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Remediation of in-Land Wastewater
(Case Study Makkah Treatment Plant)

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الملخص:
تم اختيار موقع التخلص من مياه الصرف الصحي المعالجة من محطة مكة كحالة للدارسة والمنطقة التي خضعت لهذه الدراسة تحتوي على منطقة هي الجزء المنخفض من وادي عرنه وهي منطقة ضيقة نسبياً عند أعلى المصب ثم تتسع في اسفل المصب قرب المصب و يتم التخلص من المياه المتدفقة من محطة مكه للمعالجة في وادي عرنه الذي هو أحد روافد حوض وادي نعمان وتدفق المياة المعالجة من محطة المعالجة في وادي طبيعي ضيق يعبر تقاطعه مع طريق جدة - الطائف من خلال كوبري ثم يكمل مساره الى منطقة مسطحة مكوناً حوضاً من المياه احياناً حسب كميات الضخ والتوقيت خلال العام وذلك شمال طريق جدة – الليث وفي النهاية فإن هذه المياه تختفي بجوار طريق الليث وتجري المياه في قناة طبيعيه تجاه لبحر الأحمر وذلك لمسافة حوالي 20 كم عابراً الطريق المؤدي الى الطائف من تحت الكوبري.
وتساهم المياه المعالجة في تلوث الخزان الجوفي في هذه المنطقة وقد تم التمذجة العديدية على تلوث المياة الجوفية وذلك من اجل إيجاد الطريقة الأكثر كفاءة وفعالية لتنظيف مستودع المياه الجوفية وقد تم عمل نمذجة عديدية لآبار الحقن وطريقة الانتشار السطحي ثم تم عمل سيناريوهات عديدية شاملة آبار حقن في وجود الرشح السطحي.و آبار الضخ مع ايقاف آبار الحقن والانتشار على سطح الارض ثم استخدام جدار طيني تحت الارض وقد كانت الخلاصة هي التوصية باستعمال الجدار الطيني وذلك لفاعليته ورخص ثمنه وعدم احتياجه تكنولوجيا

Abstract
The paper presents general background concerning the problem of groundwater pollution with complete assessment of the different pollution sources. The mechanics of pollution spread and attenuation including dispersion, convection, sources/ sinks, adsorption, and decay are considered. The equations of three dimensional solute transport are illustrated and discussed. Different methods of remediation of groundwater contamination are demonstrated and supported with the results of numerical simulation of some remediation methods including grouting, slurry walls, injection wells with clean water, and pumping wells. Numerical simulation of four different approached to stop contamination spread out of sewage treatment plant in the region. Use of the slurry wall proves an effective method with least costs. Finally, the research conclusion and recommendations are summarized and presented.

Background
In spite of great efforts made by the Saudi Government, water supply for the western region in particular, and other parts of the Kingdom in general, will have to be expanded in order to meet the overgrowing demands. Wastewater reuse could be a potential source of pollution in that respect. Usually, treated wastewater is disposed of by dilution in rivers and natural lakes. This is not the case in Saudi Arabia where in-land wastewater disposal simply means discharge into dry wadis. Under arid land conditions, such method results in concentration of pollutants due to the high rate of evaporation. Furthermore, the hot climate will increase bacterial activities which will result in a

higher rate of removal for the biodegradable matters. Most of the wastewater environmental studies in the western region of Saudi Arabia have been focused on the effect of wastewater disposal in the Red Sea on the groundwaster environment.

Makkah sewage treatment plant

The disposal site of the treated wastewater from is Makkah sewage treatment plant is chosen as a case study. The area which is subject of this study consists of a wadi reach which is the lower part of Wadi Uranah. The reach is, relatively, narrow at the upstream and widens at the downstream end. The effluent from Makkah treatment plant is first conveyed through a closed conduit as a partially full flow, and then is disposed of in Wadi Uranah. The channel of Wadi Uranah drains towards Red Sea. Because of the topographic feature, the stream of the waste water divides into several small channels in form of fingering. Depending on the time of the year and the discharge rate it sometimes forms a pool of water in the northern part of Jeddah- Al-Lith road. The effluent runs as natural open channel flow, towards the Red Sea for about 20 km, crossing the road to Taif through a bridge. Wild vegetation is growing on the banks of the stream (Figure-1).

Organic matters precipitating during over-flooding were observed on the banks of the stream. The stream breaches into several shallower, yet wider channels. The width of the main stream varies from about one and half to several meters. In the vicinity near the termination of the stream, there are several farms in which agricultural activities are taking place. Water supply for these farms is from wells dug out in the alluvium. It is believed the wells are in hydraulic connection with the stream. Treated wastewaters can be reused in many ways the most important of which are for agriculture and ground water recharge. The understanding of chemical and microbial qualities of this wastewater and their effects on soil, plants and subsurface water is very essential for establishing the best ways of utilizing this valuable source.

Figure (1): Plants on the precipitated around the mainstream

Geology and soil classification

Figure (2) presents a global geological map for the wadis surrounding the region of study. It shows undifferentiated alluvial wadi deposits. Figure (3) presents a legend of the geological map. Appendix – A presents soil description from boreholes at different places. Description of the top layers is as follows (Table 8-1):

- Fill of silty sand, boulders and cobbles
- Fine to medium sand with gravel dense to very dense layer
- Brown Greyish weathered Granite Rock

The bed rock is at depth 37.00 – 166.00m.

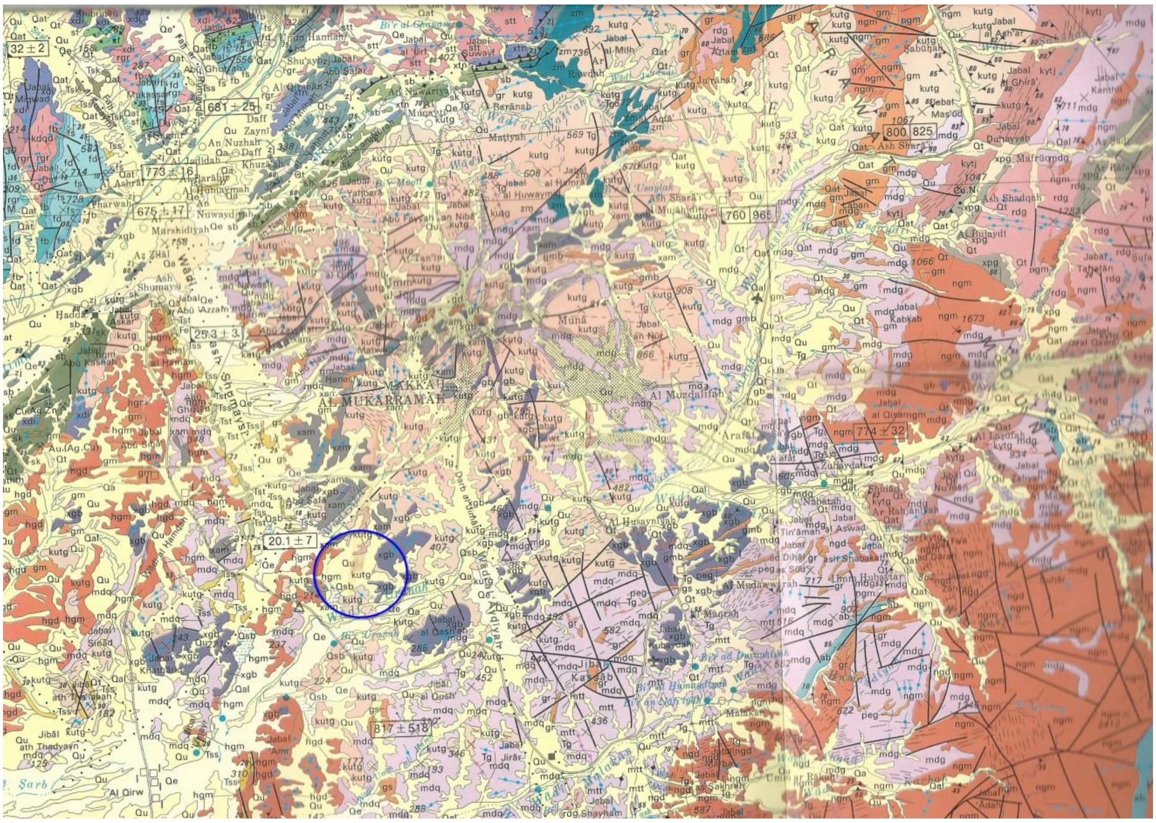

Figure (2): Geological map for the region of study

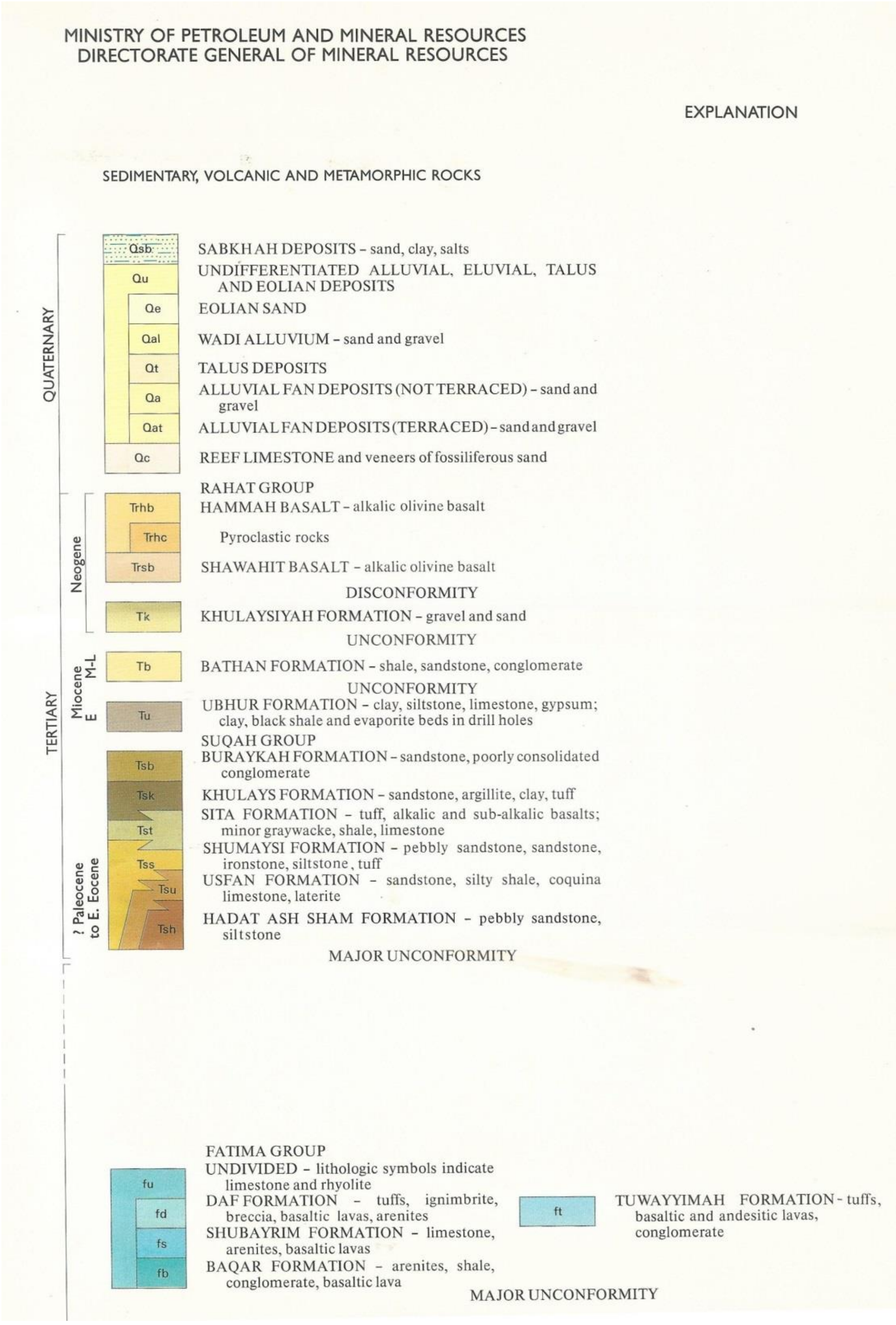

Figure (3): Legend of the geological map

Table (1) Classification of soil top layers (Appendix-A)

Location	M1	M2	M3	M4	M5
First Layer Depth(m) Type	1.16 – 0.00 Silty sand	0.85 – 0.00 Silty sand	1.16 – 0.00 Silty sand	1.16 – 0.00 Silty sand	1.16 – 0.00 Silty sand
Second Layer Depth(m) Type	3.7 – 1.16 Sand and silt	3.7 – 0.85 Sand and silt	3.70 – 1.16 Sand and silt	3.70 – 1.16 Sand and silt	5.40 – 1.16 Sand and silt
Third Layer Depth(m) Type	17 – 3.70 Sand	8.5 – 3.70 Sand	25.00 – 3.70 Sand	17.00 – 3.70 Sand	36.80 – 5.40 Sand
Depth to bed rock	37.00	45.50	57.00	97.00	86.80

Table (1) Classification of soil top layers …continued

Location	M6	M7	M8	M9	M10
First Layer Depth(m) Type	5.40 – 0.00 Silty sand	1.16 – 0.00 Silty sand	1.16 – 0.00 Silty sand	1.16 – 0.00 Silty sand	1.16 – 0.00 Silty sand
Second Layer Depth(m) Type	3.600 – 5.40 Sand	5.40 – 1.16 Sand and silt	3.70 – 1.16 Sand and clay	5.40 – 1.16 Sand and clay	5.40 – 1.16 Sand and clay
Third Layer Depth(m) Type		36.00 – 5.40 Sand	17.00 – 3.70 Sand	36.00 – 5.40 Sand	36.00 – 5.40 Sand
Depth to bed rock	160.70	96.00	120.00	101.00	86.00

Analysis of experiment to determine the aquifer dispersivity

An experiment has been performed, by the Saudi Authority, at the location of the treatment plant. The objective of the experiment was determining the disperisivity coefficient in order to numerically simulate the aquifer and test the most powerful method to stop the pollution migration. Figure (4) shows the experiment set consisting of one injection well, W and four piezometers A, B, C and D. The piezometers are at distances 10.0m 10.5m, 6m, 23.8m, and 36.6 from the injection well, respectively. Figure (5) shows the setup of the dispersion experiment. Five meters head was set in the well above the groundwater level. Injection rate of Chloride was 5.00 m^3/day. Water samples were taken from each piezometer at times 0.0, 12, 36, 48, 63, 72, 84, 96, 108, 132, 144, 180, 204, 240 hours after injection start. The Chloride initial concentration was 1400 ppm, in the groundwater. The Chloride concentration, in the injection well, was 4500 ppm.

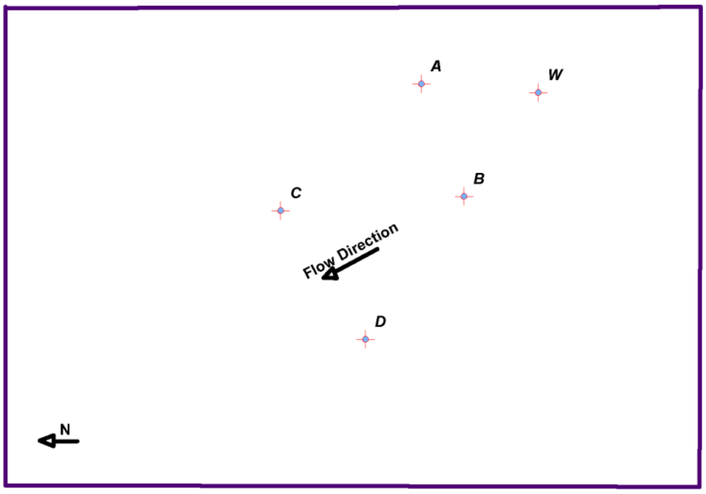

Figure (4): Layout of the injection and piezometers

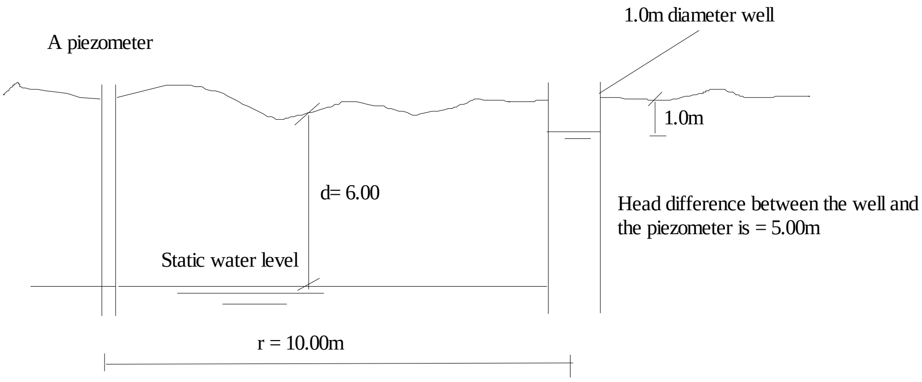

Figure (5): Setup of the dispersion experiment

Table (2): Depth to static groundwater level in the piezoeters

Piezometer	Distance (m)	Depth to groundwater (m)
A	11.0	10.7
B	11.5	10.9
C	24.8	10.8
D	37.6	10.6

The piezometer Chloride concentration was recorded. Approximate solutions of dispersion in radial flow Here, approximate solution (Hoopes and Harleman, 1971) is presented and employed. This solution assumes that at some distance from the source, If one adds the effect of molecular diffusion to the advection –dispersion equation for steady plane radial flow, one obtains

$$\frac{C}{C_o} = \frac{1}{2}\, erfc\left[\left(\frac{r_D^{\ 2}}{2} - t_D\right)\left(\frac{4}{3}\, r_D^{\ 3}\right)^{-1/2}\right].$$

Where

$$r_D = r / \alpha_L \qquad t_D = \frac{Qt}{2 \pi b \ n \ \alpha_L^{\ 2}}$$

Where erfc (x) =1 - erf (x), and erf (x) are error function and complementary error functions, respectively. For continuous injection of a substance at a steady rate Q with a concentration C_o at r =0, and b is the aquifer thickness

Table -3: Dispersion coefficient calculated from the dispersion coefficient

Piezometer	A	B	C	D
Average	1.6	1.8	3.7	4.4

Gellahsar and others (1985) undertook a critical review of field experiments at 55 sites around the world. Values of longitudinal dispersivity range from 0.01 m to 5500 m, apparently depending upon the scale of experiment. It appears that dispersivities increase indefinitely with scale. The results of calculations (of the experiment records) gave dispersion coefficient in the range of 1.58m to 4.39m. The results agree with corresponding values given, from Figure (6), for distances range of the experiment 10m-100m.

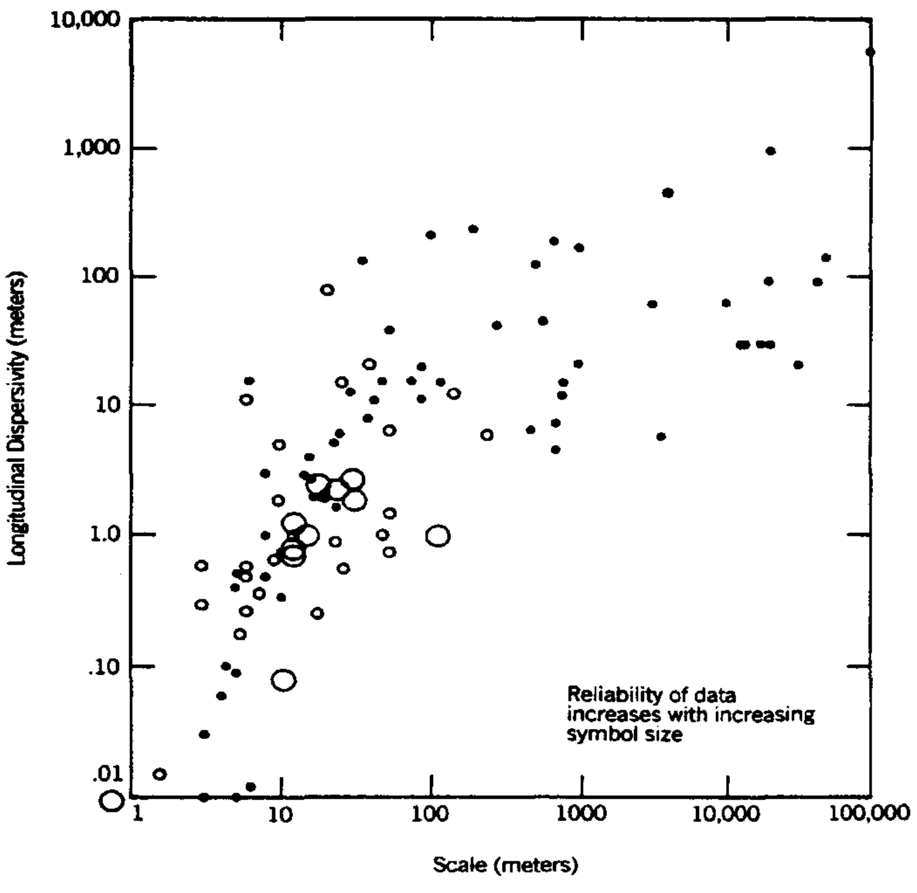

Figure (6): Scale of observation versus longitudinal dispersivity: reliability classificarion (Gelahsar and others, 1985)

Hyrogeological Characteristics of the Aquifer

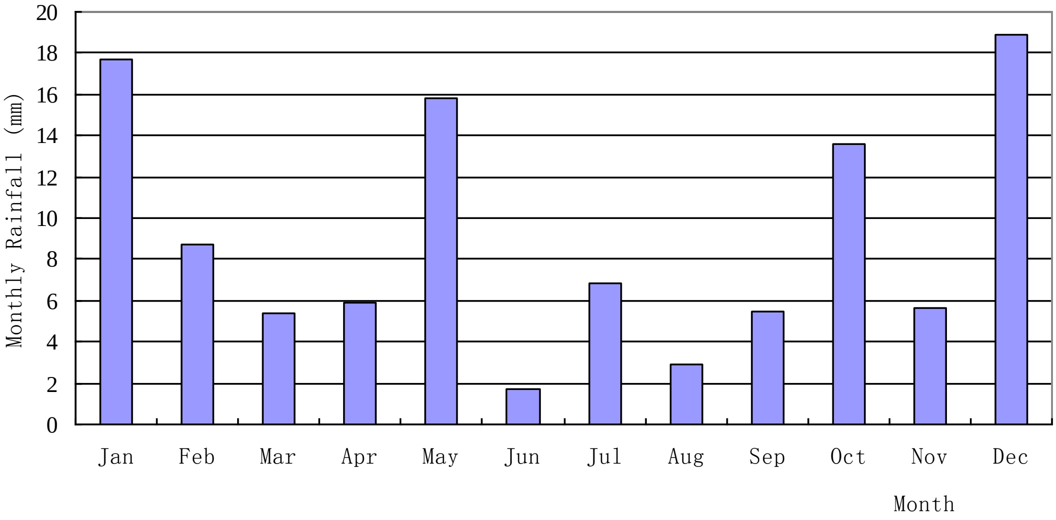

Figure (7): Monthly rainfall in the region

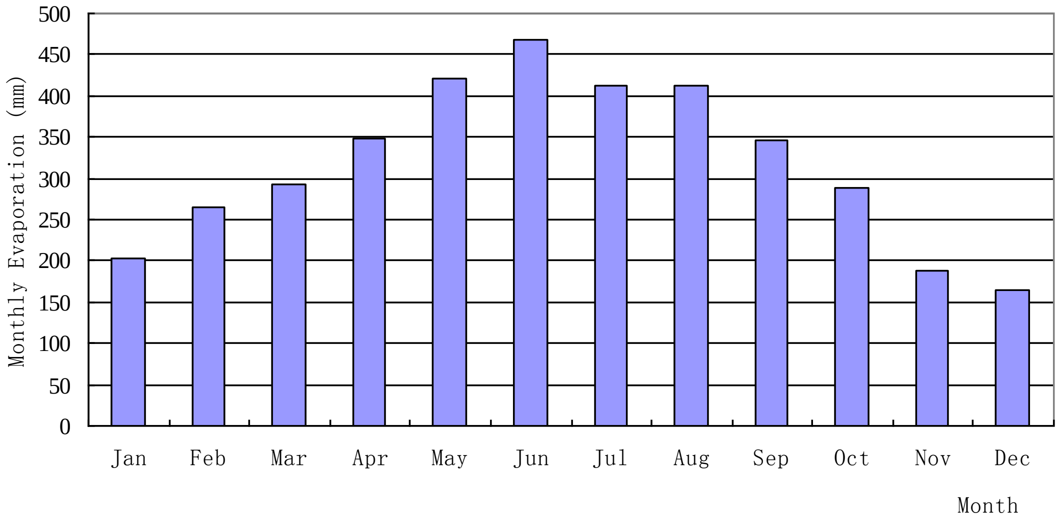

Figure (8): Monthly Evaporation in the region

Numerical Modeling

- Conceptual model

Area, around the water treatment plant, and the stream flow have been modeled using the software MODFOW and MT3D. The area has dimensions 28 km length in east-west direction and 13 km width in north- south direction. The area was subdivided into 5000 cells (100 columns and 50 rows). No flow boundaries are defined along the sides (mountains). Specified water table boundaries are assumed upstream and downstream the treatment station (9). The upstream and the downstream boundary conditions are 170m and 140m, respectively. Four outfall wells are located around the treatment station. Recharge of average rate of 69000 m3/day is considered over the entire area. The initial head is 145 m. The pollutant concentration is 3000 ppm in the injection wells and the surface recharge. Four cases had been considered for simulation. Steady state simulations are studied. The program was run for steady state.

- Calibration

Steady state calibration was done by trial and error. Figure (10) shows the results. Three observation piezometers used in calibration. The correlation coefficient is 0.90. The residual mean is -0.40. The corresponding hydraulic conductivity is Hydraulic conductivity = 43.2 m/day.

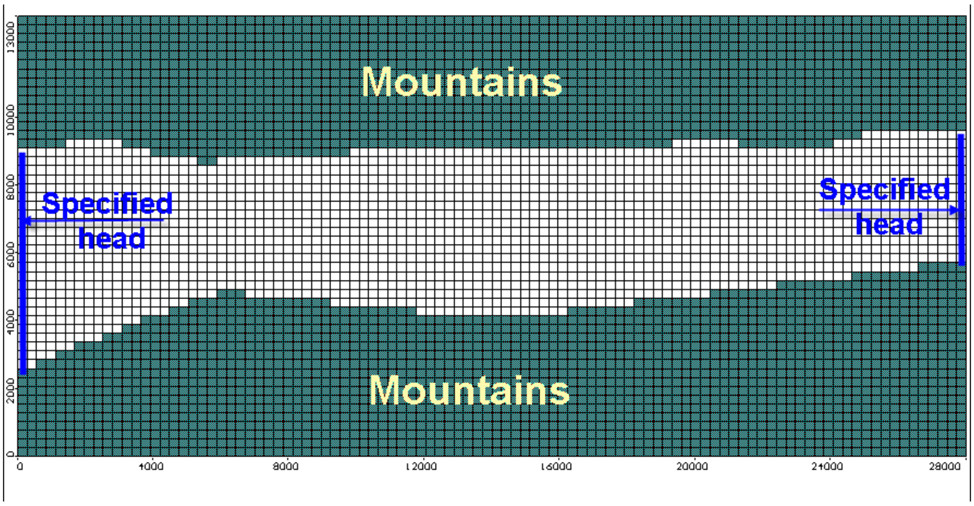

Figure (9) The model grid and boundaries

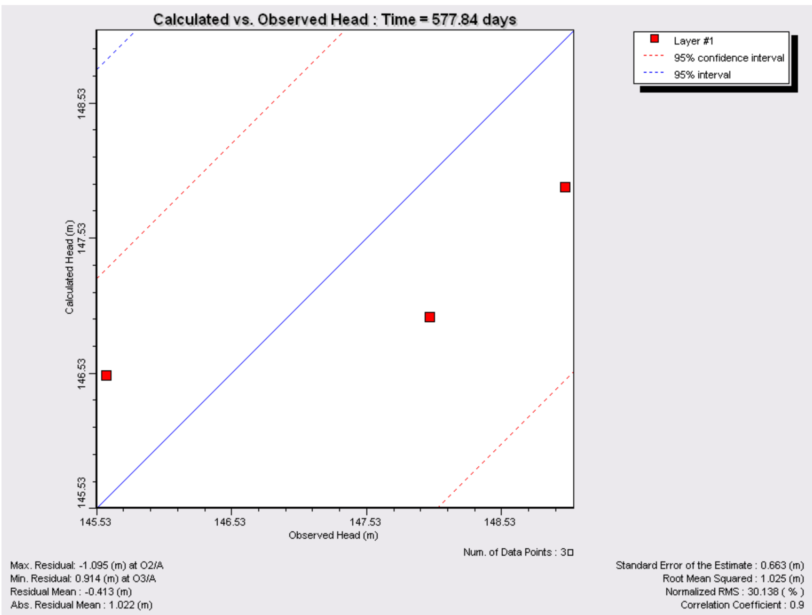

Figure (10) Calibration results

8.6.1 Injection wells with surface recharge

Injection wells with flow rates 6900 m3/day each, had been simulated injecting the aquifer. Concentration of applied waste water is 3000 ppm. Employing the software MODFLOW, Figures (11) and (12) present a plan and a longitudinal section showing the corresponding equipotential lines and velocity vectors where the injection wells and the surface recharge are acting. Then, applying the software MT3D, the contour lines of the injected pollutant are shown in Figure (13). The maximum pollution concentration is 3000ppm, at the wells location, and reaches 2950ppm at distance 28km away after 40 years.

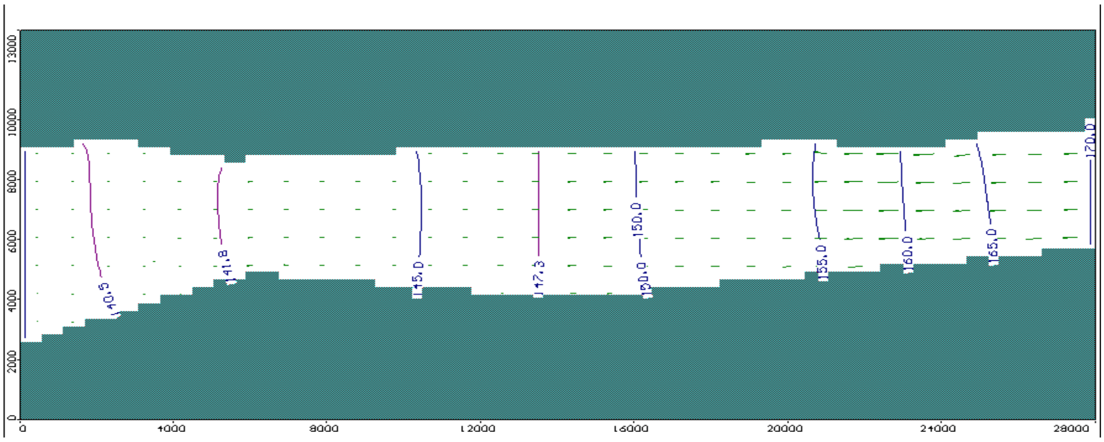

Figure (11): A plan showing Equipotential lines and velocity vectors with the injection and recharge

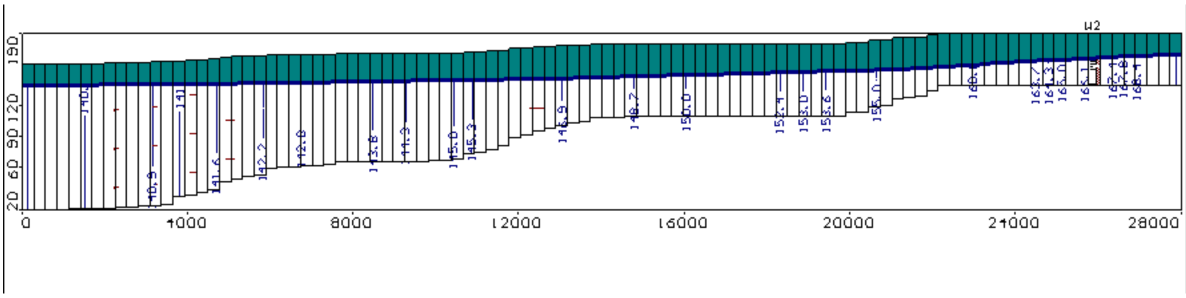

Figure (12): A section showing Equipotential lines and velocity vectors where the injection and recharge

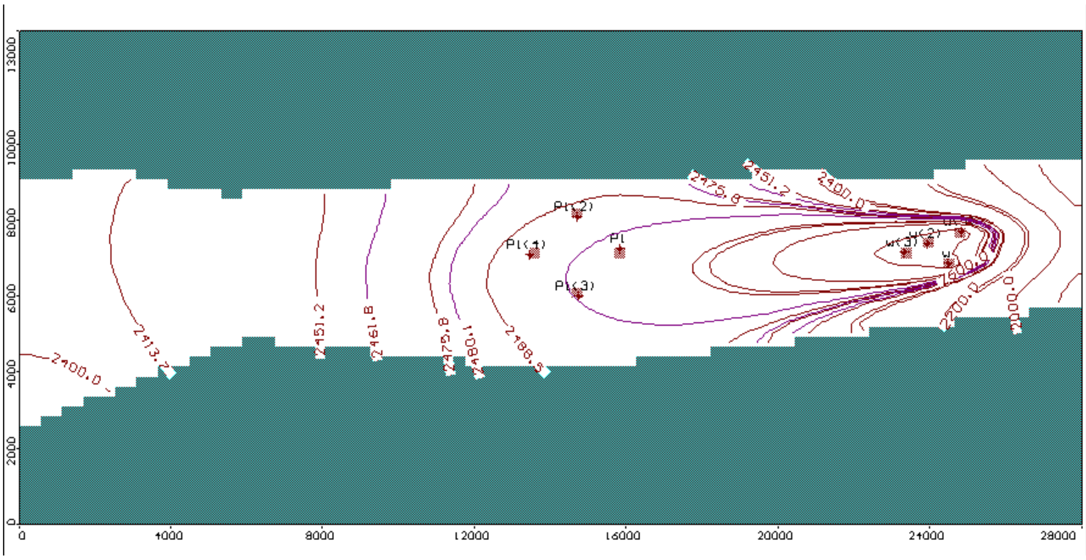

Figure (13): Contour lines of concentration of the injected pollutant

Injection wells without surface recharge

Only, the injection wells are considered without applying the surface recharge. Figure (14) presents the corresponding steady state equipotential lines, velocity vectors and the resulting contour lines of the injected pollutant. The pollutant steady state concentration reaches 2400 ppm at distance 28km in the downstream.

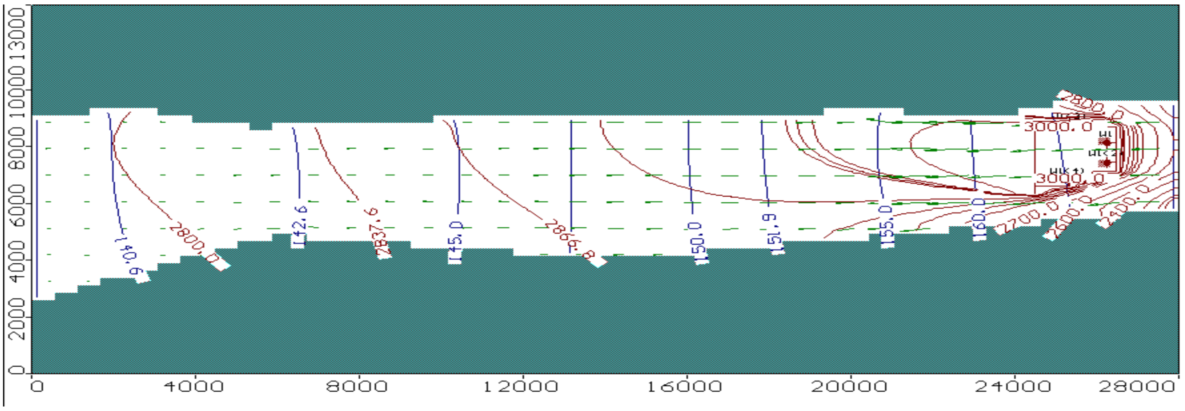

Figure (14): Pollutant concentration due to injection wells without recharge

Discharging wells with stopping the injection wells and the surface Recharge

Six discharging wells are placed, almost, in the middle of the stream. Discharge rate is 6900m3/day for each well. The injection wells and the surface recharge are stopped. As shown in Figure (15), the steady state conditions show almost clean aquifer.

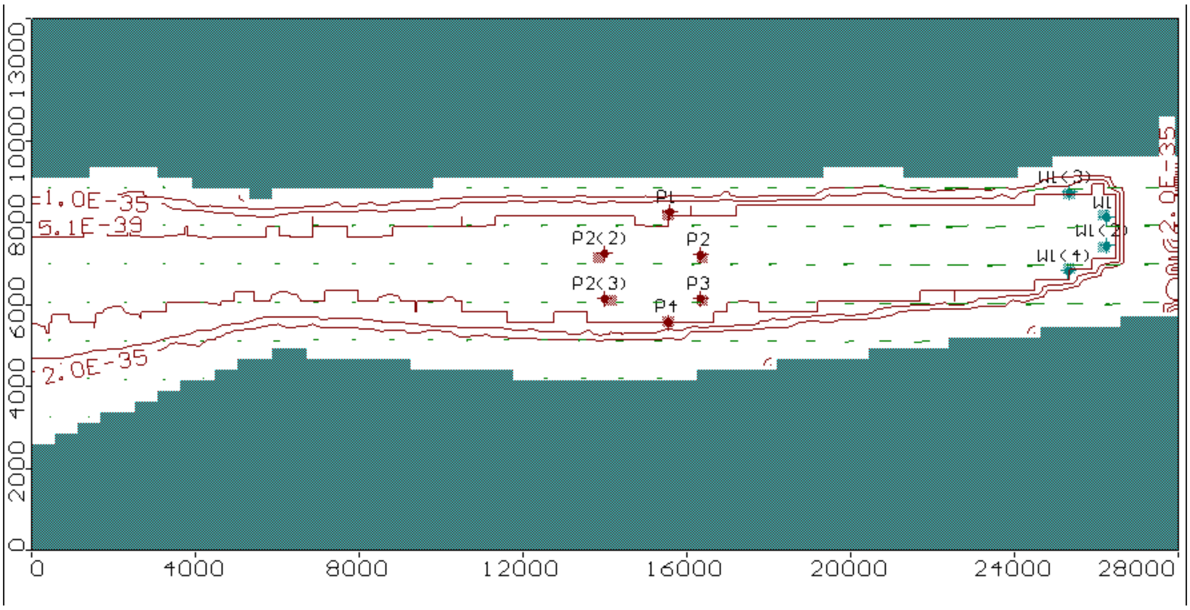

Figure (15): No recharge wells and no surface recharge, only discharging wells

Use of Slurry Wall

A slurry wall is installed at distance about 13 km downstream the sewage plant. Figure (16) presents the equipotential and the velocity vectors. The effect of the wall is simulated without injection wells and surface recharge. Contour lines of the pollutant, in case of using slurry wall, are shown in Figures (17) and (18).

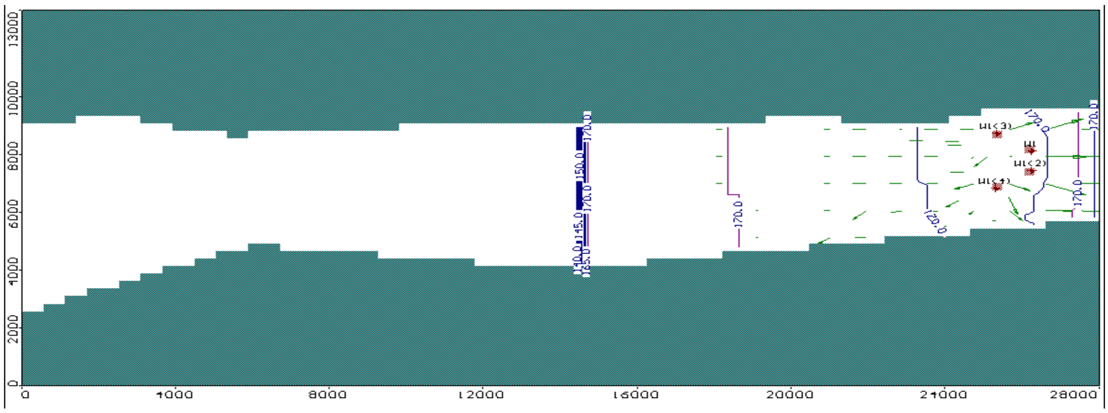

Figure (16): Equipotential lines and velocity vectors in case of using slurry wall

The alternative of slurry wall is recommended because it is built once and has no maintenance cost is required along the project life.

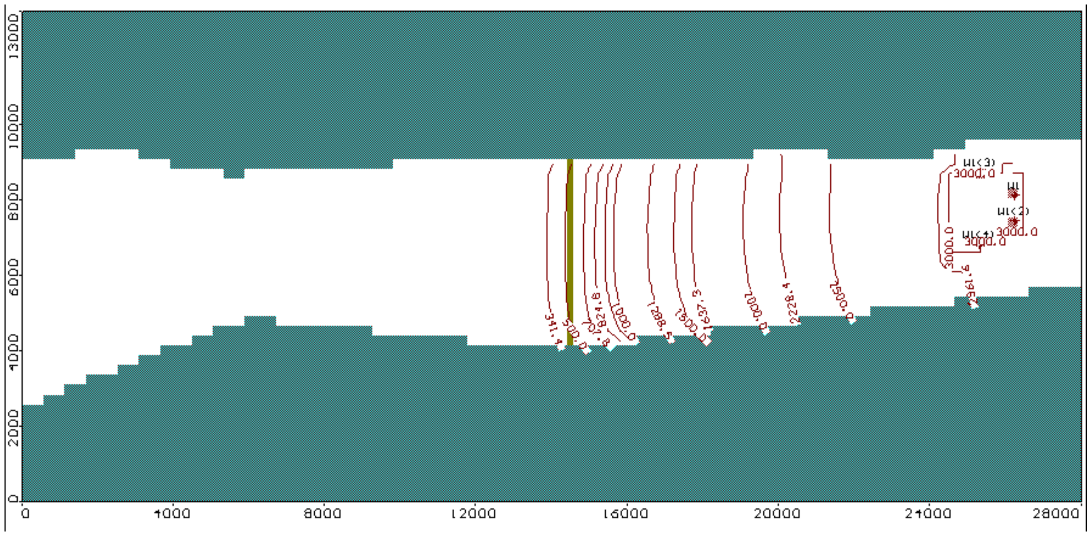

Figure (17): A plan showing contour lines of the pollutant concentration in case of using slurry wall

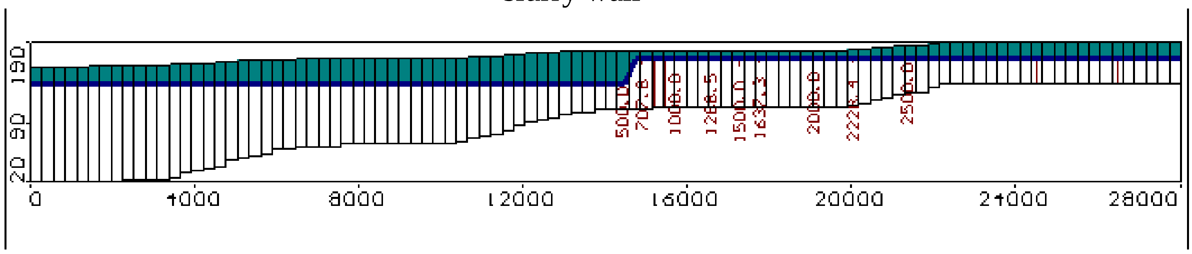

Figure (18): A longitudinal section showing contour lines of the pollutant concentration in case of using slurry wall

Conclusion

The study shows that using slurry wall to contain the pollution spread from the treatment plant proves the most effective method

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