. Transfer of theoretical expertise from Israel to Turkmenistan focused on using modern methods to simulate processes of density dependent flow and transport in soil and groundwater.

## Project Activities/Outputs:

1) *Meetings*

The first meeting took place in Ashkhabad, October 2-7, 2002. Drs. Yakirevich (BGU), Mamiyeva, Nepesov and Mr. Tashliyev (NIDFF) attended this meeting.
The second meeting took place in Sde Boker, April 28-May 6, 2003. Drs. Yakirevich, Sorek, Kuznetsov (BGU), Mamiyeva, and Mr. Tashliyev (NIDFF) attended this meeting.
The third meeting took place in Ashkhabad, May 3-8, 2004. Drs. Yakirevich (BGU), Mamiyeva, Nepesov and Mr. Tashliyev (NIDFF) attended this meeting.
The fourth meeting took place in Sde Boker, December 28, 2004-January 6, 2005. Drs. Yakirevich, Sorek, Kuznetsov (BGU), Mamiyeva, and Mr. Tashliyev (NIDFF) attended this meeting.

2) *Training*

Dr. Mamiyeva and Mr. Tashliyev stayed in Israel from November 28, 2004 till January 8, 2005. During this period they were trained to use the comprehensive mathematical model and the FEFLOW code for simulations of density driven flow and transport. They were also consulted at the chemical lab to use modern equipment for chemical analyses of water samples.

3) *List of publications*

Yakirevich, A., M. Kuznetsov, S. Sorek and I. Mamieva, "Simulating artificial lenses of fresh groundwater in desert conditions" in: "Groundwater and saline intrusion". Publications of Geological Institute of Spain, Series on Hydrogeology and Groundwater, 15, 151- 161, 2005.

The results were orally presented at the 18th Salt Water Intrusion Meeting (Cartagena, Spain, May 31 - June 3, 2004), and a poster was demonstrated in the Fall Meeting of the American Geophysical Union (San-Francisco, USA, December, 11-17, 2004).

*List of participants:*

Israeli team: Dr. Alexander Yakirevich – PI, Prof. Shaul Sorek – co-PI, Dr. Mikhail Kouznetsov – researcher, Mr. Shai Arnon – Ph. D. student.
Turkmenistan team: Dr. Irina Mamiyeva – co-PI, Dr. Mukhamet Nepesov – researcher, Mr. Serdar Tashliyev – Ph. D. student, technicians.

## Project Productivity

We believe that the project accomplishes all of the proposed goals. The obtained results indicate good prospects for future application of the developed technique for storing water collected at the takyr watersheds and using it effectively during dry periods for nomad animal husbandry. Factors affecting ALFGW formation and exploitation were studied with the developed numerical model. The Turkmenistan institution researchers acquired knowledge of modern methods to simulate processes of density dependent flow and transport in soil and groundwater.

## Future Work

Future work can be focused on assessment and forecast of watering desert pastures occupying almost 95% of agricultural land in Turkmenistan. Nowadays, about 60% of pastures are watered. For this purpose seasonal runoff water is usually used. Reassessment of existing water resources in pastures, harvesting and storing additional water is an important task. Solving this problem will increase stability of animal husbandry in Turkmenistan. Application of the developed model to specific sites will improve planning abilities of local water authorities.

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**Appendix**

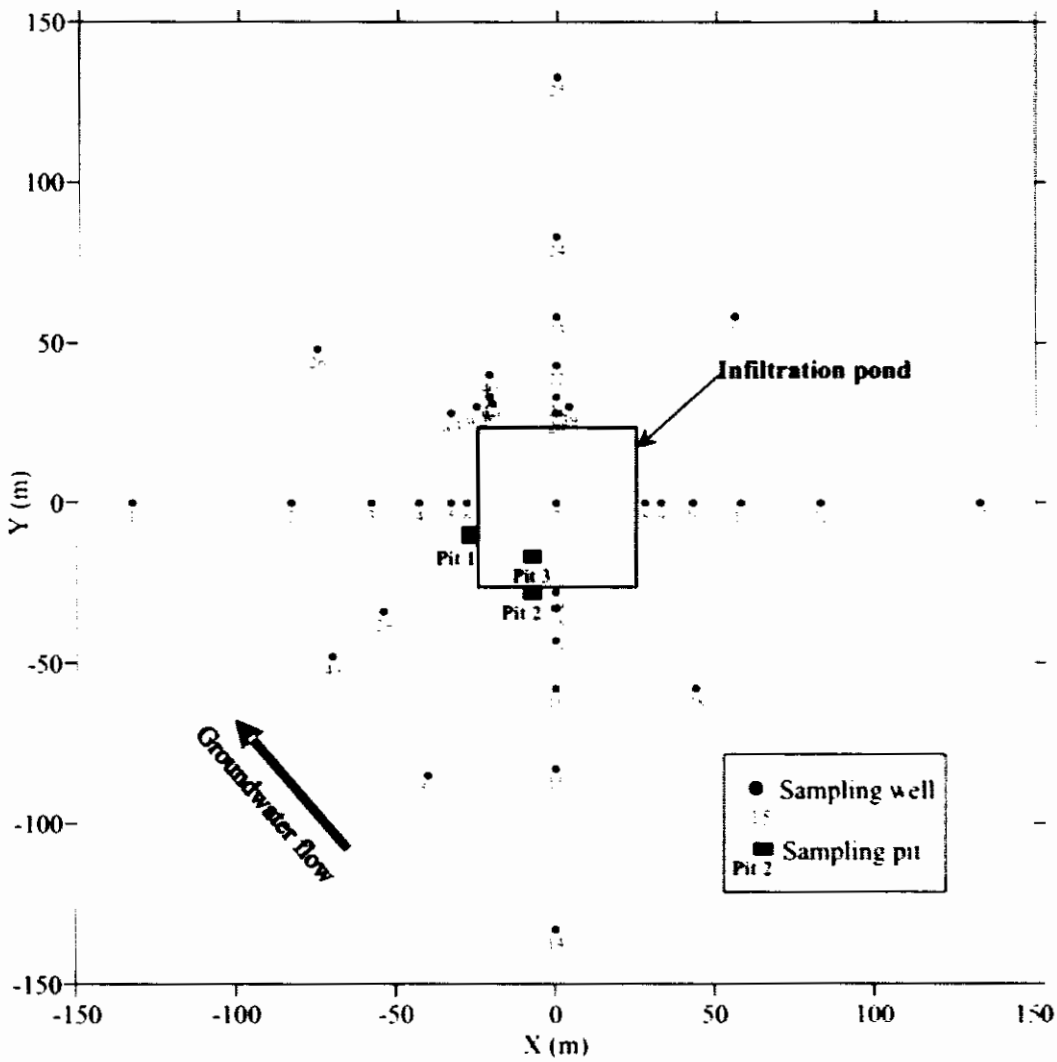


Figure 1A. Location sampling wells and pits.

Table 1. Chemical composition of rain water collected at the takyr Karrykul

| Date | TDS mg/l | $HCO3^-$ mg/l | $CL^-$ mg/l | $SO4^{2-}$ mg/l | $Ca^{2+}$ mg/l | $Mg^{2+}$ mg/l | $Na^++K^+$ mg/l |
|---|---|---|---|---|---|---|---|
| 23.03.2003 | 0.184 | 56.0 | 32.0 | 32.0 | 21.0 | 1.0 | 31.0 |
| 04.04.2004 | 0.232 | 45.0 | 11.0 | 89.0 | 20.0 | 3.0 | 38.0 |
| 05.04.2005 | 0.188 | 62.0 | 11.0 | 44.0 | 23.0 | 5.0 | 16.0 |

Table 2. Chemical composition of runoff water collected at the takyr Karrykul

| Date | Sampling time | TDS mg/l | $HCO3^-$ mg/l | $CL^-$ mg/l | $SO4^{2-}$ mg/l | $Ca^{2+}$ mg/l | $Mg^{2+}$ mg/l | $Na^++K^+$ mg/l |
|---|---|---|---|---|---|---|---|---|
| 25/10/2003 | Beginning | 570 | 99.9 | 275.4 | 36.2 | 27.6 | 6.3 | 189.9 |
| | Middle | 388 | 87.7 | 169.9 | 21.4 | 27.6 | 37.9 | 4.2 |
| | End | 550 | 106.7 | 252.0 | 16.5 | 27.6 | 6.3 | 168.0 |
| 19/02/2004 | Beginning | 314 | 118.5 | 62.4 | 19.7 | 19.4 | 4.7 | 62.2 |
| | Middle | 400 | 177.8 | 50.3 | 37.0 | 38.8 | 11.8 | 56.3 |
| | End | 288 | 0.98 | 46.8 | 32.9 | 19.4 | 7.0 | 47.3 |
| 2/03/2004 | Beginning | 396 | 126.9 | 65.5 | 23.8 | 11.6 | 4.7 | 96.9 |
| | Middle | 394 | 161.9 | 65.5 | 23.8 | 23.3 | 4.7 | 78.9 |
| | End | 200 | 118.5 | 49.9 | 14.0 | 23.3 | 2.4 | 52.4 |
| 12/04/2004 | Beginning | 430 | 94.0 | 140.4 | 35.4 | 19.4 | 4.7 | 112.3 |
| | Middle | 436 | 94.0 | 148.2 | 25.5 | 21.3 | 3.5 | 112.7 |
| | End | 496 | 139.6 | 171.6 | 18.9 | 27.1 | 7.3 | 128.4 |
| 25/04/2004 | Beginning | | | | | | | |
| | Middle | 424 | 88.3 | 128.7 | 80.9 | 13.6 | 4.7 | 121.4 |
| | End | 482 | 171.0 | 113.1 | 42.8 | 21.3 | 5.6 | 122.7 |
| 7/05/2004 | Beginning | 290 | 90.1 | 21.8 | 75.3 | 11.6 | 2.3 | 66.4 |
| 8/05/2004 | Beginning | 312 | 84.3 | 40.5 | 66.2 | 9.7 | 2.3 | 74.2 |
| 09/05/2004 | Beginning | 361 | 122.0 | 45.2 | 77.7 | 9.7 | 1.1 | 99.2 |
| 10/05/2004 | Beginning | 336 | 155.0 | 23.4 | 19.7 | 15.5 | 11.8 | 42.9 |
| 27/03/2005 | End | 644 | 236.0 | 118.0 | 58.0 | 18.0 | 2.0 | 168.0 |
| 4/04/2005 | Beginning | 544 | 130.0 | 110.0 | 53.0 | 14.0 | 2.0 | 129 |
| | Middle | 578 | 140.0 | 105.0 | 59.0 | 14.0 | 2.0 | 133 |
| | End | 536 | 138.0 | 105.0 | 57.0 | 12.0 | 1.0 | 136 |
| 5/04/2005 | Beginning | 564 | 173.0 | 112.0 | 32.0 | 14.0 | 3.0 | 134.0 |
| | Middle | 592 | 164.0 | 110.0 | 60.0 | 12.0 | 3.0 | 142.0 |
| | End | 654 | 176.0 | 158.0 | 73.0 | 14.0 | 2.0 | 184.0 |
| 6/04/2005 | Beginning | 680 | 155.0 | 137.0 | 80.0 | 16.0 | 2.0 | 163.0 |
| | Middle | 596 | 118.0 | 131.0 | 53.0 | 10.0 | 2.0 | 142.0 |
| | End | 572 | 155.0 | 124.0 | 44.0 | 12.0 | 1.0 | 144.0 |

Table 3. Physical and hydraulic properties in the soil profiles

| Well | Depth | Bulk Density | Water capacity | | $K_s$ | Particle size distribution, % | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | g/cm³ | full | field | m/day | 0.5-0.25 mm | 0.25-0.1 mm | 01.-0.05 mm | 0.05-0.01 mm | 0.01-0.005 mm | 0.005-0.001 mm | < 0.001 mm |
| 6 | 1.0 | 1.53 | 0.4437 | 0.3825 | 0.034 | 0.2 | 2.4 | 31.4 | 46.7 | 6.8 | 5.2 | 7.3 |
| | 2.0 | | | | | | 3.0 | 37.0 | 17.0 | 10.6 | 13.9 | 18.5 |
| | 3.0 | 1.62 | 0.3888 | 0.3564 | 0.85 | 0.6 | 26.2 | •58.4 | 11.5 | 2.9 | 0.2 | 0.2 |
| | 4.0 | 1.59 | 0.3816 | 0.3498 | 0.26 | 0.2 | 30.0 | 56.6 | 6.3 | 0.1 | 2.1 | 4.7 |
| | 7.0 | 1.63 | | | 0.35 | | 14.6 | 53.2 | 21.9 | 2.1 | 4.3 | 3.9 |
| | 9.0 | 1.56 | 0.4212 | 0.39 | 0.45 | | 17.4 | 52.6 | 12.4 | 5.9 | 4.4 | 7.3 |
| | 11.0 | 1.58 | 0.395 | 0.3634 | 1.66 | 1.6 | 41.8 | 41.0 | 6.9 | 3.0 | 1.0 | 4.7 |
| | 12.0 | | | | | | 11.0 | 12.6 | 19.9 | 14.5 | 17.5 | 24.5 |
| | 13.0 | 1.69 | 0.3718 | 0.3549 | 0.77 | 1.0 | 39.6 | 42.4 | 8.9 | 3.1 | 1.3 | 3.7 |
| | 15.0 | 1.65 | 0.396 | 0.3795 | 0.84 | 0.6 | 57.6 | 35.2 | 1.0 | 5.6 | | |
| | 20.0 | 1.66 | 0.3818 | 0.3652 | 2.19 | 3.4 | 54.4 | 39.4 | 0.8 | 2.0 | | |
| | 25.0 | 1.58 | 0.395 | 0.3792 | 2.1 | 1.0 | 55.0 | 41.2 | 1.0 | 1.8 | | |
| | 30.0 | 1.64 | 0.3608 | 0.3116 | 4.48 | 16.4 | 64.2 | 17.2 | 0.4 | 1.8 | | |
| | 30.8 | | | | | 2.0 | 5.0 | 7.2 | 10.4 | 9.7 | 29.8 | 35.9 |
| 7 | 1.0 | 1.56 | 0.4212 | 0.39 | 0.03 | | 1.0 | 17.6 | 55.1 | 6.5 | 9.4 | 10.4 |
| | 2.0 | | | | | | 7.0 | 61.6 | 10.9 | 5.6 | 2.8 | 12.1 |
| | 3.0 | 1.57 | 0.4396 | 0.3925 | 0.042 | | 5.0 | 22.4 | 50.3 | 6.9 | 5.4 | 10.0 |
| | 3.5 | | | | | | 0.2 | 4.0 | 22.0 | 16.6 | 27.7 | 29.5 |
| | 4.0 | 1.55 | 0.434 | 0.3875 | 0.034 | | 1.8 | 20.8 | 46.1 | 6.4 | 11.9 | 13.0 |
| | 4.3 | 1.36 | 0.4352 | 0.3808 | 0.012 | 0.4 | 0.4 | 3.2 | 23.2 | 16.7 | 27.7 | 28.4 |
| | 5.0 | 1.53 | 0.4743 | 0.459 | 0.06 | 16.0 | 10.0 | 11.4 | 14.6 | 12.6 | 15.4 | 20.0 |
| | 7.0 | 1.53 | 0.4437 | 0.4131 | 0.45 | 1.0 | 7.0 | 55.0 | 30.2 | 2.2 | 1.8 | 2.8 |
| | 8.0 | 1.33 | 0.399 | 0.3724 | 0.003 | | 1.4 | 5.0 | 14.6 | 2.4 | 34.2 | 42.4 |
| | 9.0 | 1.64 | 0.3608 | 0.328 | 0.1 | 12.4 | 23.4 | 44.6 | 2.0 | 17.6 | | |
| | 10.0 | 1.58 | 0.3792 | 0.3634 | 7.0 | 5.4 | 74.0 | 16.0 | 0.2 | 4.4 | | |
| | 11.0 | 1.56 | 0.3588 | 0.3432 | 3.5 | | 3.0 | 52.4 | 36.0 | 6.6 | 2.0 | |
| | 13.0 | 1.44 | 0.3888 | 0.3744 | 2.3 | | 1.0 | 31.0 | 55.0 | 9.2 | 3.8 | |
| | 15.0 | 1.54 | 0.4004 | 0.385 | 1.42 | | 1.0 | 25.0 | 57.0 | 15.3 | 1.7 | |
| | 20.0 | 1.58 | 0.3792 | 0.3634 | 3.20 | 2.0 | 50.0 | 44.0 | 1.0 | 3.0 | | |

Table 3. Continued

| Well | Depth | Bulk Density | Water capacity | | $K_s$ | Particle size distribution, % | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | g/cm³ | full | field | m/day | 0.5-0.25 mm | 0.25-0.1 mm | 01.-0.05 mm | 0.05-0.01 mm | 0.01-0.005 mm | 0.005-0.001 mm | < 0.001 mm |
| 7 | 25.0 | 1.6 | 0.4 | 0.368 | 3.75 | 21.0 | 59.0 | 19.0 | 0.2 | 0.8 | | |
| | 30.0 | 1.60 | 0.416 | 0.4 | 6.30 | 8.0 | 74.0 | 16.0 | 0.2 | 1.8 | | |
| | 30.5 | 1.42 | 0.4402 | 0.426 | 0.07 | 1.0 | 6.0 | 8.0 | 49.1 | 5.1 | 1.6 | 29.2 |
| 8 | 1.0 | 1.47 | 0.4851 | 0.441 | 0.10 | | 1.0 | 21.0 | 66.4 | 4.3 | 0.5 | 6.8 |
| | 2.0 | | | | | | 3.0 | 20.0 | 55.1 | 5.0 | 4.0 | 12.9 |
| | 3.0 | 1.4 | 0.42 | 0.378 | 0.05 | 0.4 | 3.4 | 21.2 | 35.4 | 11.2 | 14.7 | 13.7 |
| | 3.5 | | | | | | | | | | | |
| | 4.0 | 1.45 | 0.3915 | 0.377 | | 0.6 | 1.2 | 3.2 | 32.6 | 17.3 | 20.3 | 24.8 |
| | 5.0 | 1.7 | | | | 1.5 | 33.5 | 50.2 | 5.8 | 0.8 | 2.0 | 6.2 |
| | 6.0 | 1.73 | | | 2.28 | 0.2 | 49.2 | 42.1 | 5.7 | 0.2 | 0.6 | 2.0 |
| | 7.0 | 1.54 | | | 0.18 | | 4.5 | 30.0 | 52.5 | 3.6 | 4.2 | 5.2 |
| | 9.0 | 1.16 | | | 0.38 | | 5.0 | 70.5 | 16.5 | 1.4 | 2.2 | 4.4 |
| | 10.0 | 1.71 | | | 2.45 | | 41.7 | 45.0 | 8.7 | 1.2 | 0.8 | 2.6 |
| | 11.0 | | | | | | 0.1 | 3.6 | 17.5 | 15.6 | 29.4 | 33.8 |
| | 12.0 | 1.58 | | | 0.74 | | 9.5 | 63.5 | 17.4 | 1.2 | 3.2 | 5.2 |
| | 13.0 | 1.71 | | | 1.54 | 5.0 | 40.0 | 40.5 | 7.5 | 1.8 | 1.6 | 3.6 |
| | 15.0 | 1.68 | | | 1.49 | 0.5 | 30.0 | 56.5 | 8.8 | 1.2 | 1.2 | 1.8 |
| | 20.0 | 1.64 | | | 3.39 | 2.0 | 63.0 | 32.0 | 1.0 | 2.0 | | |
| | 25.0 | 1.71 | | | 1.47 | 12.5 | 37.0 | 41.5 | 6.0 | 1.0 | 0.4 | 1.6 |
| | 30.0 | 1.75 | | | 2.24 | 19.5 | 52.5 | 20.0 | 5.2 | 1.6 | 0.2 | 1.0 |
| | 30.4 | | | | | 0.5 | 4.5 | 6.5 | 7.1 | 11.2 | 32.0 | 38.2 |
| 19 | 1.0 | 1.46 | | | 0.024 | | 0.1 | 6.9 | 66.6 | 10.2 | 7.6 | 8.6 |
| | 2.0 | 1.67 | | | 0.7 | 0.2 | 25.5 | 54.3 | 11.2 | 1.6 | 1.8 | 5.4 |
| | 3.0 | 1.55 | | | 0.039 | | 4.5 | 20.0 | 60.1 | 4.2 | 3.4 | 7.8 |
| | 4.0 | | | | | | 0.1 | 2.4 | 20.5 | 16.8 | 29.2 | 31.0 |
| | 5.0 | | | | | | 0.1 | 1.4 | 1.5 | 13.8 | 46.6 | 36.6 |
| | 6.0 | 1.6 | 0.4 | 0.384 | 1.3 | 0.6 | 45.6 | 42.8 | 1.2 | 9.8 | | |

Table 3. Continued

| Well | Depth | Bulk Density | Water capacity | | K, | Particle size distribution, % | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | g/cm³ | full | field | m/day | 0.5-0.25 mm | 0.25-0.1 mm | 01.-0.05 mm | 0.05-0.01 mm | 0.01-0.005 mm | 0.005-0.001 mm | < 0.001 mm |
| 19 | 7.0 | 1.56 | 0.4368 | 0.4056 | 0.11 | | 7.0 | 40.2 | 37.1 | 3.0 | 5.8 | 6.9 |
| | 8.0 | 1.57 | | | 0.66 | | 8.4 | 62.6 | 17.6 | 4.3 | 1.0 | 6.1 |
| | 11.0 | 1.68 | 0.3864 | 0.3192 | 1.73 | 0.4 | 67.0 | 22.4 | 2.2 | 8.0 | | |
| | 12.0 | | | | | | 2.6 | 3.0 | 21.9 | 12.6 | 33.4 | 26.5 |
| | 14.0 | | | | | | 0.6 | 5.8 | 17.9 | 6.4 | 29.3 | 40.0 |
| | 15.0 | 1.61 | 0.4347 | 0.4025 | 1.14 | 1.8 | 38.0 | 50.4 | 3.6 | 6.2 | | |
| | 17.0 | 1.68 | 0.3864 | 0.3528 | 2.89 | 9.0 | 57.0 | 30.0 | 1.4 | 2.6 | | |
| | 20.0 | 1.62 | 0.4212 | 0.3564 | 4.48 | 2.4 | 64.8 | 30.8 | 0.4 | 1.6 | | |
| | 25.0 | 1.57 | 0.3925 | 0.3768 | 4.52 | 1.6 | 65.0 | 26.8 | 2.4 | 4.2 | | |
| | 30.0 | 1.61 | 0.3864 | 0.3703 | 4.2 | 1.4 | 66.0 | 23.4 | 0.8 | 3.4 | | |
| | 30.5 | | | | | 0.6 | 0.6 | 3.0 | 16.5 | 12.4 | 32.8 | 34.1 |
| 20 | 1.0 | 1.55 | 0.3255 | 0.31 | 0.07 | | 3.0 | 32.0 | 49.0 | 5.0 | 3.0 | 6.0 |
| | 2.0 | 1.47 | 0.4704 | 0.4557 | 0.16 | | 1.0 | 13.6 | 45.4 | 14.0 | 10.0 | 16.0 |
| | 3.0 | 1.5 | | | 0.17 | | 10.0 | 48.0 | 19.0 | 3.0 | 8.0 | 12.0 |
| | 4.0 | 1.45 | 0.435 | 0.406 | 0.5 | | 7.4 | 51.6 | 29.0 | 3.0 | 2.0 | 7.0 |
| | 5.0 | 1.4 | | | 0.03 | | 1.0 | 1.0 | 16.0 | 19.0 | 31.0 | 32.0 |
| | 6.0 | 1.56 | 0.3744 | 0.3276 | 5.2 | 1.0 | 71.0 | 19.0 | 4.0 | 1.0 | 1.0 | 3.0 |
| | 7.0 | 1.44 | 0.4608 | 0.4176 | 0.54 | | 6.0 | 51.0 | 26.0 | 17.0 | | |
| | 9.0 | 1.45 | 0.435 | 0.406 | 0.07 | | 10.0 | 23.0 | 44.0 | 7.0 | 4.0 | 12.0 |
| | 10.0 | | | | | | 2.0 | 15.4 | 21.6 | 12.0 | 21.0 | 28.0 |
| | 11.0 | 1.44 | 0.4032 | 0.36 | 0.27 | | 15.0 | 34.0 | 33.0 | 4.0 | 4.0 | 10.0 |
| | 12.0 | 1.63 | 0.4238 | 0.4075 | 1.6 | 1.0 | 51.0 | 39.0 | 2.0 | 7.0 | | |
| | 13.0 | 1.6 | 0.352 | 0.336 | 1.8 | 3.0 | 69.0 | 22.0 | 2.0 | 4.0 | | |
| | 15.0 | 1.54 | 0.385 | 0.3696 | 4.2 | 4.0 | 76.0 | 14.0 | 2.0 | 4.0 | | |
| | 20.0 | 1.6 | 0.368 | 0.352 | 2.2 | | 10.4 | 87.6 | 0.8 | 1.2 | | |
| | 25.0 | 1.6 | 0.384 | 0.32 | 3.7 | 4.4 | 72.4 | 20.6 | .08 | 1.8 | | |
| | 30.0 | 1.56 | 0.3432 | 0.3276 | 10.1 | 8.0 | 76.8 | 13.6 | 0.8 | 0.8 | | |

Table 4. Chemical composition of salts in the vadose zone

| Depth cm | TDS g/l | meq | | | | | | Soil |
|---|---|---|---|---|---|---|---|---|
| | | $HCO_3$ | Cl | $SO_4$ | Ca | Mg | Na + K | |
| **Pit №1** | | | | | | | | |
| 00 - 10 | 0.3 | 0.4 | 0.6 | 3.7 | 2.2 | 1.0 | 1.5 | clay |
| 10 - 20 | 0.2 | 0.3 | 0.3 | 3.0 | 1.7 | 0.8 | 1.2 | loamy sand |
| 20 - 30 | 0.4 | 0.3 | 0.2 | 4.8 | 3.6 | 0.9 | 0.8 | loamy sand |
| 30 - 40 | 0.2 | 0.3 | 0.3 | 2.0 | 0.9 | 0.8 | 0.8 | sand |
| 40 - 50 | 0.4 | 0.3 | 0.2 | 5.1 | 3.7 | 0.7 | 1.2 | sand |
| 50 - 60 | 0.8 | 0.2 | 0.2 | 10.6 | 3.2 | 0.5 | 7.4 | sand |
| 60 - 70 | 0.4 | 0.2 | 0.2 | 5.1 | 4.7 | 0.1 | 0.8 | sand |
| 70 - 80 | 0.6 | 0.3 | 0.2 | 8.4 | 6.9 | 0.7 | 1.2 | sand |
| 80 - 90 | 1.0 | 0.2 | 0.2 | 13.4 | 11.9 | 0.5 | 1.5 | sand |
| 90 - 100 | 0.3 | 0.3 | 0.3 | 4.4 | 3.4 | 0.2 | 1.4 | sand |
| 100 - 110 | 0.6 | 0.2 | 0.3 | 9.1 | 7.2 | 0.3 | 1.0 | sand |
| 110 - 120 | 0.4 | 0.3 | 0.1 | 5.3 | 4.2 | 0.6 | 1.1 | sand |
| 120 - 130 | 0.6 | 0.3 | 0.1 | 7.9 | 6.2 | 1.2 | 1.0 | sand |
| 130 - 140 | 0.5 | 0.3 | 0.2 | 7.3 | 5.8 | 0.8 | 1.2 | sand |
| 140 - 150 | 0.8 | 0.3 | 0.3 | 10.7 | 7.8 | 1.7 | 1.7 | clay |
| 150 - 160 | 0.5 | 0.4 | 0.2 | 6.6 | 4.8 | 1.4 | 1.1 | clay |
| 160 - 170 | 0.5 | 0.4 | 0.3 | 7.1 | 5.0 | 1.9 | 0.7 | clay |
| 170 - 180 | 0.8 | 0.4 | 0.3 | 10.5 | 7.7 | 1.7 | 1.7 | clay |
| 180 - 190 | 0.5 | 0.4 | 0.1 | 6.5 | 3.9 | 1.8 | 1.4 | clay |
| 190 - 200 | 0.7 | 0.3 | 0.2 | 9.7 | 6.5 | 1.7 | 1.9 | loam |
| 210 - 220 | 0.6 | 0.3 | 0.2 | 6.4 | 3.8 | 1.9 | 1.2 | loam |
| 220 - 230 | 0.4 | 0.4 | 0.2 | 6.2 | 3.4 | 2.3 | 1.0 | clay |
| 230 - 240 | 0.6 | 0.4 | 0.2 | 8.5 | 5.0 | 1.8 | 2.3 | loamy sand |
| 250 - 260 | 0.6 | 0.3 | 0.1 | 8.3 | 5.8 | 1.7 | 1.2 | loamy sand |
| 270 - 280 | 0.6 | 0.2 | 0.2 | 7.9 | 2.9 | 0.6 | 4.8 | sand |
| 280 - 290 | 0.3 | 0.3 | 0.1 | 4.2 | 3.0 | 1.6 | 0.0 | sand |
| 290 - 300 | 0.1 | 0.3 | 0.2 | 0.7 | 0.5 | 0.3 | 0.4 | sand |
| 300 - 310 | 0.1 | 0.3 | 0.1 | 1.2 | 0.7 | 0.4 | 0.6 | loamy sand |
| 310 - 320 | 0.2 | 0.3 | 0.1 | 2.7 | 1.2 | 0.9 | 1.1 | loamy sand |
| 320 - 500 | 0.1 | 0.3 | 0.3 | 1.0 | 0.6 | 0.4 | 0.6 | sand |
| 540 - 580 | 0.3 | 0.4 | 0.3 | 3.4 | 0.5 | 0.6 | 3.0 | loamy sand |
| 630 - 640 | 0.1 | 0.5 | 0.1 | 0.4 | 0.4 | 0.3 | 0.4 | sand |
| 640 - 740 | 0.1 | 0.4 | 0.1 | 0.9 | 0.6 | 0.5 | 0.4 | sand |
| **Pit №2** | | | | | | | | |
| 200 - 240 | 0.6 | 0.5 | 4.4 | 4.2 | 2.6 | 1.9 | 4.6 | sand |
| 240 - 350 | 0.2 | 0.6 | 2.6 | 0.4 | 1.2 | 0.9 | 1.5 | sand |
| 420 - 540 | 0.2 | 0.5 | 2.2 | 0.1 | 1.0 | 0.2 | 1.7 | sand |
| 540 - 550 | 2.3 | 0.6 | 4.0 | 0.2 | 1.2 | 0.2 | 3.3 | sand |
| 550 - 570 | 0.8 | 0.5 | 2.2 | 9.6 | 8.4 | 1.6 | 2.3 | loam |
| 570 - 610 | 0.6 | 0.6 | 3.3 | 6 | 5.5 | 1.6 | 2.8 | clay |
| 610 - 640 | 0.3 | 0.6 | 3.7 | 1.1 | 1.0 | 1.4 | 3.1 | loamy sand |
| 640 - 740 | 0.2 | 0.4 | 2.4 | 0.5 | 1.7 | 0.2 | 1.5 | sand |
| 740 - 780 | 0.3 | 0.6 | 3.7 | 0.4 | 1.7 | 1.4 | 1.6 | sand |
| 780 - 820 | 0.3 | 0.5 | 3.3 | 0.6 | 1.2 | 0.5 | 2.8 | sand |
| **Pit №3** | | | | | | | | |
| 300 - 380 | 0.2 | 0.6 | 2.9 | 0.3 | 1.7 | 1.6 | 0.4 | sand |
| 380 - 460 | 0.2 | 0.5 | 2.2 | 0.4 | 1.7 | 0.5 | 1.0 | sand |
| 460 - 540 | 0.3 | 0.5 | 3.3 | 0.4 | 1.0 | 0.9 | 2.4 | sand |
| 540 - 580 | 0.3 | 0.6 | 3.3 | 0.6 | 1.4 | 0.9 | 2 | sand |
| 580 - 620 | 0.3 | 0.5 | 2.2 | 2.1 | 1.4 | 0.5 | 2.9 | sand |
| 620 - 740 | 0.3 | 0.6 | 3.3 | 0.3 | 1.4 | 0.5 | 2.3 | sand |
| 740 - 760 | 0.2 | 0.5 | 2.2 | 0.8 | 1.9 | 0.2 | 1.4 | sand |
| 760 - 780 | 0.3 | 0.5 | 3.3 | 0.6 | 1.2 | 0.5 | 2.7 | sand |

Table 5. Measured groundwater depths and salinity

| Date | 14.02.2003 | | 09.03.2003 | | 17.04.2003 | | 15.05.2003 | |
|---|---|---|---|---|---|---|---|---|
| Sampling well | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l |
| W1 | 16.28 | 2.98 | 16.27 | 2.98 | 16.26 | 2.98 | 16.25 | 2.97 |
| W2 | 16.3 | 3.32 | 16.29 | 3.31 | 16.27 | 3.31 | 16.27 | 3.3 |
| W3 | 16.61 | 3.72 | 16.6 | 3.72 | 16.59 | 3.71 | 16.58 | 3.71 |
| 3 | | | 15.89 | 9.26 | 15.89 | 9.26 | 15.89 | 9.26 |
| 4 | | | 15.11 | 13.57 | 15.11 | 13.57 | 15.11 | 13.57 |
| 5 | | | | | | | | |
| 6 | 15.12 | | 15.11 | | 15.11 | | 15.09 | |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |
| 11 | | | | | | | | |
| 12 | | | | | | | | |
| 13 | | | | | | | | |
| 14 | | | | | | | | |
| 15 | | | | | | | | |
| 16 | 15.37 | | 15.34 | | 15.34 | 9.78 | 15.33 | 9.77 |
| 17 | 16.07 | | 16.07 | | 16.06 | | 16.07 | 5.17 |
| 18 | | | | | | | | |
| 19 | 15.78 | | 15.78 | | 15.78 | 3.37 | 15.77 | 3.38 |
| 20 | | | | | 15.81 | | 15.8 | |
| 21 | 15.91 | | 15.91 | | 15.91 | | 15.91 | 3.9 |
| 22 | 15.71 | | 15.71 | | 15.7 | | 15.71 | 9.94 |
| 23 | | | | | | | | |
| 24 | 15.79 | | 15.79 | | 15.78 | | 15.78 | 5.64 |
| 25 | | | | | | | | |
| 26 | | | | | | | | |
| 30 | | | | | | | | |
| 31 | 15.59 | | 15.59 | | 15.59 | 13.15 | 15.59 | 13.14 |
| 32 | 15.36 | | 15.36 | | 15.36 | 11.09 | 15.35 | 11.07 |
| 33 | 15.46 | | 15.46 | | 15.46 | 11.79 | 15.45 | 11.79 |
| 34 | 15.67 | | 15.67 | | 15.66 | 4.55 | 15.65 | 4.55 |
| 35 | 15.37 | | 15.37 | | 15.36 | | 15.36 | |
| 36 | | | | | 15.8 | | 15.79 | |
| 37 | 15.41 | | 15.4 | 8.31 | 15.39 | 8.31 | 15.38 | 8.3 |
| 38 | | | 15.88 | | 15.87 | | 15.86 | 13.47 |
| 39 | | | 15.9 | | 15.88 | | 15.88 | 4.74 |
| 40 | | | | | 15.92 | | 15.91 | |
| 41 | | | | | | | | |
| 42 | | | | | | | 15.87 | |
| 49 | | | | | | | | |
| 50 | | | | | | | | |

Table 5 (continue)

| Date | 04.06.2003 | | 26.06.2003 | | 03.07.2003 | | 29.08.2003 | |
|---|---|---|---|---|---|---|---|---|
| Sampling well | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l |
| W1 | 16.25 | 2.97 | 16.27 | 2.97 | 16.26 | 2.99 | 16.27 | 3.38 |
| W2 | 16.27 | 3.3 | 16.29 | 2.99 | 16.27 | 2.98 | 16.3 | 3 |
| W3 | 16.58 | 3.7 | 16.6 | 3.59 | 16.6 | 3.58 | 16.6 | 3.67 |
| 3 | 15.89 | 9.25 | 15.9 | 9.1 | 15.89 | 8.92 | 15.9 | 8.88 |
| 4 | 15.1 | 13.56 | 15.51 | 13.6 | 15.45 | 13.52 | 15.4 | 13.58 |
| 5 | | | | | | | | |
| 6 | 15.08 | | | | | | | |
| 7 | | | 15.81 | 8.9 | 15.8 | 4.28 | 15.83 | 3.58 |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |
| 11 | | | | | | | | |
| 12 | | | | | | | | |
| 13 | | | | | | | | |
| 14 | | | | | | | | |
| 15 | | | | | 16.27 | 6.2 | 16.29 | 6.34 |
| 16 | 15.33 | 9.77 | 15.35 | 8.65 | 15.34 | 7.54 | 15.33 | 6.92 |
| 17 | 16.08 | 5.16 | 16.08 | 4.5 | 16.13 | 4.6 | 16.12 | 4.58 |
| 18 | | | | | | | | |
| 19 | 15.77 | 3.37 | 15.81 | 3.85 | 15.86 | 4.01 | 15.79 | 5.65 |
| 20 | 15.8 | 6.35 | 15.87 | 3.02 | 15.86 | 3.1 | 15.85 | 3.05 |
| 21 | 15.9 | 4.26 | 15.91 | 2.56 | 15.95 | 2.59 | 15.92 | 2.61 |
| 22 | 15.7 | 11.2 | 15.7 | 10.6 | 15.73 | 10.45 | 15.71 | 10.09 |
| 23 | | | | | | | | |
| 24 | 15.78 | 5.83 | 15.78 | 4.6 | | | 15.8 | 4.36 |
| 25 | | | | | | | | |
| 26 | | | | | | | | |
| 30 | | | | | | | | |
| 31 | 15.58 | 13.13 | 15.61 | 15.69 | 15.67 | 15.6 | 15.72 | 15.43 |
| 32 | 15.35 | 11.05 | 15.35 | 13.08 | 15.36 | 13.11 | 15.34 | 13.09 |
| 33 | 15.45 | 11.78 | 15.48 | 11.9 | 15.5 | 12.01 | 15.49 | 11.95 |
| 34 | 15.65 | 4.53 | 15.65 | 4.57 | 15.67 | 4.46 | 15.68 | 4.41 |
| 35 | 15.35 | | | | | | | |
| 36 | 15.79 | | | | | | | |
| 37 | 15.38 | 8.3 | 15.4 | 8.29 | 15.43 | 8.22 | 15.48 | 8.34 |
| 38 | 15.86 | 13.47 | 15.9 | 13.11 | 15.89 | 12.13 | 15.86 | 11.09 |
| 39 | 15.87 | 4.75 | 15.88 | 4.23 | 15.86 | 3.97 | 15.89 | 3.75 |
| 40 | 15.91 | | | | | | | |
| 41 | | | | | | | | |
| 42 | 15.85 | | | | | | | |
| 49 | | | | | | | | |
| 50 | | | | | | | | |

Table 5 (continue)

| Date | 26.09.2003 | | 24.10.2003 | | 19.11.2003 | | 12.12.2003 | |
|---|---|---|---|---|---|---|---|---|
| Sampling well | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l |
| W1 | 16.27 | 3 | 16.26 | 3.04 | 16.29 | 3.07 | 16.28 | 3 |
| W2 | 16.38 | 2.97 | 16.35 | 2.99 | 16.33 | 2.98 | 16.32 | 2.96 |
| W3 | 16.62 | 3.52 | 16.6 | 3.53 | 16.62 | 3.52 | 16.61 | 3.51 |
| 3 | 15.9 | 8.93 | 15.89 | 8.9 | 15.9 | 8.88 | 15.88 | 8.87 |
| 4 | 15.45 | 13.54 | 15.43 | 13.59 | 15.45 | 13.56 | 15.42 | 13.54 |
| 5 | | | | | | | | |
| 6 | | | | | | | | |
| 7 | 15.82 | 3.47 | 15.81 | 3.48 | 15.82 | 3.49 | 15.8 | 3.47 |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |
| 14 | | | | | | | | |
| 15 | 16.28 | 6.27 | 16.29 | 6.24 | 16.28 | 6.23 | 16.27 | 6.18 |
| 16 | 15.35 | 6.86 | 15.33 | 6.79 | 15.34 | 6.82 | 15.32 | 6.77 |
| 17 | 16.13 | 4.59 | 16.11 | 4.53 | 16.12 | 4.56 | 16.1 | 4.52 |
| 18 | | | | | | | | |
| 19 | 15.8 | 5.54 | 15.79 | 5.51 | 15.81 | 5.49 | 15.78 | 5.43 |
| 20 | 15.87 | 3.08 | 15.85 | 3.06 | 13.84 | 3.04 | 15.81 | 3.03 |
| 21 | 15.94 | 2.59 | 15.93 | 2.6 | 15.94 | 2.58 | 15.91 | 2.54 |
| 22 | 15.75 | 10.11 | 15.73 | 10.09 | 15.71 | 10.08 | 15.7 | 10.06 |
| 23 | | | | | | | | |
| 24 | | | | | | | | |
| 25 | | | | | | | | |
| 26 | | | | | | | | |
| 30 | | | | | | | | |
| 31 | 15.65 | 15.4 | 15.6 | 15.38 | 15.58 | 15.34 | 15.56 | 15.3 |
| 32 | 15.35 | 13.12 | 15.33 | 13.05 | 15.35 | 13.09 | 15.32 | 12.98 |
| 33 | 15.48 | 11.93 | 15.47 | 11.98 | 15.48 | 11.92 | 15.46 | 11.86 |
| 34 | 15.66 | 4.32 | 15.69 | 4.24 | 15.65 | 4.25 | 15.64 | 4.19 |
| 35 | | | | | | | | |
| 36 | | | | | | | | |
| 37 | 15.46 | 8.23 | 15.43 | 8.18 | 15.42 | 8.19 | 15.41 | 8.17 |
| 38 | 15.87 | 10.73 | 15.86 | 9.45 | 15.57 | 8.81 | 15.85 | 8.3 |
| 39 | 15.87 | 3.47 | 15.9 | 3.14 | 15.87 | 3.16 | 15.86 | 3.03 |
| 40 | | | | | | | | |

Table 5 (continue)

| Date | 08.01.2004 | | 07.02.2004 | | 09.03.2004 | | 05.04.2004 | |
|---|---|---|---|---|---|---|---|---|
| Sampling well | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l |
| W1 | 16.27 | 3.50 | 16.25 | 3.54 | 16.24 | 3.69 | 16.225 | 6.02 |
| W2 | 16.31 | 3.32 | 16.29 | 3.14 | 16.28 | 3.01 | 16.27 | 2.91 |
| W3 | 16.59 | 3.94 | 16.57 | 3.76 | 16.56 | 3.48 | 16.555 | 3.20 |
| 3 | 15.88 | 10.14 | 15.9 | 10.28 | 15.89 | 10.39 | 15.89 | 10.56 |
| 4 | 15.43 | 15.46 | 15.52 | 15.71 | 15 | 15.77 | 15.58 | 15.76 |
| 5 | | | | 0.00 | | | | |
| 6 | 15.85 | 3.27 | 15.86 | 3.18 | 15.86 | 3.13 | 15.85 | 3.08 |
| 7 | 15.81 | 4.73 | 15.79 | 5.30 | 15.78 | 5.51 | 15.765 | 5.76 |
| 8 | | | | | | | | |
| 9 | 15.81 | 3.38 | 15.79 | 3.19 | 15.77 | 2.92 | 15.765 | 2.77 |
| 10 | 15.83 | 3.97 | 15.82 | 3.79 | 15.81 | 3.62 | 15.8 | 3.48 |
| 11 | | | | | | | | |
| 12 | | | | | | | | |
| 13 | | | | | | | | |
| 14 | | | | | | | | |
| 15 | 16.27 | 6.99 | 16.29 | 7.03 | 16.31 | 7.01 | 16.28 | 7.09 |
| 16 | 15.33 | 7.66 | 15.39 | 8.15 | 15.57 | 10.11 | 16.45 | 10.12 |
| 17 | 16.1 | 5.56 | 16.12 | 6.05 | 16.11 | 6.69 | 16.1 | 7.65 |
| 18 | | 0.00 | | | | | | |
| 19 | 15.8 | 6.19 | 15.81 | 6.22 | 15.8 | 6.23 | 15.8 | 6.24 |
| 20 | 15.81 | 4.51 | 15.82 | 6.06 | 15.82 | 7.28 | 15.825 | 8.19 |
| 21 | 15.92 | 3.61 | 15.91 | 4.10 | 15.91 | 4.63 | 15.9 | 5.40 |
| 22 | 15.72 | 11.50 | 15.71 | 12.48 | 15.72 | 14.52 | 15.72 | 15.58 |
| 23 | 15.88 | 8.31 | 15.89 | 8.89 | 15.88 | 9.15 | 15.875 | 9.58 |
| 24 | 15.79 | 4.96 | 15.78 | 5.48 | 15.79 | 5.78 | 15.78 | 6.16 |
| 25 | | | | | | | 16.3 | |
| 26 | 15.88 | 4.51 | 15.87 | 4.69 | 15.88 | 4.61 | 15.87 | 4.58 |
| 30 | | | | | | | | |
| 31 | 15.56 | 17.24 | 15.57 | 17.27 | 15.58 | 17.25 | 15.585 | 17.24 |
| 32 | 15.33 | 14.65 | 15.49 | 14.89 | 15.69 | 15.17 | 16.04 | 15.53 |
| 33 | 15.47 | 13.75 | | | | | 16.14 | 14.03 |
| 34 | 15.66 | 4.31 | | | | | 15.59 | 4.07 |
| 35 | 15.72 | 3.38 | 15.75 | 3.54 | 15.79 | 3.66 | 15.82 | 3.90 |
| 36 | 15.83 | 5.40 | 15.82 | 5.42 | 15.81 | 5.39 | 15.81 | 5.38 |
| 37 | 15.41 | 9.80 | 15.42 | | 15.42 | | 15.42 | 17.38 |
| 38 | 15.85 | 9.92 | 15.87 | 9.80 | 15.88 | 10.31 | 15.89 | 17.31 |
| 39 | 15.83 | 3.80 | 15.85 | 3.89 | 15.87 | 4.03 | 15.89 | 4.07 |
| 40 | 15.94 | 16.91 | 15.96 | 16.76 | 15.97 | 16.62 | 15.95 | 16.52 |
| 41 | 16.2 | 12.66 | 16.1 | 12.37 | 16.15 | 12.24 | 16 | 12.04 |
| 42 | | | | | | | | |
| 49 | 15.53 | 17.47 | 15.51 | 17.48 | 15.52 | 17.50 | 15.5 | 17.43 |
| 50 | 14.71 | 14.50 | 14.67 | 14.14 | 14.65 | 14.19 | 14.6 | 14.21 |

Table 5 (continue)

| Date | 28.04.2004 | | 05.05.2004 | | 04.06.2004 | | 06.07.2004 | |
|---|---|---|---|---|---|---|---|---|
| Sampling well | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l |
| W1 | 16.23 | 4.06 | 16.23 | 4.2 | 16.23 | 3.87 | 16.23 | 3.81 |
| W2 | 16.23 | 2.75 | 16.23 | 3.71 | 16.23 | 2.71 | 16.23 | 2.68 |
| W3 | 16.55 | 3.13 | 16.56 | 3.31 | 16.56 | 3.06 | 16.54 | 3.02 |
| 3 | 15.87 | 10.47 | | | | | | |
| 4 | 15.56 | 15.73 | 16.5 | 17.8 | 16.38 | 13 | 16.37 | 12.85 |
| 5 | | | | | | | | |
| 6 | 15.8 | 3.35 | 15.83 | 3.32 | 15.81 | 3.3 | 15.84 | 3.6 |
| 7 | 15.76 | 5.67 | 15.73 | 7.21 | 15.71 | 7.21 | 15.71 | 6.97 |
| 8 | | | | | | | | |
| 9 | 15.775 | 2.77 | 15.74 | 4.55 | 15.73 | 3.45 | 15.73 | 3.23 |
| 10 | 15.84 | 3.01 | 15.81 | 3.21 | 15.82 | 2.99 | 15.79 | |
| 11 | | | | | | | | |
| 12 | | | | | | | | |
| 13 | | | | | | | | |
| 14 | | | | | | | | |
| 15 | 16.26 | 6.84 | | | | | 16.25 | 6.98 |
| 16 | 16.42 | 9.46 | | | | | 16.4 | 9.13 |
| 17 | 16.085 | 7.44 | | | 16.04 | 8.4 | 16.04 | 8.11 |
| 18 | | | | | | | | |
| 19 | 15.785 | 5.61 | 15.76 | 4.52 | 15.78 | 7.05 | 15.76 | 6.73 |
| 20 | 15.805 | 6.99 | 15.77 | 4.19 | 15.82 | 6.69 | 15.78 | 6.47 |
| 21 | 15.92 | 5.34 | 15.88 | 5.6 | 15.9 | 5.66 | 15.88 | 5.53 |
| 22 | 15.7 | 13.57 | | | 15.68 | 11.3 | 15.66 | 10.67 |
| 23 | 15.86 | 10.45 | | | | | 15.84 | 8.12 |
| 24 | 15.76 | 4.68 | | | | | 15.75 | 4.51 |
| 25 | | | | | | | | |
| 26 | 15.84 | 8.43 | | | | | 15.81 | 7.59 |
| 30 | | | | | | | | |
| 31 | 15.59 | 16.52 | 15.54 | 17.6 | 15.53 | 13.8 | 15.52 | 13.14 |
| 32 | 16.14 | 13.79 | 16.23 | 14.6 | 16.24 | 12.4 | 16.19 | 11.24 |
| 33 | 16.125 | 12.35 | 16.12 | 13.1 | 16.12 | 10.7 | 16.12 | 9.84 |
| 34 | 15.72 | 3.90 | | | 15.78 | 4.09 | 15.74 | 3.97 |
| 35 | 15.805 | 3.29 | 15.93 | 3.68 | 15.85 | 3.57 | 15.73 | 3.64 |
| 36 | 15.805 | 5.24 | 15.88 | 5.08 | 15.82 | 4.79 | 15.79 | 4.48 |
| 37 | 15.4 | 16.66 | 15.39 | 17.2 | 15.43 | 12.9 | 15.4 | 10.85 |
| 38 | 15.87 | 16.23 | 15.85 | 17.4 | 15.88 | 12.6 | 15.86 | 10.84 |
| 39 | 15.875 | 3.67 | 15.97 | 4.06 | 15.89 | 3.92 | 15.86 | 3.73 |
| 40 | 15.935 | 12.30 | | | | | 15.9 | 11.79 |
| 41 | 15.99 | 11.82 | | | | | 15.97 | 10.93 |
| 42 | | | | | | | | |
| 49 | 15.46 | 17.24 | | | | | 15.42 | 16.98 |
| 50 | 14.62 | 12.72 | | | | | 14.59 | 12.84 |

Table 5 (continue)

| Date | 10.08.2004 | | 07.09.2004 | | 05.10.2004 | | 21.11.2004 | |
|---|---|---|---|---|---|---|---|---|
| Sampling well | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l |
| W1 | 16.22 | 3.76 | 16.18 | 3.72 | 16.18 | 3.64 | 16.19 | 3.61 |
| W2 | 16.20 | 2.64 | 16.19 | 2.62 | 16.18 | 2.6 | 16.19 | 2.59 |
| W3 | 16.54 | 2.99 | 16.53 | 2.97 | 16.51 | 2.96 | 16.52 | 2.95 |
| 3 | | | | | | | | |
| 4 | 16.28 | 11.97 | 16.23 | 11.21 | 16.19 | 10.35 | 16.17 | 9.55 |
| 5 | | | | | | | | |
| 6 | 15.83 | 3.4 | 15.82 | 3.41 | 15.83 | 3.35 | 15.80 | 3.38 |
| 7 | 15.7 | 6.84 | 15.68 | 6.66 | 15.7 | 6.59 | 15.72 | 6.53 |
| 8 | | | | | | | | |
| 9 | 15.74 | 3.14 | 15.72 | 2.97 | 15.7 | 2.92 | 15.72 | 2.8 |
| 10 | 15.78 | | 15.77 | | 15.78 | | 15.78 | 2.3 |
| 11 | | | | | | | | |
| 12 | | | | | | | | |
| 13 | | | | | | | | |
| 14 | | | | | | | | |
| 15 | 16.23 | 7.33 | 16.21 | 8.45 | 16.2 | 9.17 | 16.2 | 9.8 |
| 16 | 16.39 | 8.87 | 16.37 | 8.54 | 16.37 | 8.38 | 16.36 | 8.06 |
| 17 | 16.01 | 7.84 | 16 | 7.69 | 16.02 | 7.47 | 16.05 | 7.29 |
| 18 | | | | | | | | |
| 19 | 15.75 | 6.18 | 15.74 | 5.86 | 15.75 | 5.29 | 15.75 | 4.94 |
| 20 | 15.77 | 6.13 | 15.77 | 5.81 | 15.77 | 5.58 | 15.77 | 5.29 |
| 21 | 15.86 | 5.44 | 15.85 | 5.37 | 15.86 | 5.29 | 15.85 | 5.21 |
| 22 | 15.64 | 10.21 | 15.65 | 9.43 | 16.67 | 8.95 | 15.68 | 8.54 |
| 23 | 15.82 | 3.57 | 15.81 | 3.11 | 15.83 | 1.8 | 15.84 | 1.32 |
| 24 | 15.77 | 4.45 | 15.76 | 4.3 | 15.74 | 4.27 | 15.74 | 4.26 |
| 25 | | | | | | | | |
| 26 | 15.8 | 6.43 | 15.78 | 5.77 | 15.79 | 4.98 | 15.79 | 4.57 |
| 30 | | | | | | | | |
| 31 | 15.51 | 12.67 | 15.51 | 11.87 | 15.52 | 10.96 | 15.52 | 9.89 |
| 32 | 16.16 | 10.76 | 16.09 | 9.98 | 15.03 | 9.32 | 15.96 | 8.89 |
| 33 | 16.11 | 9.61 | 16.1 | 9.24 | 16.11 | 9.11 | 16.11 | 8.84 |
| 34 | 15.69 | 3.83 | 15.63 | 3.79 | 15.59 | 3.74 | 15.55 | 3.71 |
| 35 | 15.62 | 3.61 | 15.54 | 3.47 | 15.43 | 3.39 | 15.31 | 3.57 |
| 36 | 15.75 | 4.15 | 15.76 | 3.89 | 15.77 | 3.63 | 15.76 | 3.44 |
| 37 | 15.38 | 10.49 | 15.36 | 10.18 | 15.37 | 10.1 | 15.37 | 9.95 |
| 38 | 15.83 | 9.96 | 15.81 | 9.84 | 15.82 | 9.69 | 15.83 | 9.61 |
| 39 | 15.82 | 3.47 | 15.78 | 3.31 | 15.79 | 3.24 | 15.80 | 3.11 |
| 40 | 15.86 | 9.93 | 15.88 | 8.85 | 15.9 | 8.56 | 15.92 | 7.95 |
| 41 | 15.94 | 8.84 | 15.96 | 8.42 | 15.97 | 7.61 | 15.97 | 7.49 |
| 42 | | | | | | | | |
| 49 | 15.4 | 16.94 | 15.43 | 16.81 | 15.44 | 16.74 | 15.45 | 16.8 |
| 50 | 14.58 | 12.79 | 14.59 | 12.81 | 14.6 | 12.75 | 14.61 | 12.7 |

Table 5 (continue)

| Date | 18.01.2005 | | 16.02.2005 | | 04.03.2005 | | 10.04.2005 | |
|---|---|---|---|---|---|---|---|---|
| Sampling well | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l |
| W1 | 16.26 | 3.47 | 16.29 | 2.95 | 16.35 | 2.53 | 16.4 | 2.2 |
| W2 | 16.25 | 2.45 | 16.31 | 2.36 | 16.39 | 2.19 | 16.45 | 2 |
| W3 | 16.61 | 2.73 | 16.68 | 2.59 | 16.73 | 2.41 | 16.79 | 2.2 |
| 3 | | | | | | | | |
| 4 | 16.2 | 8.47 | 16.25 | 6.93 | 16.28 | 5.61 | 16.3 | 4.89 |
| 5 | | | | | | | | |
| 6 | 15.85 | 2.89 | 15.89 | 2.67 | 15.95 | 2.48 | 16 | 2.3 |
| 7 | 15.78 | 6.24 | 15.83 | 5.98 | 15.89 | 5.67 | 15.95 | 5.45 |
| 8 | | | | | | | | |
| 9 | 15.79 | 2.66 | 15.82 | 2.49 | 15.9 | 2.27 | 15.95 | 2.05 |
| 10 | 15.86 | 2.08 | 15.91 | 1.89 | 15.95 | 1.81 | 16 | 1.77 |
| 11 | | | | | | | | |
| 12 | | | | | | | | |
| 13 | | | | | | | | |
| 14 | | | | | | | | |
| 15 | | | | | | | | |
| 16 | 16.42 | 8.29 | 16.49 | 8.57 | 16.53 | 8.77 | 16.57 | 8.85 |
| 17 | 16.14 | 7.04 | 16.19 | 6.71 | 16.22 | 6.41 | 16.26 | 6.05 |
| 18 | | | | | | | | |
| 19 | 15.81 | 4.88 | 15.87 | 4.75 | 15.93 | 4.69 | 15.97 | 4.65 |
| 20 | 15.87 | 5.03 | 15.91 | 4.82 | 15.95 | 4.64 | 15.98 | 4.55 |
| 21 | 15.88 | 4.97 | 15.9 | 4.31 | 15.92 | 4.07 | 15.93 | 3.75 |
| 22 | | | | | | | | |
| 23 | 15.91 | 1.24 | 15.96 | 1.13 | 16.01 | 1.33 | 16.08 | 1.41 |
| 24 | 15.82 | 3.98 | 15.89 | 3.67 | 15.92 | 3.44 | 15.95 | 3.19 |
| 25 | | | | | | | | |
| 26 | 15.85 | 4.28 | 15.91 | 4.06 | 15.96 | 3.77 | 16 | 3.6 |
| 30 | | | | | | | | |
| 31 | 15.56 | 9.86 | 15.53 | 9.84 | 15.52 | 9.81 | 15.51 | 9.8 |
| 32 | 15.98 | 8.67 | 16.01 | 8.43 | 16.02 | 8.29 | 16.07 | 8.15 |
| 33 | 16.13 | 8.33 | 16.11 | 8.09 | 16.1 | 7.91 | 15.99 | 7.53 |
| 34 | 15.59 | 3.44 | 15.62 | 3.06 | 15.66 | 2.94 | 15.69 | 2.6 |
| 35 | 15.36 | 3.41 | 15.4 | 3.07 | 15.46 | 2.54 | 15.51 | 2 |
| 36 | 15.77 | 3.36 | 15.78 | 3.11 | 15.79 | 2.59 | 15.81 | 2.1 |
| 37 | 15.36 | 9.77 | 15.365 | 9.54 | 15.36 | 9.31 | 15.36 | 9.05 |
| 38 | 15.84 | 9.64 | 15.845 | 9.21 | 15.85 | 8.86 | 15.86 | 8.55 |
| 39 | 15.8 | 2.86 | 15.81 | 2.67 | 15.8 | 2.46 | 15.8 | 2.25 |
| 40 | 15.98 | 8.02 | 16.05 | 8.26 | 16.11 | 8.44 | 16.14 | 8.65 |
| 41 | 16.08 | 7.98 | 16.14 | 8.06 | 16.19 | 8.53 | 16.23 | 8.9 |
| 42 | | | | | | | | |
| 49 | 15.52 | 14.32 | 15.59 | 11.58 | 15.63 | 9.65 | 15.66 | 7.85 |
| 50 | 14.71 | 11.82 | 14.78 | 10.58 | 14.86 | 9.49 | 14.9 | 8.52 |

Table 5 (continue)

| Date | 09.05.2005 | | 10.06.2005 | | 02.07.2005 | |
|---|---|---|---|---|---|---|
| Sampling well | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l | Ground water depth, m | TDS, g/l |
| W1 | 16.43 | 2.1 | 16.48 | 1.95 | 16.5 | 1.91 |
| W2 | 16.51 | 1.76 | 16.57 | 1.51 | 16.6 | 1.28 |
| W3 | 16.85 | 1.95 | 16.89 | 1.52 | 16.93 | 1.35 |
| 3 | | | | | | |
| 4 | 16.31 | 4.22 | 16.32 | 3.94 | 16.31 | 3.52 |
| 5 | | | | | | |
| 6 | 15.96 | 2.06 | 15.93 | 1.65 | 15.91 | 1.31 |
| 7 | 15.91 | 4.68 | 15.89 | 3.51 | 15.875 | 2.15 |
| 8 | | | | | | |
| 9 | 15.94 | 1.94 | 15.96 | 1.89 | 15.97 | 1.85 |
| 10 | 16.01 | 1.56 | 16.02 | 1.43 | 16.03 | 1.31 |
| 11 | | | | | | |
| 12 | | | | | | |
| 13 | | | | | | |
| 14 | | | | | | |
| 15 | | | | | | |
| 16 | 16.62 | 7.31 | 16.69 | 5.98 | 16.74 | 4.15 |
| 17 | 16.31 | 5.24 | 16.38 | 4.17 | 16.4 | 3.4 |
| 18 | | | | | | |
| 19 | 15.67 | 3.86 | 15.34 | 3.08 | 15.17 | 2.5 |
| 20 | 16.07 | 3.66 | 16.14 | 2.99 | 16.2 | 2.35 |
| 21 | 16.09 | 3.19 | 16.17 | 2.81 | 16.25 | 2.11 |
| 22 | | | | | | |
| 23 | 16.14 | 1.47 | 16.18 | 1.52 | 16.2 | 1.6 |
| 24 | 15.97 | 2.88 | 15.99 | 2.54 | 16 | 2.2 |
| 25 | | | | | | |
| 26 | 16.05 | 3.67 | 16.08 | 3.54 | 16.04 | 3.51 |
| 30 | | | | | | |
| 31 | 15.53 | 8.04 | 15.51 | 6.8 | 15.5 | 5.1 |
| 32 | 16.04 | 6.54 | 16.02 | 4.28 | 16 | 2.8 |
| 33 | 16.03 | 6.07 | 16.09 | 5.46 | 16.105 | 4.32 |
| 34 | 15.72 | 2.08 | 15.76 | 1.76 | 15.78 | 1.4 |
| 35 | 15.53 | 1.84 | 15.57 | 1.65 | 15.6 | 1.3 |
| 36 | 15.82 | 1.76 | 15.85 | 1.53 | 15.875 | 1.22 |
| 37 | 15.34 | 7.52 | 15.345 | 5.41 | 15.355 | 3.85 |
| 38 | 15.84 | 6.43 | 15.87 | 5.53 | 15.875 | 4 |
| 39 | 15.81 | 1.64 | 15.805 | 1.38 | 15.8 | 1.14 |
| 40 | 16.05 | 6.24 | 15.71 | 4.91 | 15.35 | 3.32 |
| 41 | 16.34 | 6.25 | 16.38 | 4.88 | 16.41 | 3.41 |
| 42 | | | | | | |
| 49 | 15.67 | 7.89 | 15.68 | 7.92 | 15.67 | 7.9 |
| 50 | 14.91 | 8.56 | 14.9 | 8.53 | 14.9 | 8.54 |