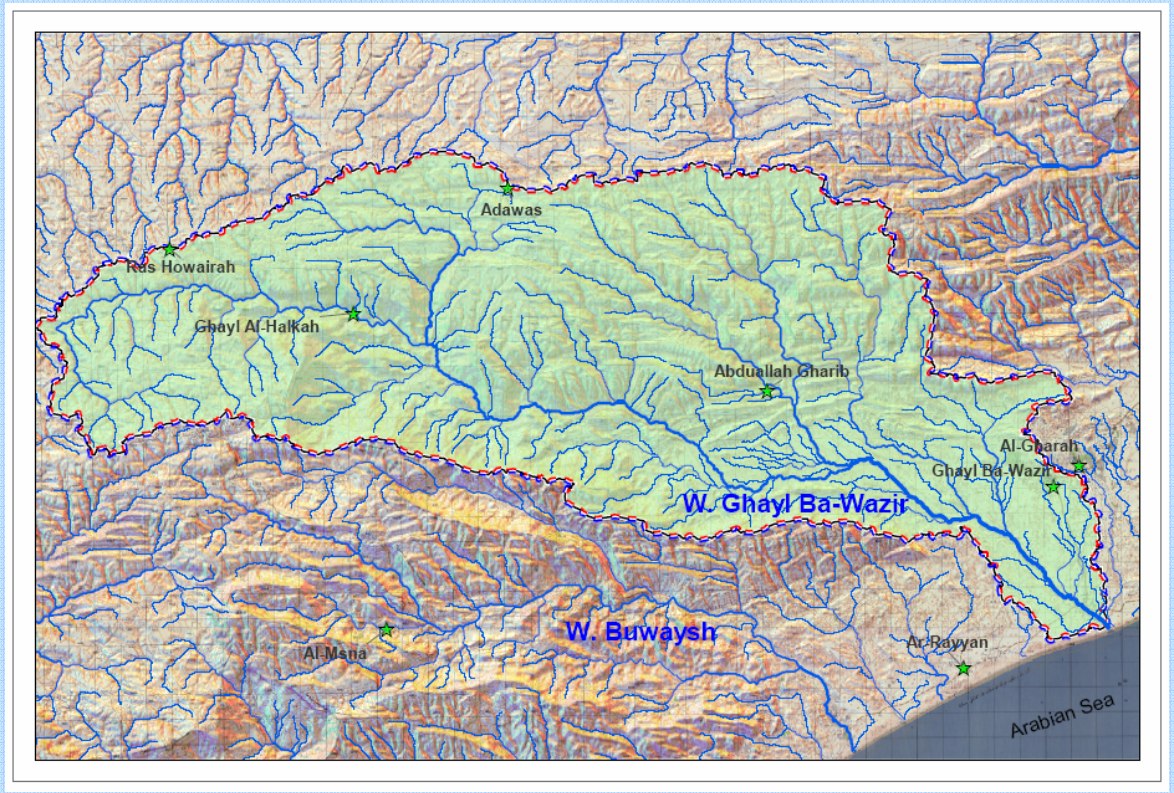
Republic of Yemen
Ministry of Water & Environment
National Water Resources Authority

DELINEATION OF GROUNDWATER PROTECTION ZONES FOR THE GHAYL BA-WAZIR MUNICIPAL WELLS



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National Programme on Integrated Water Resources Management

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NATIONAL WATER RESOURCES AUTHORITY (NWRA)

UNITED NATIONS PROGRAMME: SUSTAINABLE HUMAN DEVELOPMENT

DELINEATION OF GROUNDWATER PROTECTION ZONES FOR THE GHAYL BA-WAZIR MUNICIPAL WELLS

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EXECUTIVE SUMMARY

Groundwater protection zones should be defined in order to prevent or decrease the risk of contamination of groundwater resources by chemicals and organisms hazardous to human health. The entire area to be protected around public water well should be classified into different zones depending on the potential contamination risk that usually decreases with the distance of the activity contributing to groundwater contamination from the production well. The delineation of the protection zones has to be done taking into account the competing interests of different water users

The size of the Immediate Protection Zone (Zone I) is recommended to be at least 15 m in all directions of the operating municipal well. The area of Zone I should be entirely fenced and an access is allowed only to authorized persons. No activities are allowed except those needed to operate the well.

The size of the Inner Protection Zone (Zone II) is calculated based on the following assumptions:

1. Because the municipal wells are situated very close to each other, Zone II would be delineated for all operating wells taken together as a single cluster of wells which is operating with a combined yield equals to the sum of yields of all currently operating wells.
2. An average gradient of groundwater flow is estimated from the Groundwater Contour Map. The map was constructed based on the static water level measurements collected by the NWRA/Seyun team during the very recent well inventory.
3. Due to high uncertainties concerning the hydraulic parameters and the design of operating wells, the size of Zone II is calculated based on the average parameters adopted from the previous studies.

In the vicinity of the operating LCWSS wells the Outer Protection Zone (Zone III) incorporates all zones I and II. Southward Zone III extends a distance of around 4 km from the operating wells to include the entire catchment area with the exception of the uppermost part of the mountain range.

An additional major task of the actual study is to recommend adequate protection measures to be implemented in cooperation with the local administration of Ghayl Ba-Wazir.

LIST OF ABBREVIATIONS

EC	Electrical conductivity (of groundwater)
LCWSS	Local Corporation for Water Supply and Sanitation in Hadhramawt Governorate – Coastal Areas
masl	Meters above sea level
l/s	Liters per second
MWE	Ministry of Water and Environment, Yemen
NWRA	National Water Resources Authority, Yemen

Contents

1. INTRODUCTION

An access to good quality water is a fundamental human right, almost a “right to life” issue because clean drinking water plays a crucial role in the health of a community. Community access to clean drinking water can be improved by protecting water sources from contamination. Water quality protection should not be a bureaucratic issue, but rather a practical regulatory action towards maintaining quality of public water sources.

All water that seeps into the ground is contaminated to some extent even before entering the saturated subsurface environment. Rainwater picks up carbon dioxide, minerals, bacteria and inorganic contaminants from the atmosphere and soil. Once in the ground, any water percolating downward picks up additional bacteria, viruses and other pollutants. Also, pesticides, herbicides, fertilizers, industrial solvents and toxic chemical residues can heavily contaminate water seeping through soils on cultivated lands, urban territories, solid waste disposal sites or near certain industries. Percolation of wastewater from primitive septic systems (cesspools) also poses a serious threat to groundwater quality.

However, groundwater is in general much more naturally protected from contamination than surface water due to chemical and biological processes which take place in the unsaturated zone. Those processes lead to a retardation, adsorption or degradation of many substances hazardous to ground water. The protection of groundwater from contamination is of critical importance because the rehabilitation of a contaminated aquifer is very complicated in technical, financial and administrative aspects.

Groundwater protection zones should be defined in order to prevent or decrease the risk of contamination of groundwater resources by chemicals and organisms hazardous to human health. The entire area to be protected around public water well should be classified into different zones depending on the potential contamination risk that usually decreases with the distance of the activity contributing to groundwater contamination from the production well. The delineation of the protection zones has to be done taking into account the competing interests of different water users:

- The zones should be as large as necessary for a safeguarding the public water source;
- The zones should be as small as possible for avoiding inadequate inconveniences for local farmers.

In order to provide uniformity between different NWRA documentation, the guidelines recently prepared by NWRA for a delineation of protection zones [2, 3] were used as the theoretical basis for the present study.

An additional major task of the actual study is to initiate adequate protection measures to be implemented in cooperation with the local administration of Ghayl Ba-Wazir.

2. GENERAL CLASSIFICATION OF THE GROUNDWATER PROTECTION ZONES

Protection zones are defined in order to prevent and eliminate contamination of groundwater resource by chemicals, organic matter and bacteria potentially hazardous to human health. Therefore, areas intended for the groundwater protection should normally comprise the entire catchment area of a well (or a group of wells) producing groundwater for the drinking supply. Protection areas should be classified to reflect the different risks implied by man-made activities contributing to groundwater contamination as a function of the type, the place and the duration of the activity. Restrictions on the land-use in the different protection zones should also reasonably reflect different risk potentials. A risk potential normally decreases as the distance of the activity from the well increases in conditions of homogeneous groundwater flow pattern without preferential flow directions. For this type of aquifers (unconsolidated or fractured) the travel time is the main factor for the delineation of the protection zones. In karst aquifers – that is the case in the project area - the vulnerability of the aquifer system upstream of the production well should be analyzed for the establishment of the protection zones.

A system of three protection zones is widely accepted in many countries based on the principle of the general protection of groundwater from pollution (Figure 1):

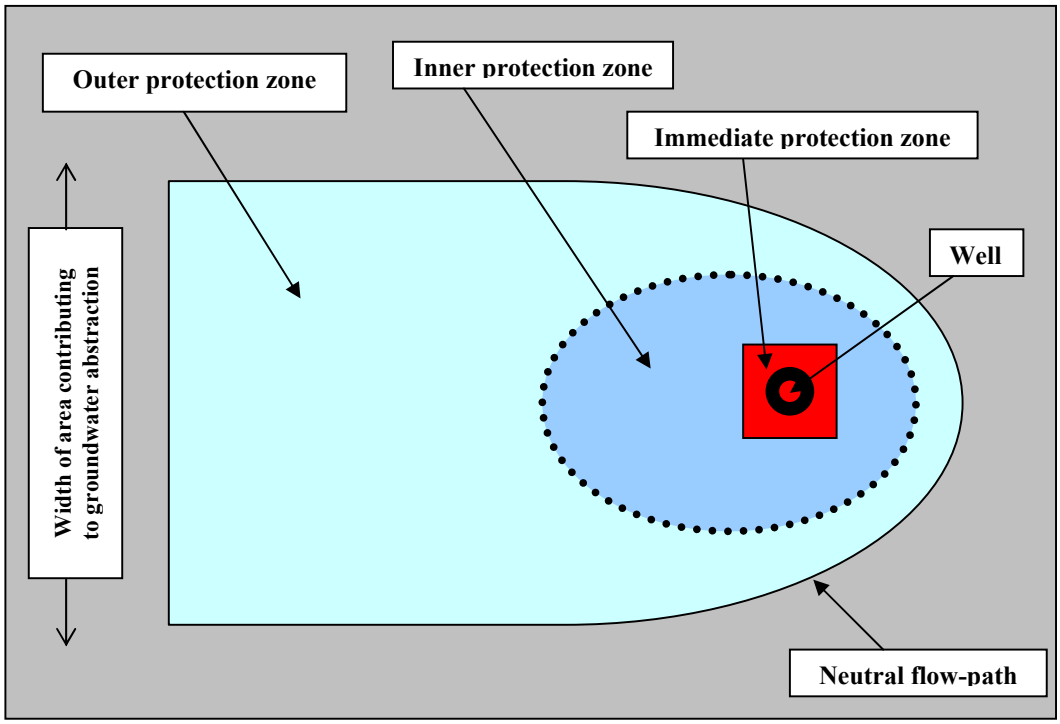

Figure 1. General Zoning System

Outer Protection Zone (Zone III)

This zone protects groundwater from contamination affecting water over long distances such as contamination by the chemicals which are non- or hardly degradable.

Zone III should normally extend to the boundary of the sub-catchment area. Areas from which surface water is drained into the subsurface catchment area are included in Zone III. For groundwater flow velocities of 10 m/d or less (in the case of porous or finely fissured aquifers), the boundary of the outer protection zone should be defined approximately 2 km upstream of the well. In the case of uncovered karstic aquifers with high groundwater flow velocities, Zone III may not be subdivided, if the time required for groundwater from the top of the catchment area to flow to the well is less than 50 days and the catchment area have, therefore, be classified as Zone II.

Inner Protection Zone (Zone II)

Zone II protects groundwater from contamination by pathogenic microbiological constituents such as bacteria, viruses, parasites and worm eggs and from other contamination which may be hazardous as far as it occurs at a short distance from the well.

The inner protection zone should comprise the area between the well and a line from which the groundwater will flow at least 50 days until it reaches the production well. This minimum flow time will usually ensure that no pathogenic constituents will reach the production well.

The line from which groundwater takes 50 days to flow to the well are determined by geohydraulic methods, such as numerical modeling or simple mathematical approximation methods based on the Darcy Law and the Dupuit-Thiem steady radial flow equation [2,3]. To determine the 50 days line and the lower culmination (stagnation point), the average daily discharge of the operating well should be taken into consideration. The extension of Zone II should in no case be less than 100 m.

For a karstic aquifer, Zone II would often comprise the entire catchment area or most of it and should incorporate the following areas of a potential hazard to groundwater:

- Slopes of dry valleys declining towards the catchment area. Upstream length of Zone II should be at least 300 m from the production well;
- Karstic basins and sinks and their immediate environment;
- Areas in which karstic aquifers are excavated;
- Outcropping fault areas.

The boundaries of Zones II and III should follow (where possible) roads, tracks, property lines and other landmarks.

Immediate Protection Zone (Zone I)

Zone I protects the production wells and their immediate environment from any possible contamination. The immediate zone should extend over a distance of not less than 10 m around the well if groundwater level occurs at a depth not less than 50 m below ground or 15 m for a shallow groundwater occurrence.

It is worth stressing that the delineation of the inner and outer zones is usually based on considerable uncertainties due to a poor knowledge of many of the required parameters which usually are highly variable or uncertain, including the geometry of the aquifer system, groundwater recharge, abstraction, aquifer parameters and hydraulic boundary conditions. In general terms, the extent of the inner and outer protection zones should be established to be as small as possible to avoid unnecessary restrictions, but, on the other hand, it should be large enough to guarantee the protection of the resource from potential contamination.

Each of the three protection zones requires a number of different restrictions to land use and human activities. The listings of hazardous activities can be found in many national and international guidelines as well as in some relevant Yemeni regulations listed in the following chapter.

3. NATIONAL LEGAL AND INSTITUTIONAL FRAMEWORK RELATED TO THE GROUNDWATER PROTECTION ZONES

The issue of a water protection relies on the Water Law No. 33 for the year 2002 (with amendments stated in the Law No. 41 for the year 2006). The law sets forth a general task of water resources protection from depletion and pollution (Article 3), the administrative regulations and responsibilities (Article 54), and the legal consequences/penalties in a case of contamination of water resources (Article 69). The details of the establishment of groundwater protection zones are regulated by by-laws – which need to be prepared or updated based on the Water Law amendments - and Cabinet Decrees as well.

In accordance with the Water Law, the Ministry of Water and Environment (MWE) has the mandate to protect the water resources from contamination and to conserve their standard quality. The following responsibilities are assigned by the law to the MWE in the context of the water quality protection (Article 54):

- To close down (in coordination with the concerned agencies and after an approval of the Council of Ministers) the industries which dispose wastes without licenses or in contradiction with the issued license together with obliging these industries to pay compensations against any damages.
- To organize (on the basis of the by-law to be prepared in cooperation with the concerned agencies) the disposal of industrial wastes, use of agricultural fertilizers, pesticides and other substances which are hazardous to water resources and environment.

- To select locations for solid waste disposals, landfills and areas for a disposal of liquid wastes and effluents and to classify damages this could be caused by harmful activities.

The National Water Resources Authority (NWRA) is the governmental institution acting under the umbrella of the MWE with the general aim to propose a national water strategy as stipulated by the Water Law (Article 7). With the issuance of the Republican Decree No. 22 in 2005, the institutional structure of NWRA (primarily regulated by the Republican Decree No. 154 of 1995) is gradually becoming more balanced and coordinated. The following responsibilities are assigned by the Water Law to the NWRA in the context of the water quality protection:

- To approve general technical specifications for: (1) drilling of water wells; (2) sites and general design of irrigation and water structures, including wastewater and desalination plants; (3) *protected areas* of wells, floods and springs; (4) drilling rigs, materials and well casing; (5) pumps; and (6) facilities of a transmission and distribution of water for drinking purpose (Article 46). The by-law will be issued to identify these technical standards and specifications.
- To propose and submit to the MWE the definitions of the *restricted areas* in which well drilling or deepening, construction of any facilities, expansion or development of industrial activities or expansion agricultural lands, or any other activities which will adversely affect the water resources are to be prohibited. The decree shall identify the geographical boundaries of each area, the restriction period and executive procedures (Article 49).
- To identify the areas of groundwater recharge where the disposal of any waste is prohibited as well as other activities which may adversely affect groundwater quality (Article 54, paragraph 2).
- To issue orders and instructions concerning industrial waste disposals (Article 54, paragraph 4-a).
- To identify (after the approval of the MWE) the *areas protected from industries* whose effluents pose a threat to water resources. The by-laws will identify relevant protection conditions and standards (Article 54, paragraph 4-b).

Article 69 of the Water Law states that the contamination of water resources or deterioration of its quality without having a prior license is a punishable act leading to an imprisonment or the imposture of a fine. According to Article 71, paragraph 3, a penalty of imprisonment or a fine will be imposed on whosoever distributes water for drinking purpose and household consumption without carrying out regular chemical analyses of water samples and providing the NWRA with the results of these analyses.

In 2001-2002, the four national water quality standards have been introduced:

1. Yemeni Quality Standard No. 100/2000: Bottled Drinking Water;

2. Yemeni Quality Standard No. 109/2000: Drinking Water;
3. Yemeni Quality Standard No. 149/2001: Industrial and Commercial Wastewater; and
4. Yemeni Quality Standard No. 150/2001: Irrigation Water.

Until the appropriate executive by-law has been issued through the Cabinet resolution following approval of the Council of Ministers, the general approach to the establishment of groundwater protection zones is currently regulated by the Cabinet Decree No. 343 for the year 2002. The Decree does not allow drilling new deep wells or deepening existing wells within the water protection zones. It allows, however to drill new wells, or to deepen the existing wells intended for drinking purpose, to deepen the existing agricultural wells or to drill substitute wells for agricultural purposes provided that the old well has been closed or is used by NWRA for monitoring. The Decree specifies that the above drilling activities are allowed in conditions when appropriate license has been obtained from NWRA. Such a license will be granted only when NWRA specifies that a new or deepened well will not affect negatively nearby existing wells. The Decree also enables NWRA to register potential pollution sources such as industries and waste disposals. However, this regulation does not include the general guideline for a delineation of the protection zones and a detailed listing of hazardous activities contributing to groundwater contamination.

4. DESCRIPTION OF THE PROJECT AREA

The City of Ghayl Ba-Wazir is situated in the southern part of Hadhramawt Governorate in the midway between the mountain cliff and the sea (Figure 2). The area is traditionally known for its abundance of groundwater although water quality is highly variable. Wells tap a series of geological formations. Agricultural wells tapping both the underlying Oligo-Miocene and alluvium while springs are issuing from the karstic Eocene limestone.

A number of sinkholes resulting from karstic dissolution of Rus formation gypsum and limestone are found to the northwest. The sinkholes appear to be developed along roughly east-west trending fracture sets within the Rus Formation. The main sinkhole is used largely for bathing with some water channeled south for agriculture.

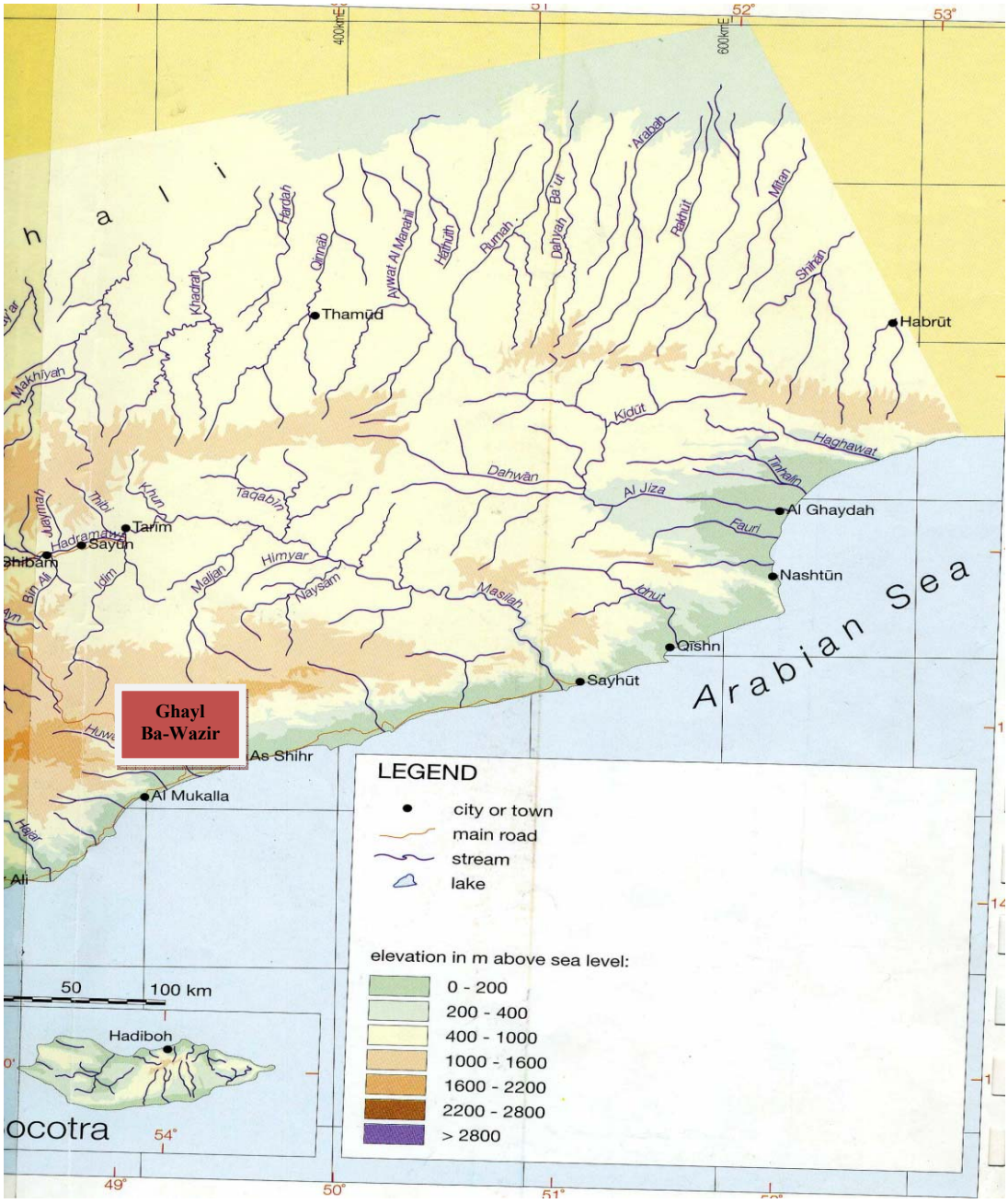

Figure 2. General Location Map of Ghayl Ba-Wazir

There are no significant industries in the city with the exception of a number of small enterprises involved in machinery servicing, fabrication and food processing. The municipal water supply system relies entirely on groundwater. The continuing pumping from the public wells caused a decline in groundwater level. As a result, the traditional irrigation system consisting of a set of underground channels diverted

spring water to cultivated lands has been collapsed because the groundwater level has declined lower than the position of the underground channels.

5. MUNICIPAL WELLS

Local Corporation for Water Supply and Sanitation (LCWSS) in Hadhramawt Governorate – Coastal Areas maintains a total of 29 municipal wells. Out of this amount, four wells are used for a monitoring of groundwater level, eight wells are currently not in use, and other seventeen wells supply drinking water to the urban population. Table 1 shows a summary of the data of the municipal (NWSA) wells available from the recent NWRA/Seyun well inventory [7]. General layout of the municipal wells is shown in Figure 3.

Hydrogeologically, the project area is complex and the presence of fresh groundwater to the north of Ghayl Ba-Wazir is related to faulting of permeable and karstic sediments up to 20 m thick. Old exploratory drilling works showed generally high transmissivities of nearly 1000m^2/day [4]. Since no observation wells were used, the calculated values of transmissivity are not very accurate. Under present conditions, however, there is no means to receive a better analysis results. The average effective porosity (=specific yield) of the alluvium and underlying Rus karstic rock units is estimated to be around 0.20.
The highly secondary nature of groundwater flow has prevented clear definition of the groundwater recharge to the target area.

The summary of chemical analyses of water samples collected by the LCWSS is shown in Table 2. The original chemical analyses are enclosed in Annex 1.

It is evident from the chemical analyses of water samples collected from the municipal wells that the total hardness of groundwater as well as concentrations of calcium and sulfate exceed the highest permissible limits of the national drinking water regulations (Yemeni Standard 109/2001). Also, the elevated fluoride concentration (1.56 mg/l) was detected at well A7. Water quality deterioration occurs after the groundwater encounter less permeable Tertiary lithologies. These cause slower groundwater movement and greater dissolution of the strata which contain significant gypsum. It is worth stressing that the available water-quality information is limited because the concentrations of sodium, potassium, toxic heavy metals and other potential contaminants have not been chemically analysed.

Table 1. Summary of municipal (LCWSS) wells

NWRA ID	LCWSS ID	Current status	UTM E	UTM N	Elevation	Depth, m	Yield, l/s	EC, µS/cm	pH	SWL, m Dec. 2009
G1-012	A9	Operating	323500	1637181	122	50	16.1			
G1-013	A11	Operating	323307	1637149	132	202	22.5	1841	7.2	
G1-014	A12	Operating	323397	1636932	122	200	21.7	1680	7.2	
G1-015	A10	Operating	323270	1636896	121	200	25.0	1800	7.2	
G1-016	A7	Operating	322949	1636815	181		14.5	1702	7.2	
G1-017	A13	Operating	322220	1636738	117	200		2260	7.0	
G1-031		Operating	321710	1636930	116	95	23.5	2390	7.7	
G1-032	AN2	Operating	322566	1636987	136	101	16.1	1684	7.6	
G1-033	AN4	Operating	322391	1636787	119		21.7	1950	7.8	
G1-034		Operating	322284	1637029	127	100	20.4	1594	7.9	
G1-035	AN14	Operating	321900	1637130	130	93	21.7	2140	7.7	
G1-036	PA9	WL monitoring	321963	1636778	120			4270	7.6	16.92
G1-037	AN5	Operating	321973	1636758	122	102	21.7	2380	7.6	
G1-038	PA5	WL monitoring	321513	1637101	120					22.43
G1-039	AN7	Operating	321445	1637136	121	96	19.2	2380	7.6	
G1-040	AN15	Operating	321388	1637295	125	93	21.3	1902	7.7	
G1-041	AN8	Operating	321243	1637309	124	95	21.7	1855	7.6	
G1-042	AN4	Operating	321086	1637392	129		11.8	1794	7.7	
G1-043	PA6	WL monitoring	320646	1637774	128			2210	7.5	29.61
G1-044	AN	Operating	320649	1637766	132	98	17.2	2120	7.6	
G1-045	AN3	Not in use	322678	1636703	126					
G1-047	AN16	WL monitoring	323751	1636964	125			1472	7.9	19.38
G1-071		Not in use	323496	1637177	130					
G1-072		Not in use	323317	1637105	126					
G1-073		Not in use	323367	1636955	130					
G1-074		Not in use	323243	1636880	123					
G1-075		Not in use	323245	1636885	122					
G1-076		Not in use	320645	1637770	134					
G1-077		Not in use	322235	1636732	121					

Source: [7].

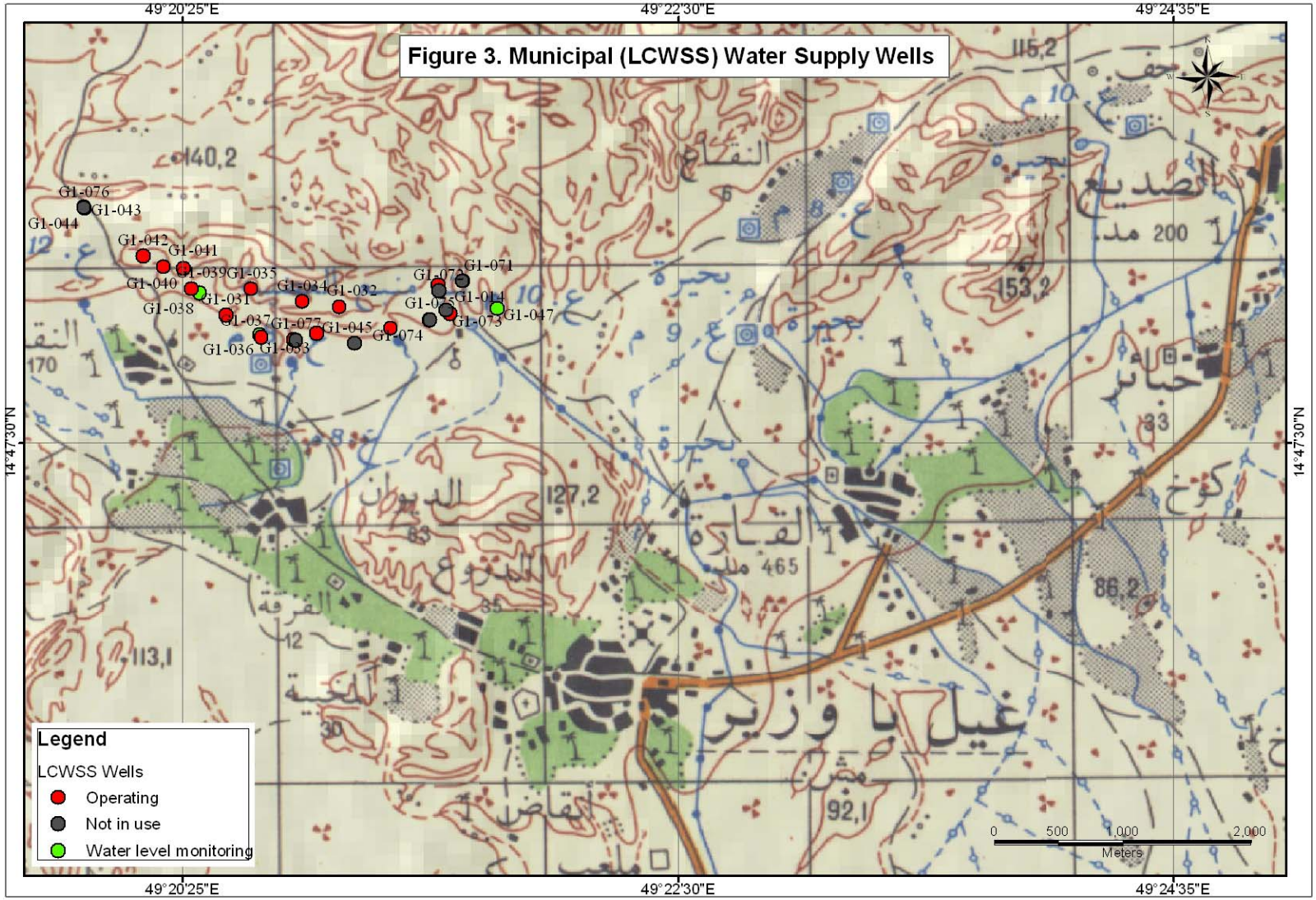
Figure 3. Municipal (LCWSS) Water Supply Wells
49°20'25"E
49°22'30"E
49°24'35"E
14°47'30"N
G1-076
G1-043
G1-044
G1-042
G1-041
G1-039
G1-035
G1-040
G1-031
G1-034
G1-032
G1-038
G1-037
G1-077
G1-045
G1-074
G1-036
G1-053
G1-072
G1-071
G1-014
G1-075
G1-073
G1-047
Legend
LCWSS Wells
Operating
Not in use
Water level monitoring
0
500
1,000
2,000
Meters

Table 2. Summary of Groundwater Quality

Parameters	Well ID												Yemen Guidelines	
	AN2	**AN4**	**AN5**	**AN8**	**AN14**	**AN15**	**A10**	**A12**	**A7**	**A13**	**A11**	**A9**	**OL**	**HPL**
EC, µS/cm	1683	1919	2290	1805	2070	1848	1837	1657	1822	2230	1782	1724	450-1000	**2500**
pH	7.16	7.54	7.22	7.27	7.19	7.27	7.34	7.36	7.17	7.32	7.32	7.31	6.5-8.5	**9**
TDS, mg/l	1077	1228	1466	1155	1325	1183	1176	1050	1166	1427	1140	1103	650	**1500**
T. hardness	275	910	1270	805	1060	1035	820	645	865	830	695	770	100	**500**
Ca^{2+}(mg/l)	166	232	304	230	284	232	202	150	206	248	196	176	75	**200**
Mg^{2+}(mg/l)	62	79	115	55	84	109	76	65	84	50	49	79	30	**150**
Fe^{2}+(mg/l)	0.02	0.15	0.32	1.10	0.06	0.18	0.32	0.34	0.09	0.16	0.24	0.18	0.3	**1**
Cl^{-}	225	225	230	175	240	220	215	215	250	180	250	265	200	**600**
SO_4^{2-}(mg/l)	710	1100	1300	1000	1250	1075	925	700	750	1125	800	580	200	**400**
HCO_3^{-}(mg/l)	312	261	266	256	266	275	293	295	246	251	337	259	150	**500**
F^{-}(mg/l)	0.99	1.14	0.99	0.98	1.43	0.53	1.31	1.25	1.56	1.23	1.32	1.45	0.5	**1.5**
NO_3^{-}(mg/l)	4.8	4.5	3.4	7.4	5.9	6.8	2.3	3.9	3.2	4.0	5.9	2.6	10	**50**

OL = Optimal Limit of the Yemeni Standard 109/2001

HPL = Highest Permissible Limit of the Yemeni Standard 109/2001

Note: Elevated concentrations of chemical constituents which exceed HPL are highlighted in violet.

6. DELINEATION OF THE GROUNDWATER PROTECTION ZONES

The groundwater protection zones are proposed to establish at all the operating public water sources (LCWSS wells). Sizes of the groundwater protection zones are delineated in accordance with the guidelines recently prepared and adopted by the NWRA [2, 3].

6.1 Immediate Protection Zone (Zone I)

Currently, none of the municipal operating wells is surrounded by the Immediate Protection Zone (Figure 4).

Figure 4. Typical municipal well without Immediate Protection Zone

Therefore, Immediate Protection Zones are recommended to establish at all operating LCWSS wells.

The size of Zone I is recommended to be at least 15 m in all directions of the operating well. The area of Zone I should be entirely fenced and an access is allowed only to authorized persons. No activities are allowed except those needed to operate the well.

6.2 Inner Protection Zone (Zone II)

Zone II should comprise the area between the operating well and a line from which the groundwater will flow at least 50 days until it reaches the well. The line from which groundwater takes 50 days to flow to the well may be determined by numerical modeling or simple mathematical approximation method based on the Darcy Law. This minimum travel time will ensure that no pathogenic constituents will reach the production well. The actual groundwater flow velocity (v_a) is calculated from the equation [3]:

$$va \approx 2 * \frac{kI}{no} \quad (1)$$

Where:

k= hydraulic conductivity, m/d

I= hydraulic gradient of groundwater flow

no= effective porosity

Other required parameters characterizing the extent of zone II can be calculated using the following formulas [3]:

$$B = \frac{Q}{H * k * i} \quad (2)$$

Where:

B= width of contribution zone in the upstream area, m

H= saturated thickness of aquifer, m

Q= abstraction at the regarded well, m^3/day

$$b = \frac{B}{2} \quad (3)$$

Where:

b= width of contribution zone at operating well

$$x_0 = \frac{B}{2\pi} \quad (4)$$

Where:

x_0= distance of lower culmination from operating well following the main axis of groundwater flow, m

$$t = \frac{x - x_0 \cdot \ln\left(1 + \frac{x}{x_0}\right)}{v_a} \quad (5)$$

Where:

t= travel time in days measured from operating well to point Px following the main axis of groundwater flow

Px= position of 50-days travel time distance on the main axis of groundwater flow at distance x from operating well

The size of Zone II recommended for the public water sources (LCWSS operating wells) is calculated based on the following assumptions:

4. Because the municipal wells are situated very close to each other, Zone II would be delineated for all operating wells taken together as a single cluster of wells which is operating with a combined yield (∑**Q**)equals to the sum of yields of all 17 currently operating wells (see Table 1).
5. The maximum gradient of groundwater flow (I) is estimated to be 0.0075 from the Groundwater Contour Map (Figure 5). The map was constructed based on the static water level measurements collected by the NWRA/Seyun team during the very recent well inventory [7].
6. Due to high uncertainties concerning the hydraulic parameters and the design of operating wells, the size of Zone II is calculated based on the average parameters adopted from the previous studies [4, 5, and7] as tabulated in Table 3.

Table 3. Average parameters used for calculation of the size of Zone II

Parameters							
H, m	∑Q, l/s	Daily production, m^3/d	Transmissivity, m^2/d	K, m/d	I	n_o	v_a(m/d)
100	335	29000	1000	10	0.0075	0.03	5

Note: Explanation of terms and symbols see in formulas (1) – (5)

The size of Zone II calculated by formulas (1) – (5) from the average hydraulic parameters for the cluster of 17 operating wells is summarized in Table 4. The general layout of Zone II is shown in Figure 6.

Table 4. Size of Protection Zone II

Size of Zone II			
B, m	b, m	X_0, m	X, m
4100	2050	650	750

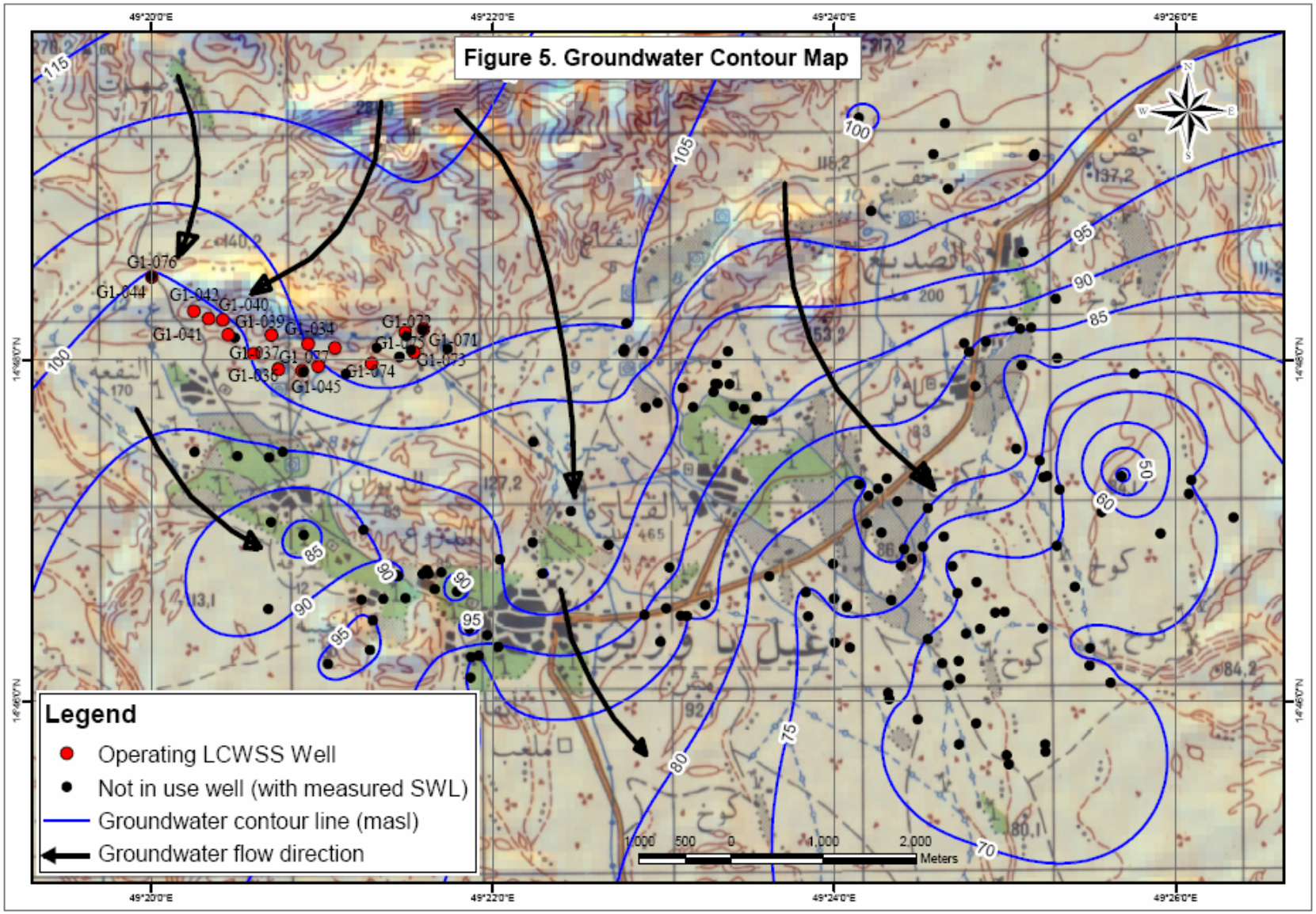
Figure 5. Groundwater Contour Map
Legend
Operating LCWSS Well
Not in use well (with measured SWL)
Groundwater contour line (masl)
Groundwater flow direction
G1-076
G1-044
G1-043
G1-040
G1-039
G1-034
G1-041
G1-037
G1-036
G1-045
G1-074
G1-072
G1-071
G1-073
115
105
100
95
90
85
80
75
70
60
50
1,000 500 0 1,000 2,000
Meters

6. 3 Outer Protection Zone (Zone III)

Protection Zone III is delineated based on the groundwater contour map shown in Figure 6. In the vicinity of the operating LCWSS wells zone III incorporates all zones I and II. Southward Zone III extends a distance of around 4 km from the operating wells to include the entire catchment area with the exception of the uppermost part of the mountain range.

The general layout of the groundwater protection zones recommended to establish in Ghayl Ba-Wazir is shown in Figure 7. If the decision is made by the LCWSS and the Local Government to establish protection zones according to these recommendations, more detailed and site-related map showing the sizes of groundwater protection zones will be constructed by NWRA.

7. LAND-USE RESTRICTIONS IN THE PROTECTION ZONES

7.1 Outer Protection Zone (Zone III)

- The construction of new industries are allowed under the condition that they will not cause any hazard to groundwater;
- Existing and new storage facilities for substances hazardous to groundwater which are hardly degradable have to be controlled;
- No landfills are allowed;
- Transportation of substances hazardous to groundwater has to be controlled;
- Uses of fertilizers and pesticides are not allowed;
- Drilling operations must be controlled.

7.2 Inner Protection Zone (Zone II)

- The same restrictions listed for zone III **and**
- No construction of new roads, no extension of existing roads;

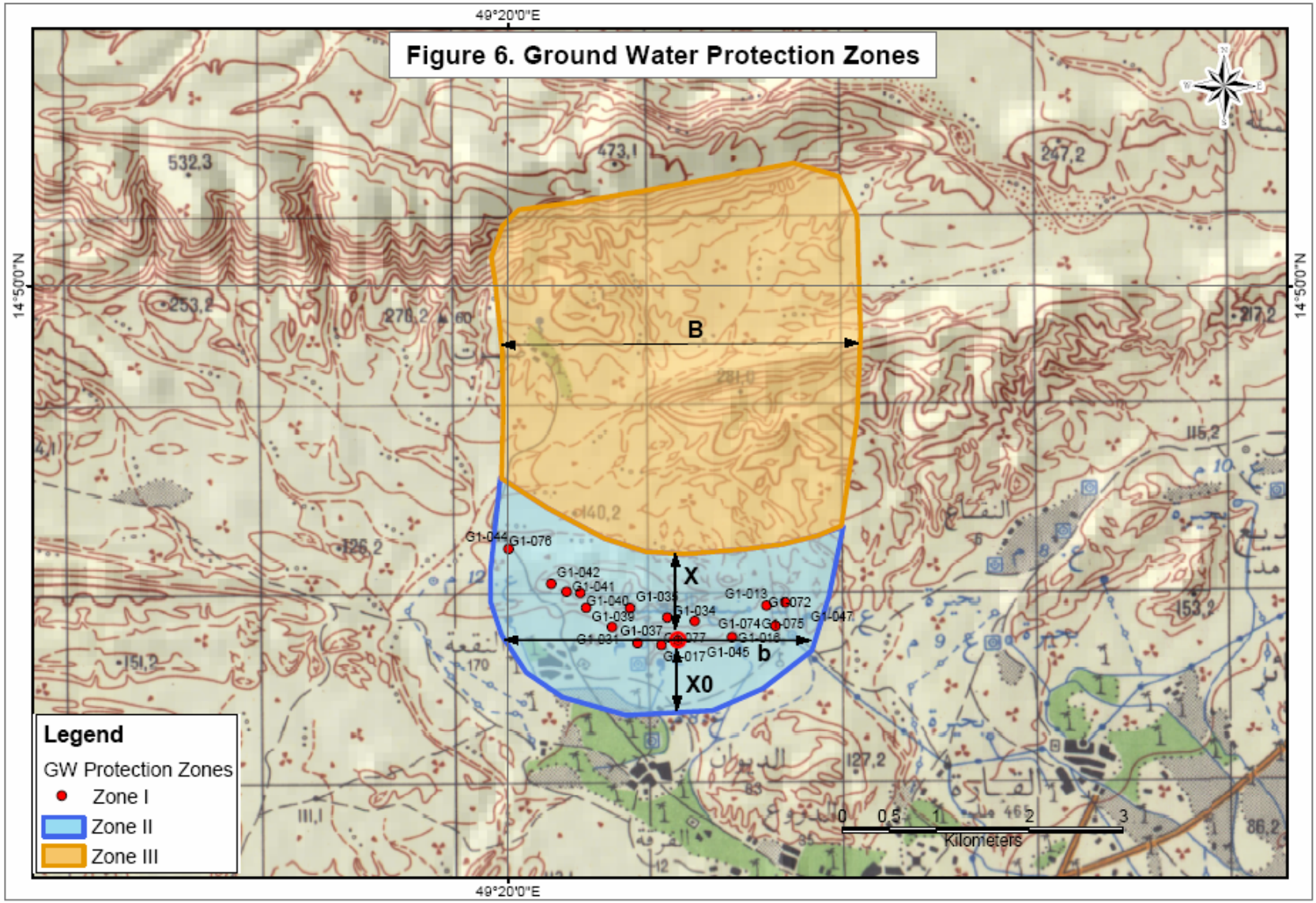
Figure 6. Ground Water Protection Zones
49°20'0"E
14°50'0"N
B
X
X0
b
G1-044
G1-076
G1-042
G1-041
G1-040
G1-039
G1-037
G1-034
G1-013
G1-072
G1-074
G1-075
G1-047
G1-016
G1-017
G1-045
Legend
GW Protection Zones
Zone I
Zone II
Zone III
0 0.5 1 2 3
Kilometers

- No new construction of sewage collection and treatment facilities;
- Installation of new animal husbandries are prohibited, existing ones have to be controlled.

7.3 Immediate Protection Zone (Zone I)

No activities are allowed except those needed to operate the well. The area of zone I should be totally fenced around and access is allowed only to authorized LCWSS staff.

9. RECOMMENDATIONS FOR LAND-USE PRACTICES IN THE GROUNDWATER PROTECTION ZONES

1. Protection Zones I: It seems that not all the land around the LC wells (radius = 15m) proposed to be protection zone I is owned by the Government. Therefore, some additional land should be acquired by the Government in order to implement the proposed protection measures in the immediate surroundings of the public water sources.

2. Drilling operations in Zones II and III: The drilling operations are allowed under strict control. Before drilling, an official license should be received from the NWRA. The license includes, among other things, an allowed maximum depth of the well, possible yield and purpose of the water use. It is expected that NWRA will issue (after examination of a well site) only licenses for drilling wells which will be used only for drinking purpose. The water use will be regularly inspected by NWRA, and if it is found that the water is used for a purpose other than allowed, a penalty of imprisonment or a fine should be imposed on the well owner in accordance with Article (71) of the Water Law No. 41 of 2006.

3. Agriculture: The use of pesticides has to be banned in all the protection zones (I, II and III). It must be frequently controlled that this ban is being followed. Fertilizers which may have a possible negative impact on the water quality and its bacteriological safety should also be banned.

4. Residential Areas: Any sewage or waste generated from residential activities like cess-pits must be disposed outside protection zones I and II.

5. An awareness campaign on water resources protection and correct environmental behavior should be initiated among the local population, involving mass-media, school teachers, posters, etc.

REFERENCES

1. **Water Law No. (41) of 2006.** Amendments to Some Articles of Law No. (33) of 2002.

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5. **Komex Int. Ltd., 1993.** Groundwater Resources Assessment: Masila Export Project.

6. **LCWSS, 2009**. Chemical Analyses of Water Samples (hard copies).

7. **NWRA/Seyun, 2009.** Well inventory (Ghayl Ba-Wazir) database.