Reclaimed Wastewater as Ground Water Recharge

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Groundwater as a Resource

- Large Regional Flow Systems
- Well Yield Analysis
- Artificial Recharge
- Conjunctive Use
- Aquifer Management

Overview

- Groundwater forms an integral part of the water cycle.
- Increasing water demands in urban and rural areas put increasing pressures on the use of groundwater.
- Increasing contamination of the resource as a result of urban, industrial and agricultural expansion, make it essential to properly manage these resources to guarantee their long term sustainability and to preserve water quality.
- Soil salinisation is often associated with irrigation practices but is also driven by natural groundwater processes.
- Integrated catchment management including groundwater is the key to solving the continuously expanding environmental problems of salinity, water logging and land degradation as well as the preservation of ecosystems.

Potential of Groundwater Resources

- Groundwater resources in many countries are coming under increasing threat from growing demands, wasteful use, and contamination.
- Surface water resources are particularly vulnerable to pollution, and are often limited in magnitude, particularly in arid regions.
- Groundwater resources are hidden and often poorly understood, but they are widespread, relatively easy to protect from contamination, and their development potential is great.
- Shallow groundwater in particular is relatively easy to access, and suitable for small scale development for domestic, livestock, and irrigation use in less developed countries.

Groundwater Replenishment

- The replenishment or recharge of shallow aquifers is of particular interest, as the annual recharge represents an upper limit of the quantity of water which can be abstracted without “mining” groundwater.
- In most situations, however, natural recharge to an aquifer emerges somewhere as natural discharge, sustaining stream flows and keeping wetlands wet.
- Therefore only a proportion of recharge can be abstracted for consumptive uses such as irrigation, in which used water is not returned to the aquifer.

Pumping Withdrawals

- Prior to exploitation by pumping, groundwater recharge is balanced by discharge to springs, streams, rivers and lakes.
- Withdrawal of water from wells is an additional stress that <u>must</u> be balanced by:
  1. An increase in recharge
  2. A reduction in discharge
  3. A reduction in groundwater storage
- Groundwater, managed in a responsible and sustainable manner is a <u>renewable</u> resource.

Safe Yield

- Management of groundwater systems requires some kind of yield analysis to determine how much groundwater is available.
- The term “safe yield”, coined by Lee(1915), is used to denote the sustainable maximum rate at which water can be withdrawn without dangerous depletion of storage.
- Lee’s definition is conceptually sound but lacks any guidance on what might constitute “dangerous depletion”.

Groundwater Basin Management

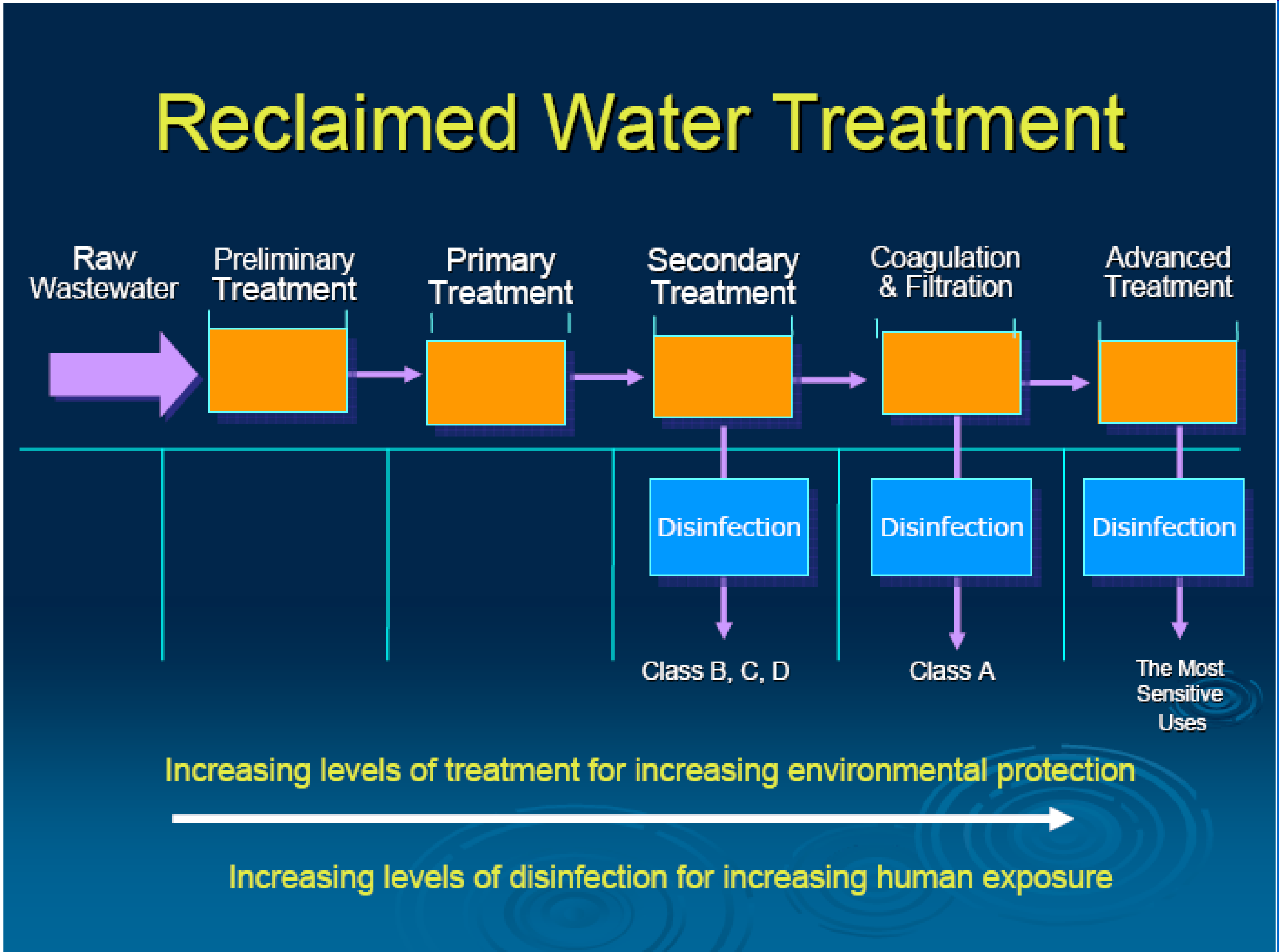
- GBM is defined as planned use of basin yield, storage space, transmission capabilities and water in storage, including:

1. Protection of natural recharge and use of artificial recharge;
2. Planned variation in the amount and location of pumping over time;
3. Conjunctive use of groundwater and surface water sources;
4. Protection and maintenance of groundwater quality.

Reclaimed Water

- Defined by statute (Ch. 90.46 RCW)
- Derived from sanitary sewage.
- Adequately and reliably treated – “at all times”.
- Suitable for beneficial use.
- **No longer a waste water.**

Reclaimed Water Treatment



GW Recharge

- The goal of artificial recharge is:
  - to store surface water, imported water and reclaimed wastewater
  - to protect groundwater freshwater against saltwater intrusion
  - to protect land subsidence due to overexploitation

GW Recharge

- Artificial recharge method can be divided into:
- deep method…. wells
- superficial methods….
  - spreading basins
  - channels
  - ditches
  - field irrigation

GW Recharge

Optimal conditions

- High vertical hydraulic conductivity
- Low horizontal hydraulic conductivity

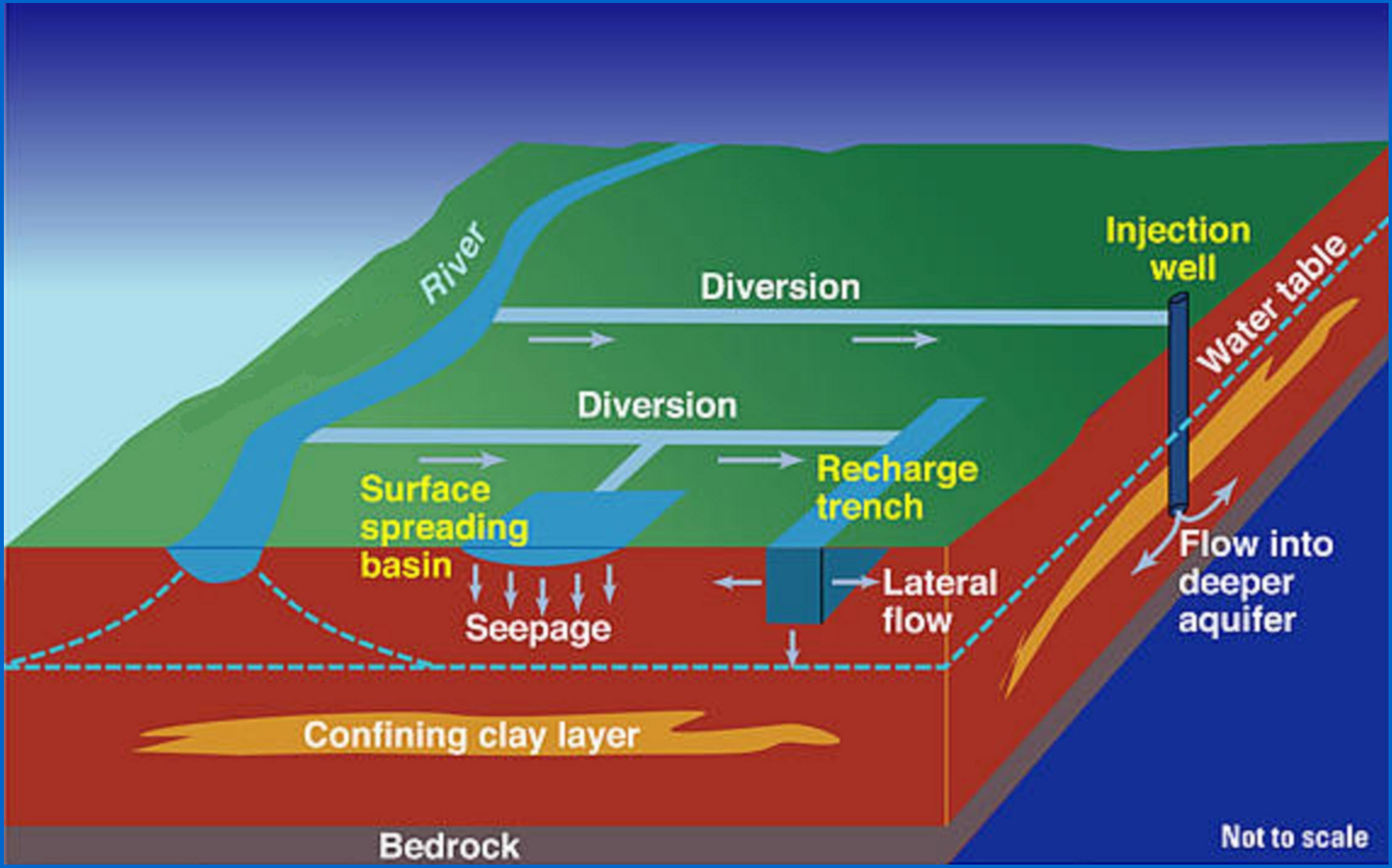
GW Recharge

- Deep method is important to prevent saltwater intrusion
- Basin method is applied when high vertical hydraulic conductivity occurs
- Problem related to the clogging, growth of bacteria and the accumulation of metabolites
- Advantage is the filtering effects of soil
- Channels and ditches are sensitive to silting, and the slope of such work cannot be too high for erosion and not too low for clogging

GW Recharge

Water quality is an essential point to decide what water treatment has to be used function of recharge objective and method.

Artificial Recharge Systems



Site Selection Factors

- soil types
- drainability
- depth
- distance to ground water
- groundwater movement
- slope
- underground formations
- degree of isolation from public

Criteria	Restrictions
Environmental	To avoid contamination by infiltration of reclaimed water or contact with humans, the following restrictions were considered: - A safety distance of 50 m away from water resources for irrigation; - A safety distance of 100 m away from water supply sources for human consumption, including adduction pipes and reservoirs; - A distance of 200 m way from urban residential areas.
Technical	- Annually available volume of reclaimed water; - Land use (the Corine Land Cover map was used to evaluate the potential land use of the studied area; all the bush areas were considered since are uncultivated areas that can be used for infiltration); - Slopes (infiltration should be preferably applied in agricultural parcels with slopes ranging between 0% and 12%, since higher slopes increase runoff, soil erosion and thus soil instability, which risks basin safety and increases refilling costs); - Soil texture (vadose zones should not contain clay layers or other soils that could restrict the downward movement of water and form perched groundwater mounds; to avoid soil clogging and to assure the SAT, the soil must have less than 10% of clay fraction); - Type of soil (the soil for reclaimed water infiltration should have the top section without soil rock; all soils were excluded except for Anthrosol, because they are soils with more than 1 m deep and have a texture such as fine sand that allows an infiltration rate of 1 m/d (most of the reclaimed water polishing occurs in the first 1 m of soil)); - Aquifer depth (aquifers should be sufficiently deep and transmissive to prevent excessive rises of the groundwater table due to infiltration. The minimum static groundwater level accepted for reclaimed water infiltration is 5 m in order to have a sufficient vadose zone for SAT).
Economic	Maximum distance of 8 Km: this criterion included water transfer costs from WWTP to the infiltration site, and the transport length should not exceed 8 Km.

The quality of the water of a recharged aquifer is a function of:

- the quality of the recharge water;
- the recharge method used;
- the physical characteristics of the vadose zone and the aquifer layers;
- the water residence time;
- the amount of blending with other sources;
- the history of the recharge.

Water Quality Issues

- microbiological risks;
- presence, concentration and health significance of pathogens and toxic substances in recycled water by region.
- fate of micro-pollutants, including pathogens in the soil and underlying geological formations;
- residence times (using models),
- extraction distances and chlorination alternatives;
- soil and aquifer attenuation.

Questions raised about retained pollutants include the following:

- Is there a risk that the pollutants may appear in the abstracted water due to changes in the physical and chemical conditions prevailing in the aquifer or due to limited adsorption capacities?
- How long can microorganisms survive?
- To what extent are toxic pollutants degraded?

Relative Risk (Bahman Sheikh, 2003)

- ✓960,000 Americans Die from Cardiovascular Disease (Eating Fatty Foods), Each Year
- ✓ 430,000 Americans Die from Smoking-Related Causes, Each Year
- ✓ 42,000 Americans Die in Car Accidents, Each Year
- ✓ 22,000 Americans Are Killed with Guns, Each Year
- ✓ 3,160 Americans Die from Coal Lung Disease Each Year
- ✓ 0 (Zero) Americans Have Ever Died From Exposure to Recycled Water

Recommended Guidelines for Water Reuse in the Mediterranean Region (Bahri and Brissaud, 2002) (continuous)

Water category	Quality criteria: Microbiological – Intestinal nematode[a] (no. eggs per liter)	Microbiological – FC or *E. coli* [b] (cfu/100 mL)	Physical-chemical SS [c] (mg/L)	Wastewater treatment expected to meet the criteria
Category IV				
a) Irrigation of vegetables guaranteeing absence of contact between reclaimed water and edible part of vegetables. b) Irrigation of crops in category III with drip irrigation (such as drip, bubbler, micro-sprinkler and subsurface). c) Irrigation with surface with drip irrigation of greenbelts and green areas with no access to the public. d) Irrigation of parks, golf courses, sport fields with sub-surface irrigation systems.	None required	None required	Pretreatment as required by the irrigation technology, but not less than primary sedimentation	
Category V				
Groundwater recharge: a) Surface spreading into non-potable aquifers	-	None required	≤ 35	Secondary treatment or equivalent (g)
b) Surface spreading into potable aquifers	-	≤ 1000(d)	≤ 20	Secondary treatment or equivalent (g) + filtration + disinfection
c)Direct injection	No detectable	No detectable	< 5	Advanced wastewater treatment processes in order to meet drinking water maximum contaminant levels

Jordan

Table 8. Jordanian Standard (JS: 893/2002) for discharge to streams, storage

Parameter	Unit	Discharge to streams, wadis and water storage areas	Ground water recharge
Group A			
BOD_5	mg/L	60.0[a]	15.0
COD	mg/L	150.0[b]	50.0
DO	mg/L	> 1.0	> 2.0
TSS	mg/L	60.0[b]	50.0
pH	unit	6.0–9.0	6.0–9.0
Turbidity	NTU	–	2.0
NO_3	mg/L	45.0	30.0
NH_4	mg/L	-	5.0
T-N	mg/L	70.0	45.0
E. coli	MPN/100 mL	1000.0	< 2.2
Intestinal helminth eggs	egg/L	≤ 1.0	≤ 1.0
FOG	mg/L	8.0	–
Group B			
Phenol	mg/L	< 0.002	< 0.002
MBAS	mg/L	25.0	25.0
TDS	mg/L	1500.0	1500.0
Total PO_4	mg/L	15.0	15.0
Cl	mg/L	350.0	350.0
SO_4	mg/L	300.0	300.0
HCO_3	mg/L	400.0	400.0
Na	mg/L	200.0	200.0
Mg	mg/L	60.0	60.0
Ca	mg/L	200.0	200.0
SAR	mg/L	6.0	6.0
Al	mg/L	2.0	2.0
As	mg/L	0.05	0.05
Be	mg/L	0.1	0.1
Cu	mg/L	0.2	0.2
F	mg/L	1.5	1.5
Fe	mg/L	5.0	5.0
Li	mg/L	2.5	2.5
Mn	mg/L	0.2	0.2
Mo	mg/L	0.01	0.01
Ni	mg/L	0.2	0.2
Pb	mg/L	0.2	0.2
Se	mg/L	0.05	0.05
Cd	mg/L	0.01	0.01
Zn	mg/L	5.0	5.0
Cr	mg/L	0.02	0.02
Hg	mg/L	0.002	0.002
V	mg/L	0.1	0.1
Co	mg/L	0.05	0.05
B	mg/L	1.0	1.0

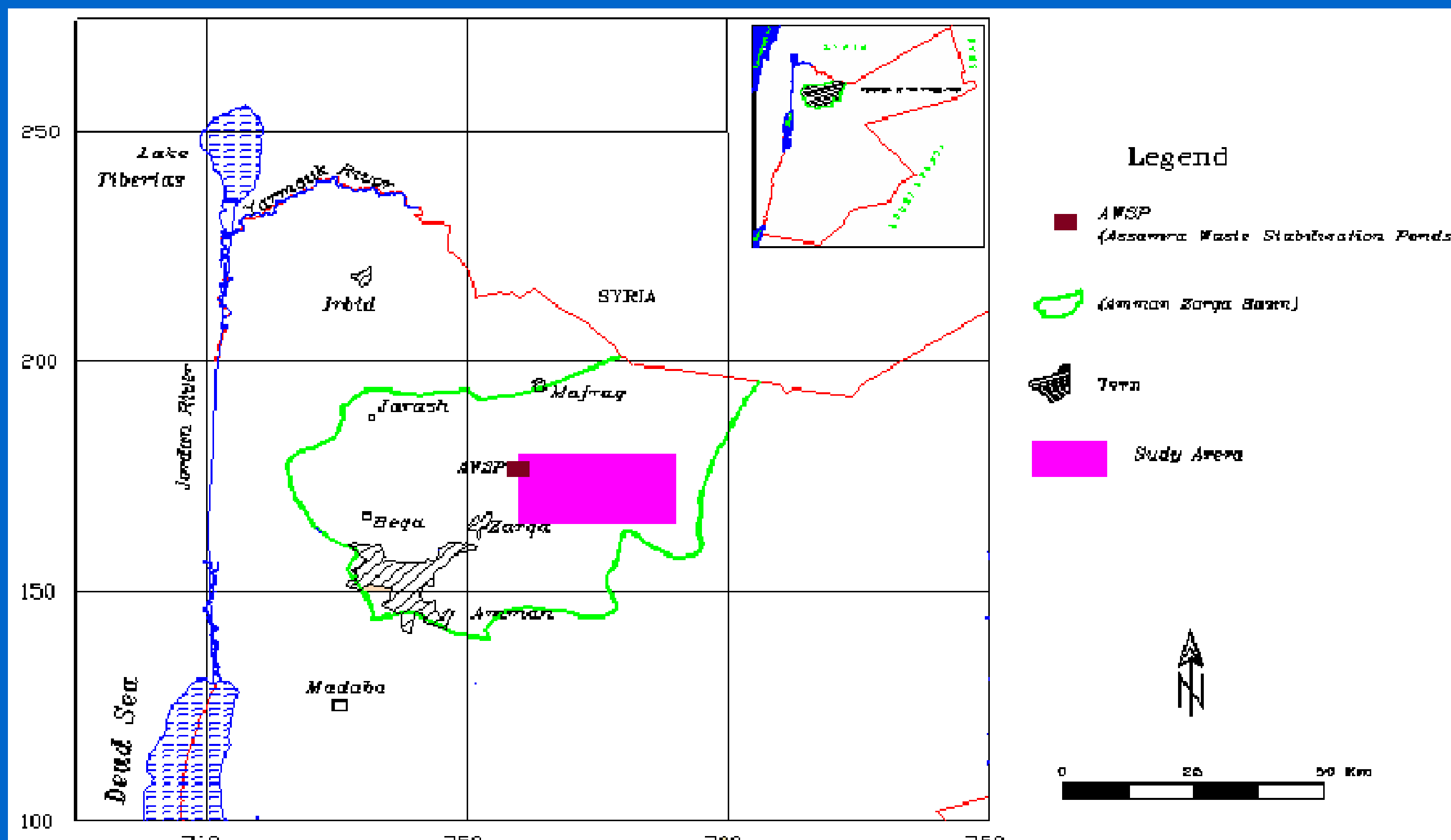
[a]: BOD_5 measured as soluble for waste stabilization ponds effluents and those with polishing ponds and as total for all others.

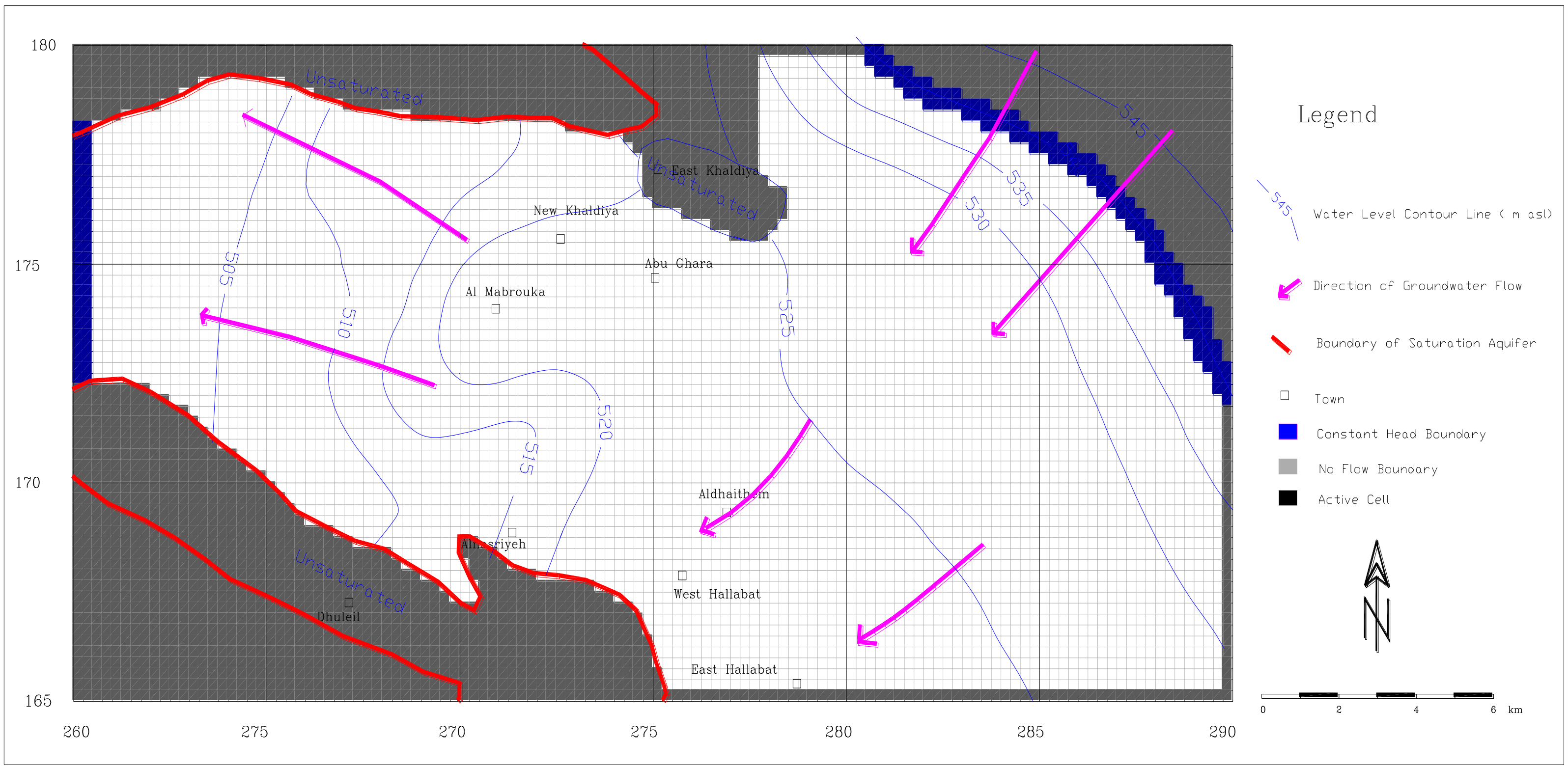
[b]: Twice this value may be allowed for effluents of waste stabilization ponds and those with polishing ponds.

Recommended Guidelines by the Palestinian Standards Institute for Treated Wastewater Characteristics according to groundwater recharge

Quality Parameter (mg/l)		Quality Parameter (mg/l)	
BOD5	60	Al	5
COD	200	Ar	0.1
DO	> 0.5	Cu	0.2
TDS	1500	F	1
TSS	50	Fe	5
pH	6 – 9	Mn	0.2
Color (PCU)	Free	Ni	0.2
		Pb	1
FOG	5	Se	0.02
Phenol	0.002	Cd	0.01
MBAS	15	Zn	2
NO3-N	50	CN	0.05
NH4-N	-	Cr	0.1
O.Kj-N	50	Hg	0.001
PO4-P	30	Co	0.05
Cl	500	B	0.7
SO4	500	FC (CFU/100 ml)	1000
Na	200	Pathogens	Free
Mg	60	Amoeba (Cyst/L)	-
Ca	400	Nematodes (Eggs/L)	< 1
SAR	9		
Residual Cl2	-		

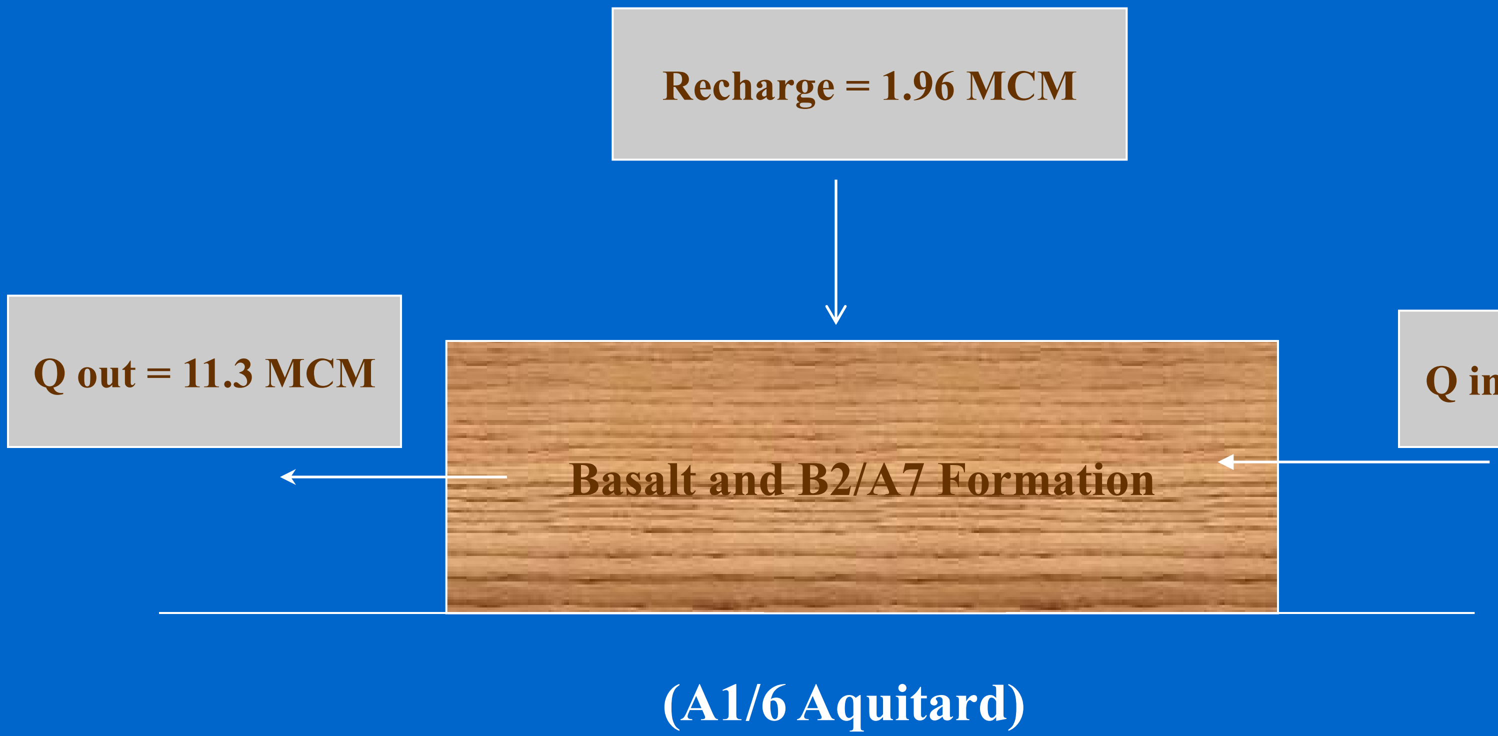
Dhuleil Area/ Amman-Zarqa Basin
(E. Shawaqfah, 2005)





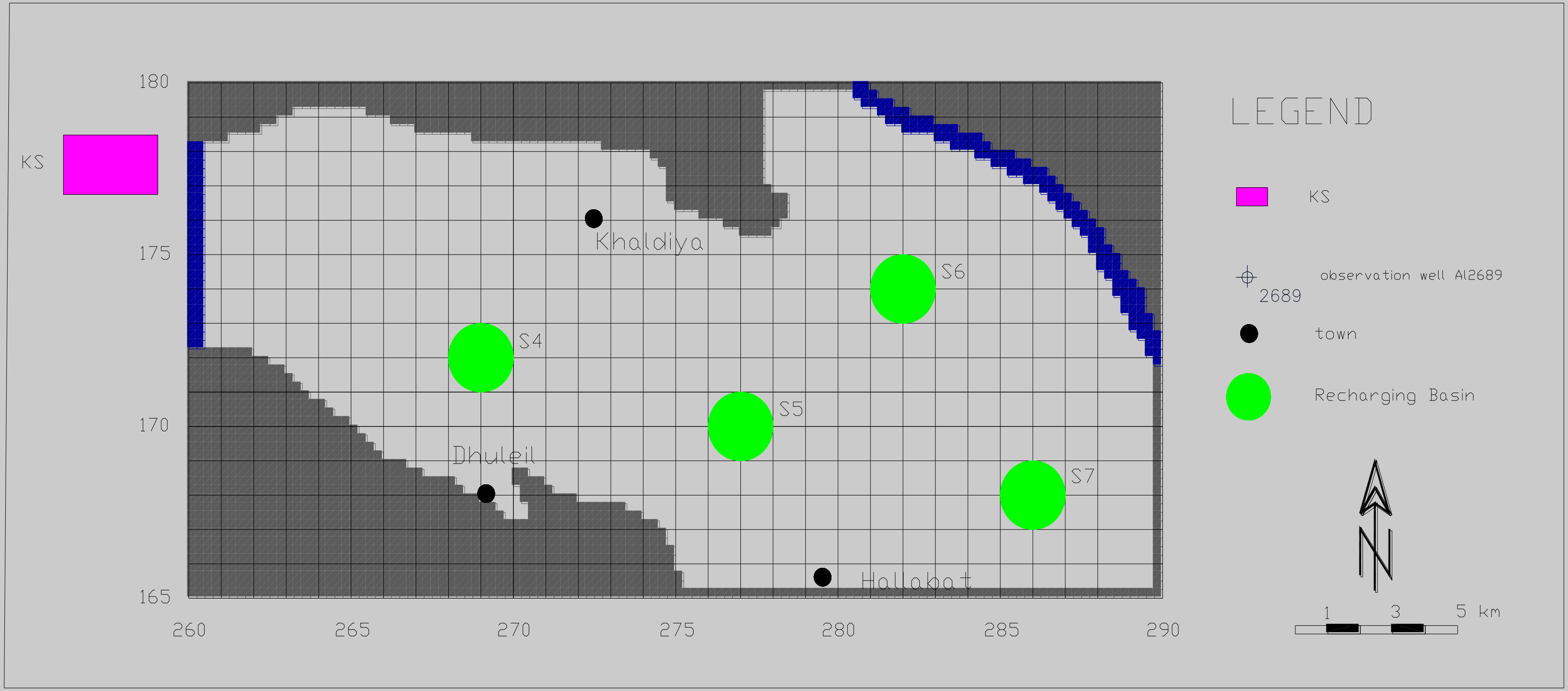
180
175
170
165
260
275
270
275
280
285
290
Unsaturated
Unsaturated
Unsaturated
East Khaldiya
New Khaldiya
Abu Ghara
Al Mabrouka
West Hallabat
East Hallabat
Dhuleil
505
510
515
520
525
530
535
545
Legend
Water Level Contour Line (m asl)
Direction of Groundwater Flow
Boundary of Saturation Aquifer
Town
Constant Head Boundary
No Flow Boundary
Active Cell
N
0
2
4
6
km

Water Balance of the model domain at the steady state conditions

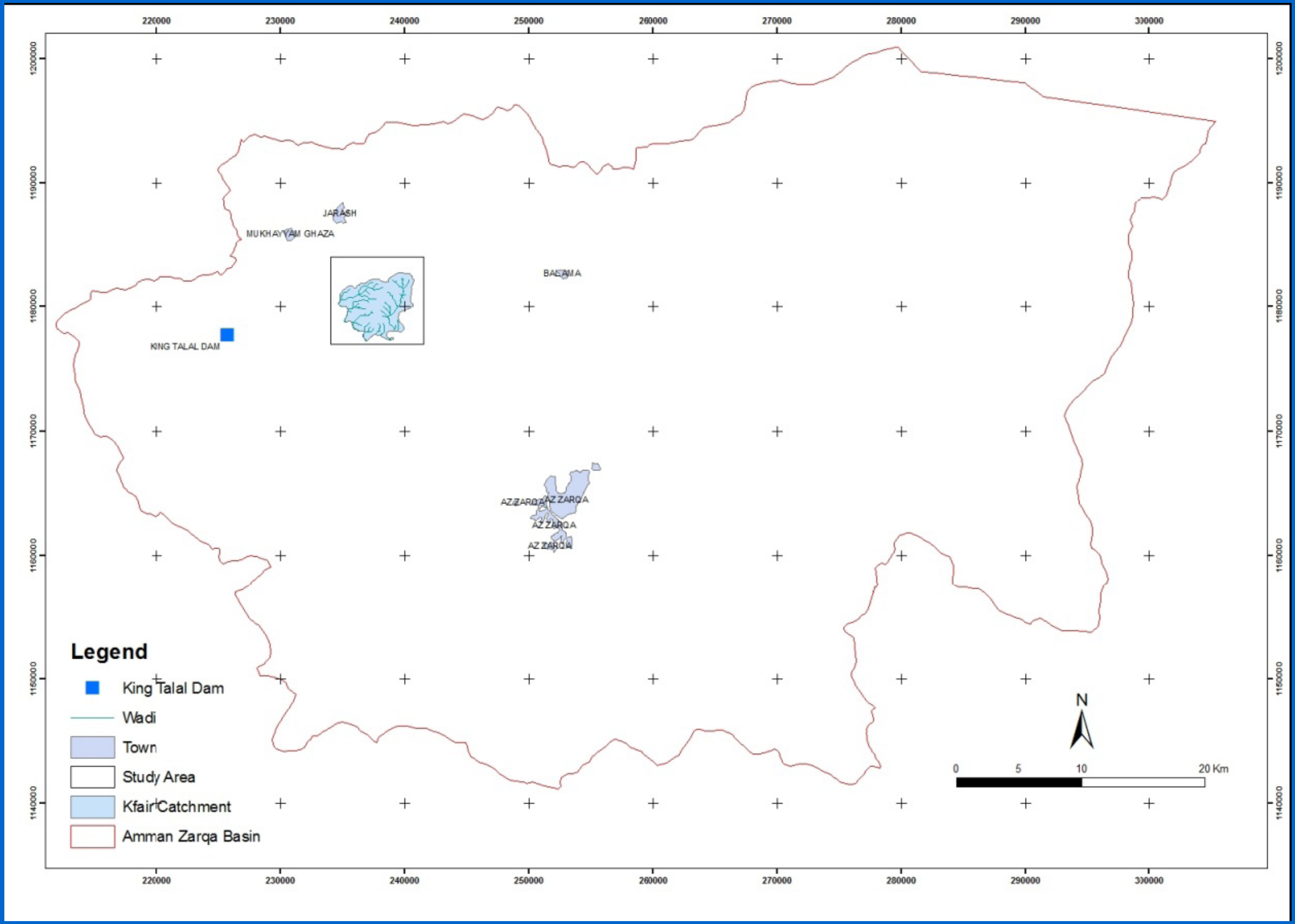


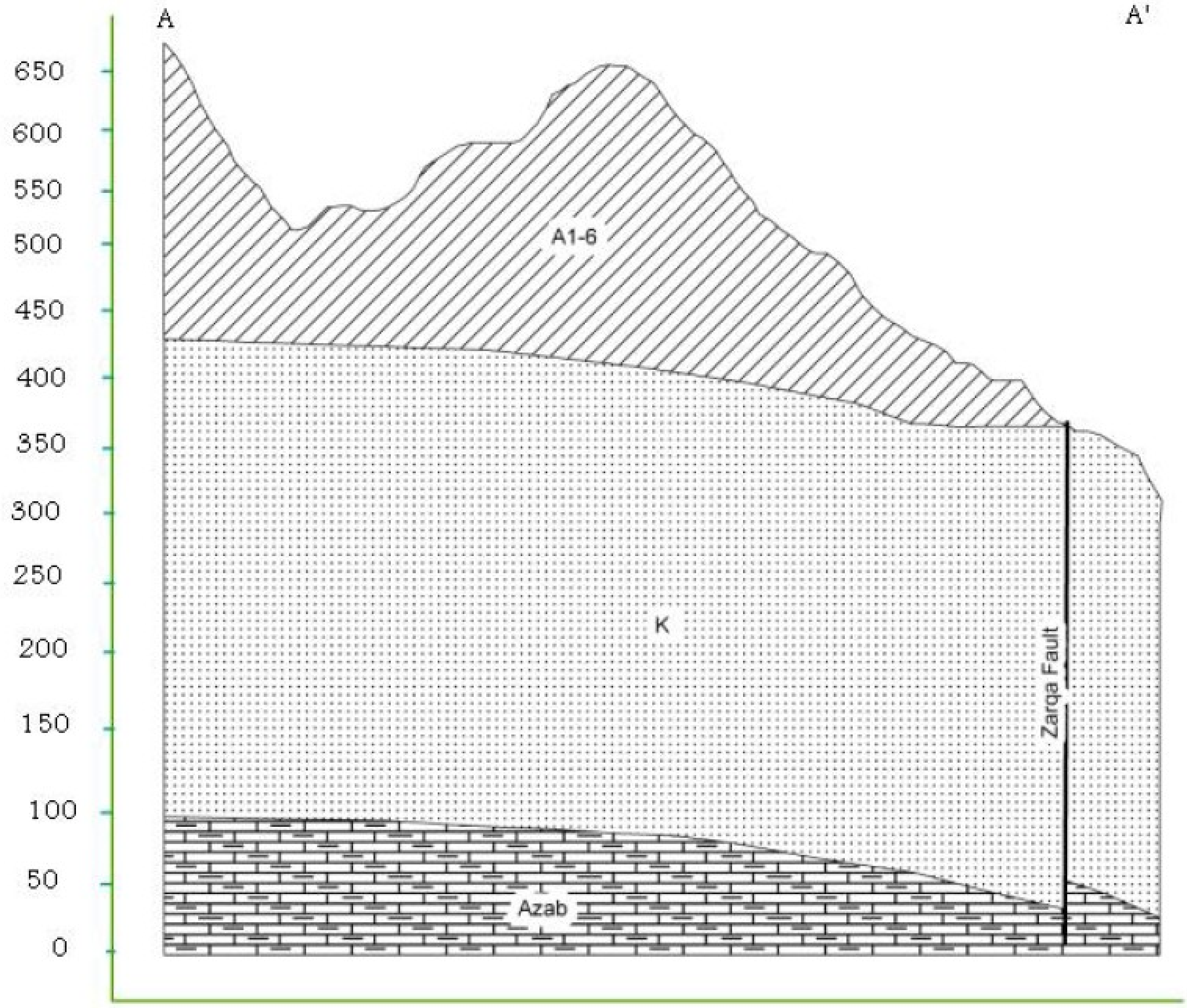
LEGEND
Inactivecell
Constant Head
Hydraulic Head
N
1 3 5 km
180
175
170
165
260
265
270
275
280
285
290
505
510
515
525
535
500

Proposed Recharging Basin Location's Map

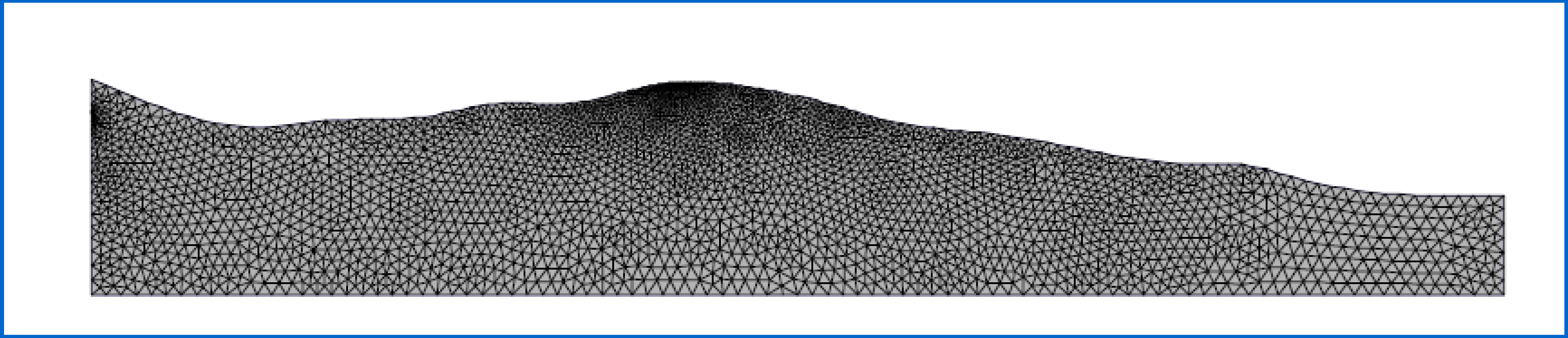


Piloting and Strengthening Adaptation Capacity to Climate Change in the Zarqa River Basin





A
A'
650
600
550
500
450
400
350
300
250
200
150
100
50
0
A1-6
K
Zarqa Fault
Azab



Ammonium (225 mg/L).

The model domain is assumed to be free of contaminant (i.e. C(t=0,X,Z)= 0.0).

The result of the tenth year simulation showed that:

- ✓ The plume of ammonium extended a round 178 m below Al-Kfair town .
- ✓ The Maximum concentration for Nitrite was 1.632 mg/L at 130.68 m below Al-Kfair town and the nitrite plume extended about 170.82 m below Al-Kfair town.
- ✓ The Maximum concentration for Nitrate was $9.68*10^{-2}$ mg/L at 131.48 m below Al-Kfair town and the nitrate plume extended about 130.7m below Al-Kfair town.
- ✓ Figure 4.7 through 4.9 show the show the Ammonium, Nitrite and Nitrate concentration after ten years.

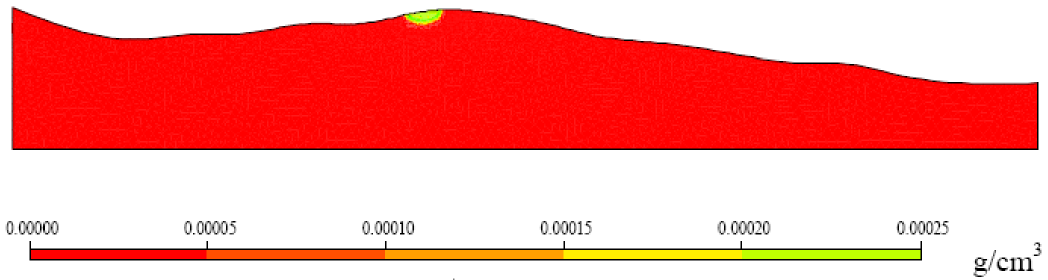


Figure 4.1: Hydrus-2D simulated NH_4^+ plumes developed under the impact septic tank systems of Al-Kfair (results at 1 year).

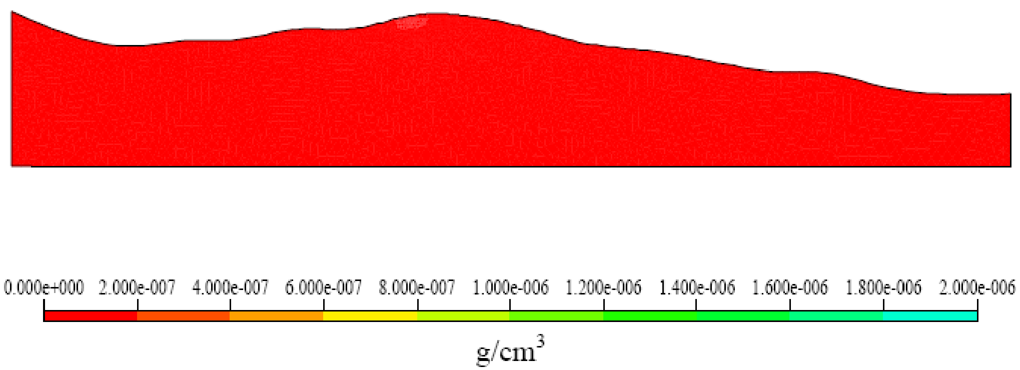


Figure 4.2: Hydrus-2D simulated NO_2^- plumes developed under the impact septic tank systems of Al-Kfair (results at 1 year).

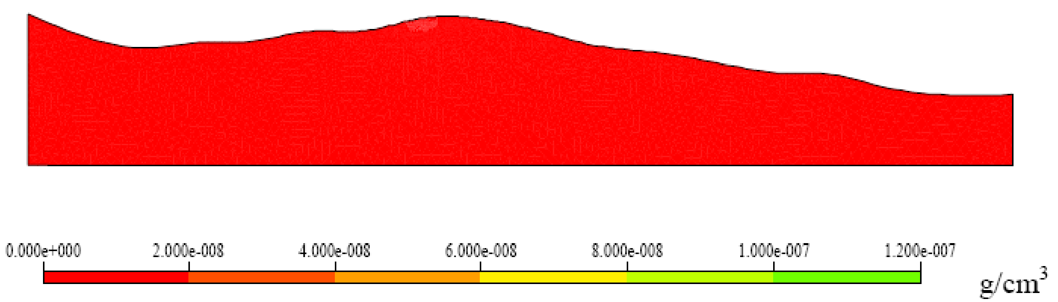


Figure 4.3: Hydrus-2D simulated NO_3^- plumes developed under the impact septic tank systems of Al-Kfair (results at 1 year).

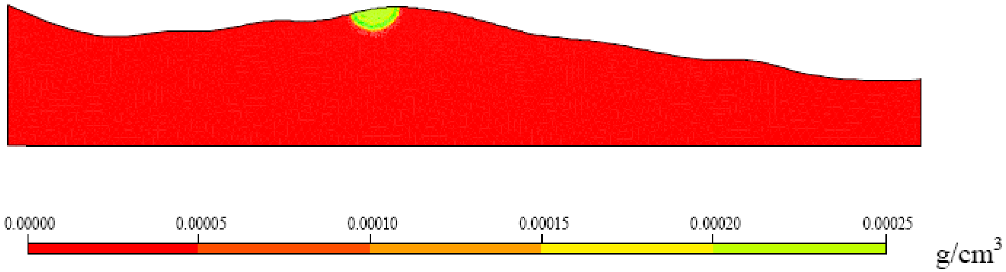


Figure 4.4: Hydrus-2D simulated NH_4^+ plumes developed under the impact septic tank systems of Al-Kfair (results at 5 years).

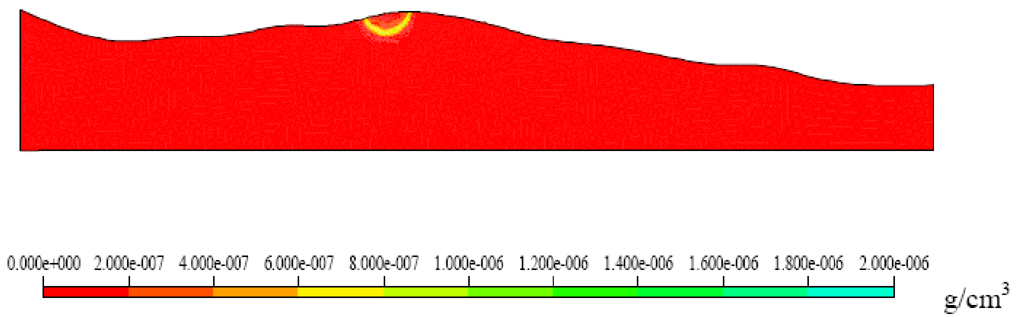


Figure 4.5: Hydrus-2D simulated NO_2^- plumes developed under the impact septic tank systems of Al-Kfair (results at 5 years).

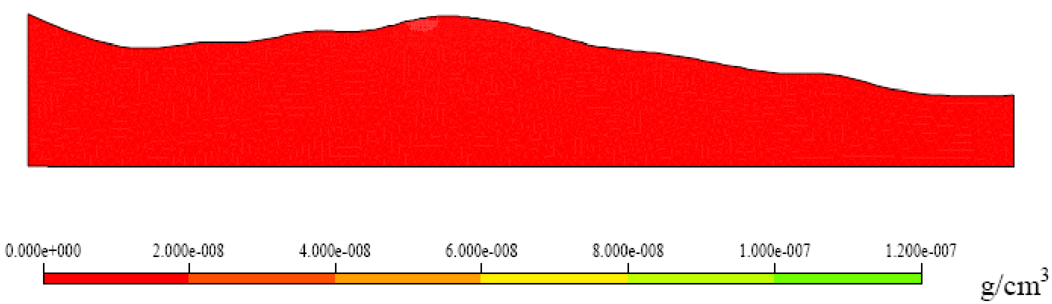


Figure 4.6: Hydrus-2D simulated NO_3^- plumes developed under the impact septic tank systems of Al-Kfair (results at 5years).

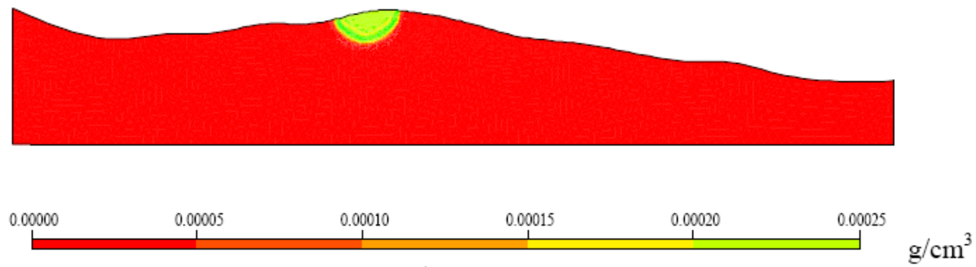


Figure 4.7: Hydrus-2D simulated NH_4^+ plumes developed under the impact septic tank systems of Al-Kfair (results at 10 years).

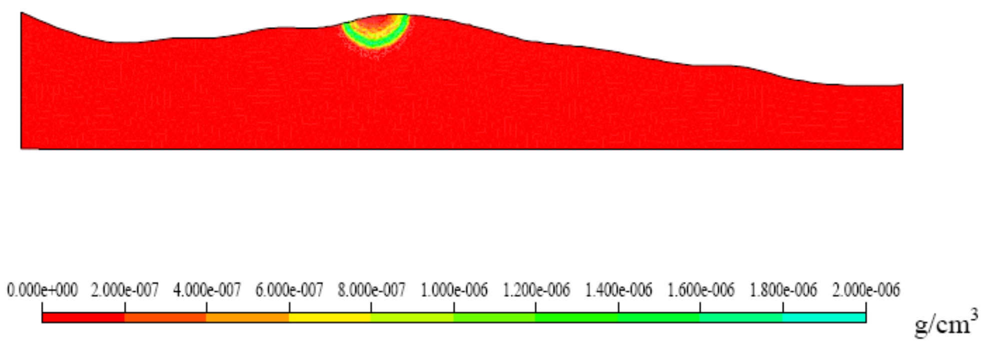


Figure 4.8: Hydrus-2D simulated NO_2^- plumes developed under the impact septic tank systems of Al-Kfair (results at 10 years).

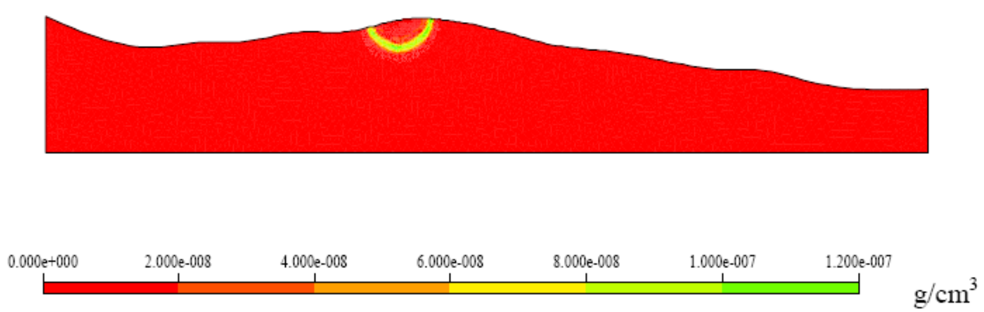


Figure 4.9: Hydrus-2D simulated NO_3^- plumes developed under the impact septic tank systems of Al-Kfair (results at 10 years).

% of people who would drink reclaimed water

Personal attitude	Direct via pipe	Indirect via aquifer (MAR)
Would drink		
Uncertain		
Would **not** drink		

Public Acceptance

% of people who would drink reclaimed water

Personal attitude	Direct via pipe	Indirect via aquifer (MAR)
Would drink	13	31
Uncertain	43	51
Would **not** drink	44	18

Thanks for your time