German-Lebanese Technical Cooperation Project

Protection of Jeita Spring

Delineation of Groundwater Protection Zones for all Springs in the Jeita Catchment, Lebanon, using a modified COP Method

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Importance of Water Resources Protection

Though water resources in Lebanon are abundant, they are increasingly at risk. The rapid and uncontrolled urban expansion has caused a severe deterioration of water quality over the past decades.

The groundwater resources of Lebanon are mostly stored in limestone aquifers which are highly karstic. In many areas the karst is exposed at the surface (open karst) and rainfall infiltrates easily. Groundwater flow velocities in the karst system are extremely high (up to 2,000 m/h). This is the reason why any contamination will reach the drinking water sources very fast and without any major attenuation. The main contamination risk results from wastewater that is infiltrating the karst aquifers unhindered from cess pits, sinkholes or even wells. Contamination is extremely high at the beginning of the rainy season.

Due to the nature of the karst, the groundwater system dewaters quickly so that at the end of the dry season water shortages frequently occur.

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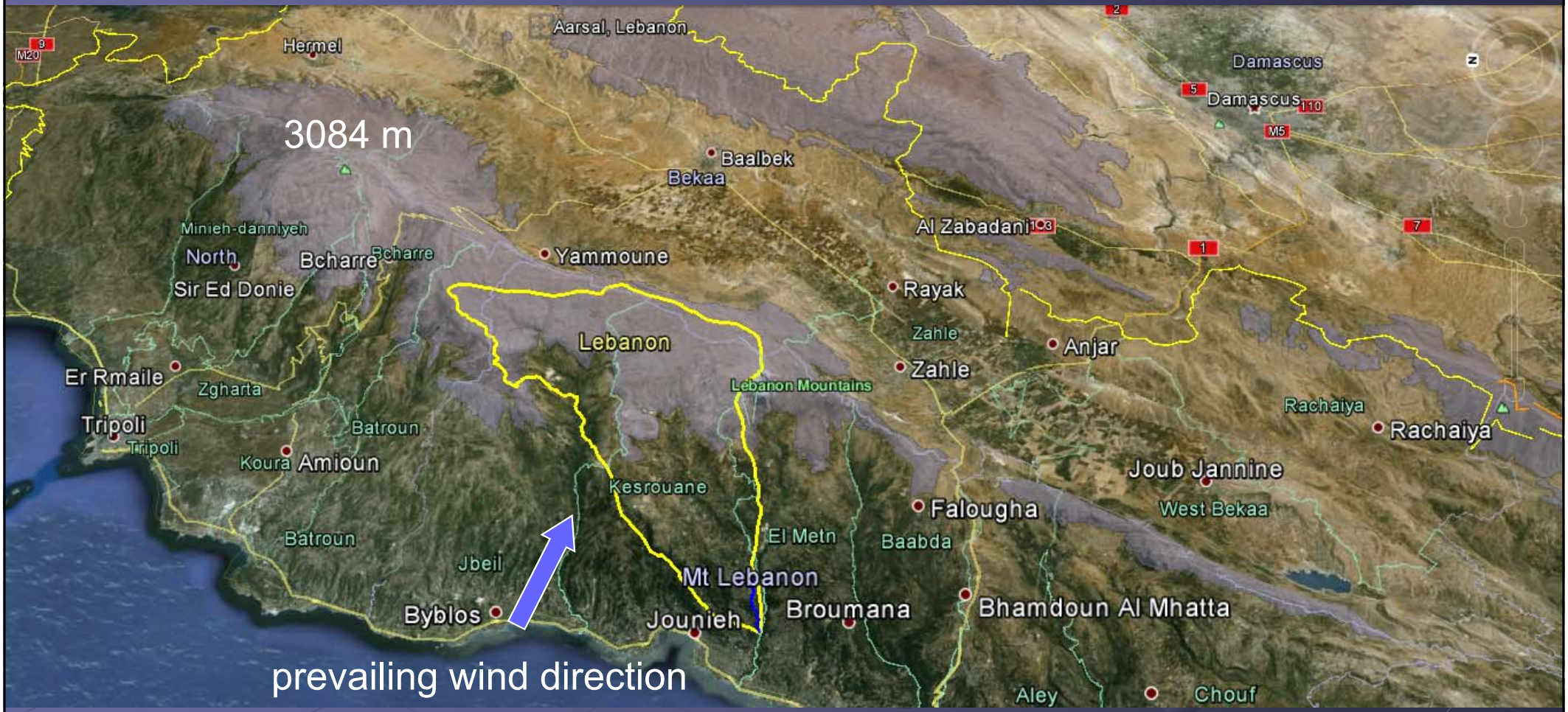
Project Area

Jeita GW catchment

50 km

Project Area


3084 m
Aarsal, Lebanon
Hermel
Damascus
Damascus
Baalbek
Bekaa
Al Zabadani
Minieh-danniyeh
North
Bcharre
Bcharre
Yammoune
Sir Ed Donie
Rayak
Lebanon
Zahle
Anjar
Zahle
Er Rmaile
Zgharta
Lebanon Mountains
Rachaiya
Rachaiya
Tripoli
Batroun
Tripoli
Koura
Amioun
Joub Jannine
Kesrouane
Faloughа
West Bekaa
Batroun
El Metn
Baabda
Jbeil
Mt Lebanon
Byblos
Jounieh
Broumana
Bhamdoun Al Mhatta
prevailing wind direction
Aley
Chouf

Area > 1600 m

Importance of Snow

high plateau - chateau d'eau
(main water source)

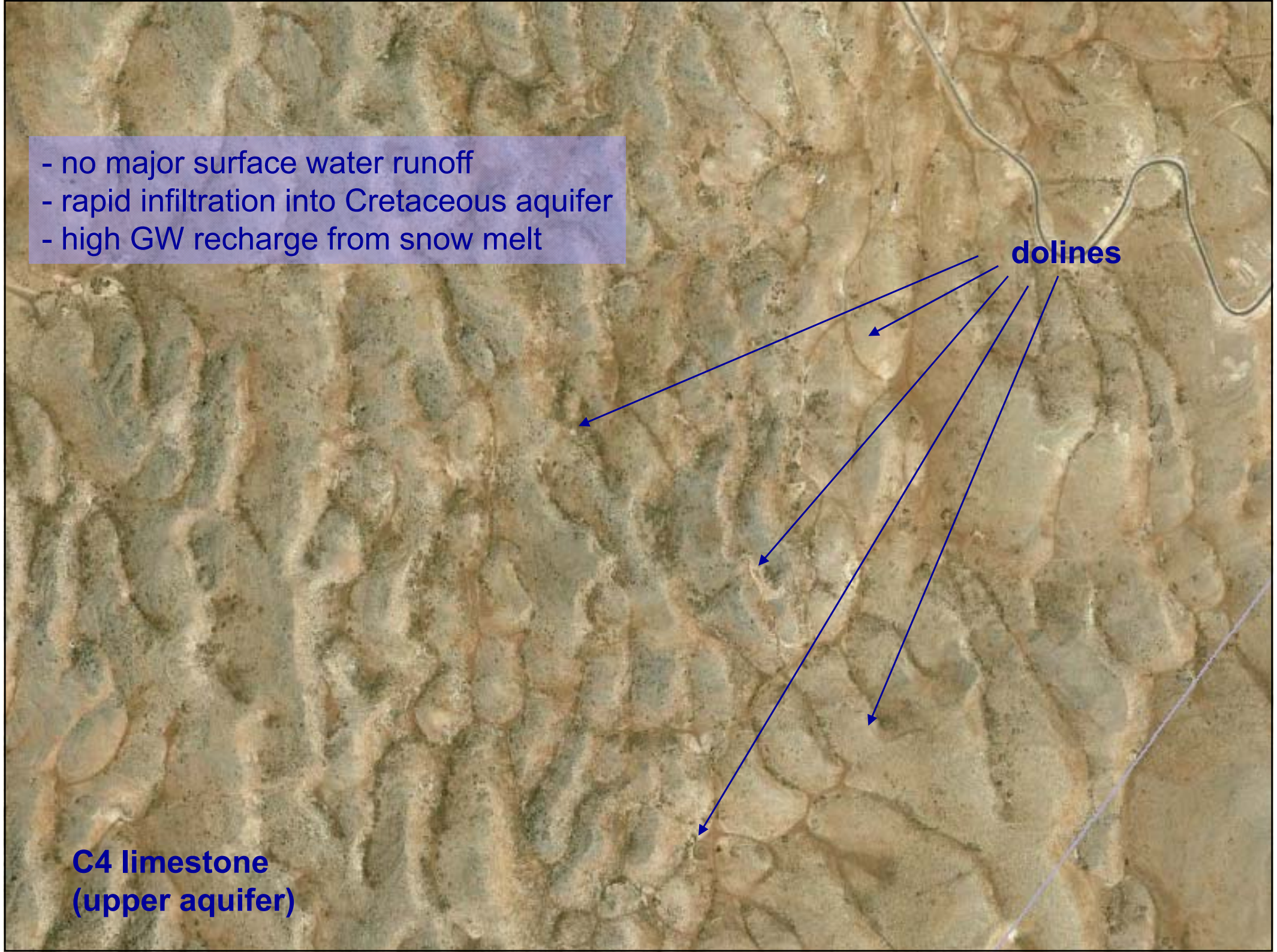
Cretaceous plateau (1,800 – 3,000 m asl):
~4 m snow (2011/12: up to 10 m and more)
December – April

Very important for GW recharge (~ 81%)
Snow is the lifeline of Lebanon

Climate change may lead to a significantly lower groundwater resources availability

Regional climatic scenarios predict less rainfall (15-30%), higher summer and winter temperatures (up to 5°C) and thus less snow and runoff, more evaporation

- **shift of orographic snow line**
- **water shortage in dry season**


- no major surface water runoff
- rapid infiltration into Cretaceous aquifer
- high GW recharge from snow melt
dolines
C4 limestone
(upper aquifer)

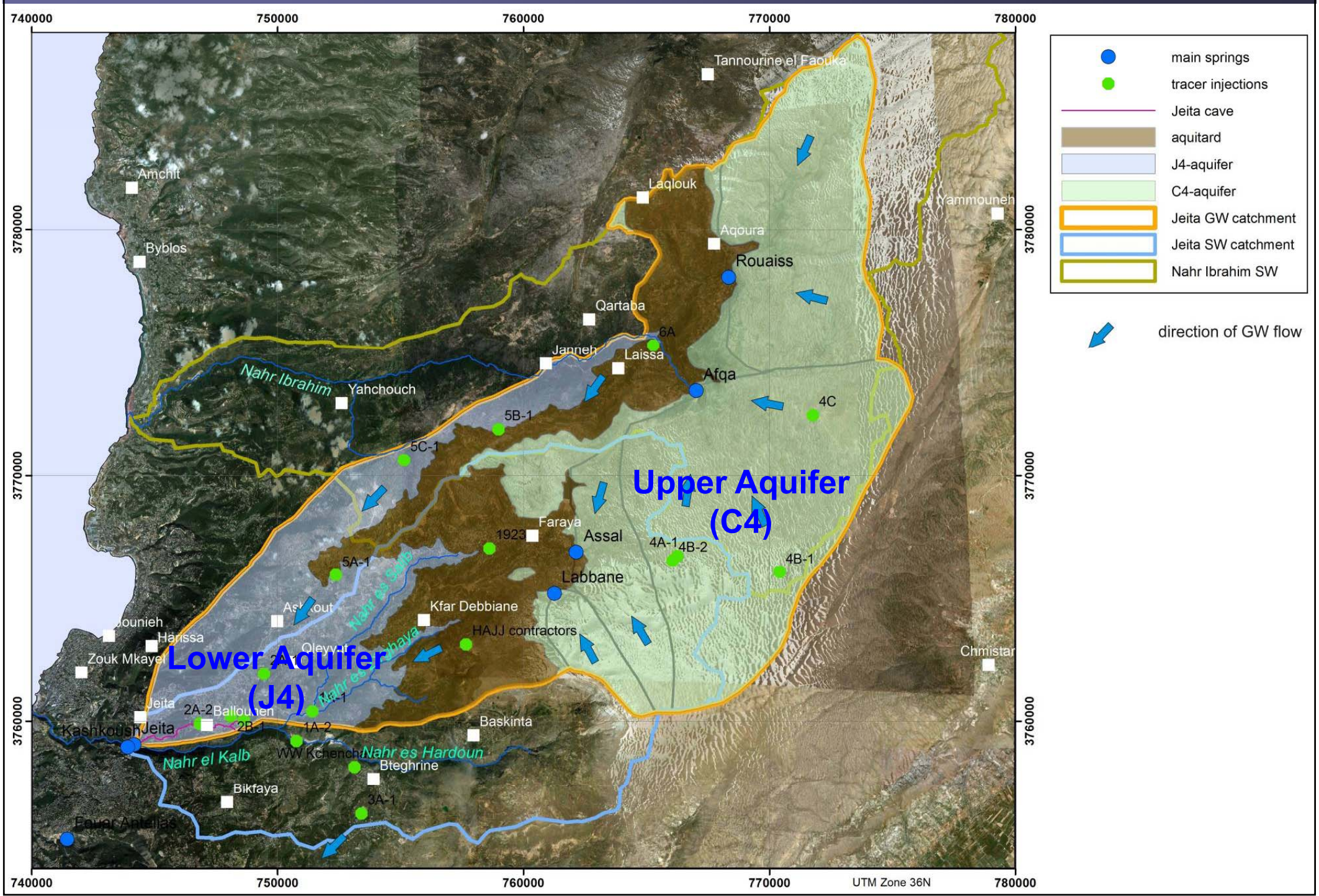
Where does Beirut's drinking water come from – Groundwater recharge

GW recharge via dolines

GW recharge 81% in C4

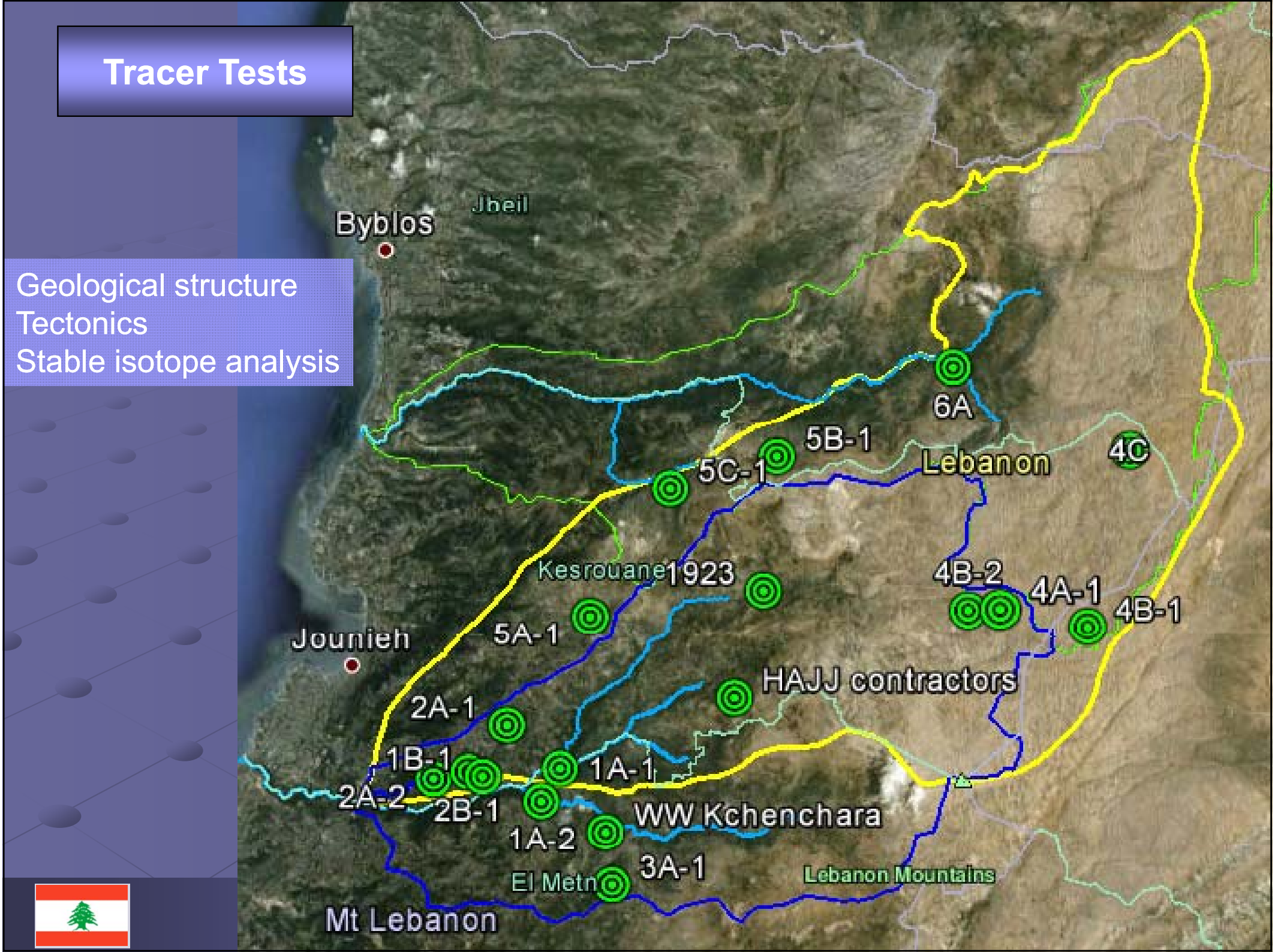
Groundwater System

Based on new geological map prepared by BGR



Tracer Tests

Geological structure
Tectonics
Stable isotope analysis



Contamination Risks from Wastewater

Currently wastewater is discharged
- **into injection wells**
- **into open cess pits or**
- **into nearby creeks/rivers/wadis**

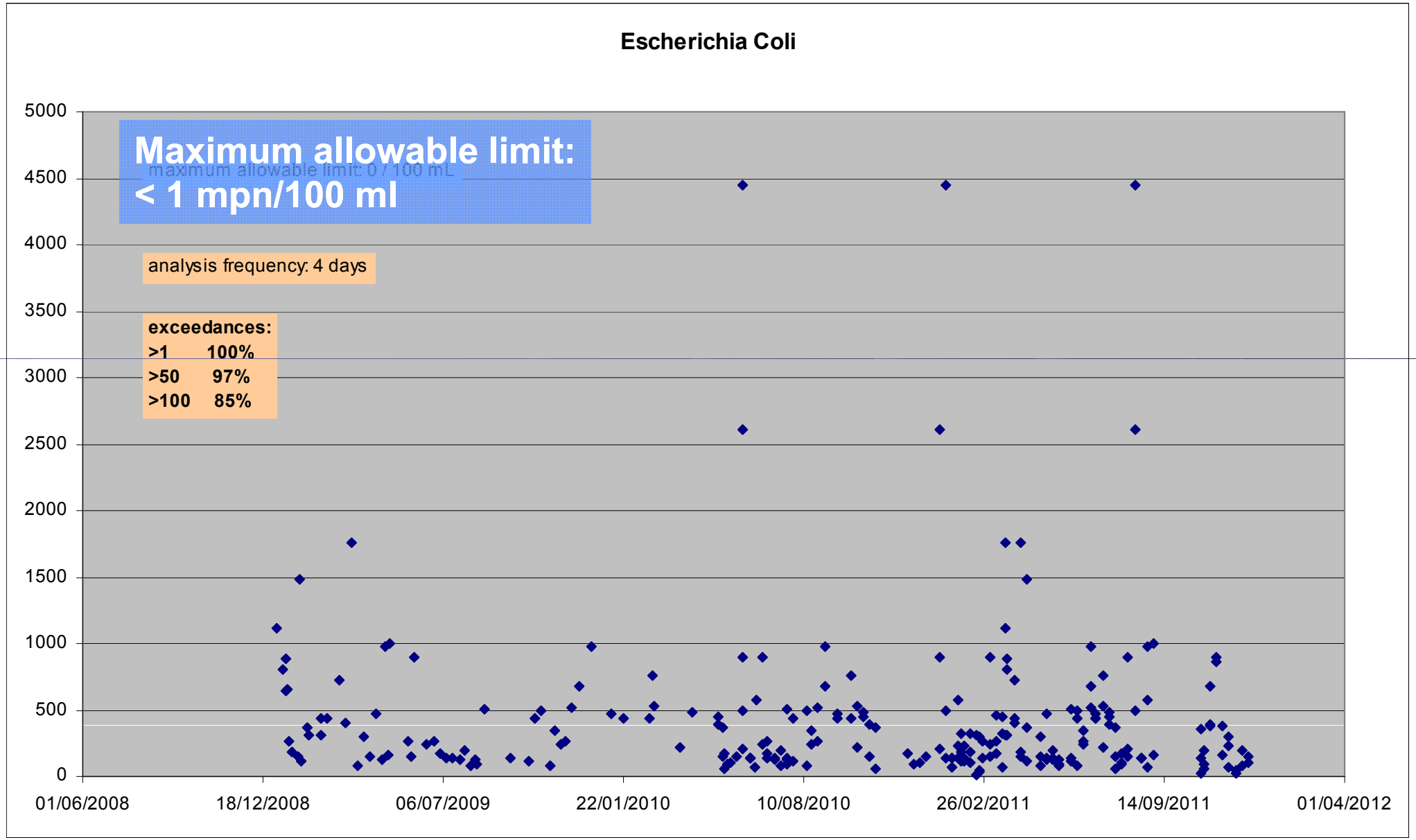
residences with no wastewater collection and treatment

Infiltration of untreated wastewater into highly karstified Jurassic limestone (Faitroun)

► microbiological contamination of Jeita spring

Dbayeh raw water (treatment plant)

High and continuous microbiological contamination



Groundwater Vulnerability

In porous aquifers:
relatively uniform infiltration and groundwater movement
- travel time, e.g. 50 days (Germany) or 10 days (Switzerland)

In karst systems groundwater protection is very difficult:
- diffuse infiltration through fractures (matrix)
- concentrated infiltration through karst network (sinkholes, dolines, conduits)
- non-uniform GW flow

International practice:
Delineation using GW vulnerability maps
- EPIK (used in CH)
- COP (proposed for entire EU), modified

Groundwater Vulnerability

COP Method
C – Concentration of flow,
O – Overlying layers and
P – Precipitation

VIAS et al. (2006) [Univ. Malaga]
EU COST 620 project
Similar to GLA (1994) / PI (2002) methods

COP-Index :
COP-Index = (C score) * (O score) * (P score)

- soil
- lithology and thickness of overlying rock layers
- confined / unconfined GW
- infiltration in sinkholes
- infiltration by sinking streams
- slope
- vegetation cover
- rainfall amount
- rainfall intensity

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O FACTOR (Overlying layers)

$[O_S]$ Soil

I

Clayey	> 30 % Clay
Silty	> 70 % Silt
Sandy	Sand > 70 % Clay ≤ 15 %
Loam	Rest

II

Thickness	Texture: Clayey	Silty	Loam	Sandy
> 1.0 m	5	4	3	2
0.5 - 1 m	4	3	2	1
< 0.5 m	3	2	1	0*

*: Also 0 when no soil is present

→ $[O_S]$

$[O_L]$ Lithology

III

Lithology and fracturation	Value
Clays	1500
Silts	1200
Marls and non-fissured metapelites and igneous rocks	1000
Marly limestones	500
Fissured metapelites and igneous rocks	400
Cemented or non-fissured conglomerates and breccias	100
Sandstones	60
Scarcely cemented or fissured conglomerates and breccias	40
Sands and gravels	10
Permeable basalts	5
Fissured carbonated rocks	3
Karstic rocks	1

Thickness of each layer

V

Confining conditions (cn)	Value
Confined	2
Semi-confined	1.5
Unconfined	1

(ly) (m) (cn)

IV

Layer index	Value
(0 - 250]	1
(250 - 1000]	2
(1000 - 2500]	3
(2500 - 10000]	4
> 10000	5

Layer index = Σ (ly · m) → Value Layer index · cn = $[O_L]$

O SCORE = $[O_S]$ + $[O_L]$

VI

O SCORE	Protection value
1	Very low
2	Low
(2 - 4]	Moderate
(4 - 8]	High
(8 - 15]	Very High

→ **O MAP**

C FACTOR (Concentration of flow)

SCENARIO 1 — **Swallow hole recharge area**

Distance to swallow hole (dh) / Slope and Vegetation (sv)

VII

Distance to swallow hole (m)	Value	Distance to swallow hole (m)	Value
≤ 500	0	(3000 - 3500]	0.6
(500 - 1000]	0.1	(3500 - 4000]	0.7
(1000 - 1500]	0.2	(4000 - 4500]	0.8
(1500 - 2000]	0.3	(4500 - 5000]	0.9
(2000 - 2500]	0.4	> 5000	1.0
(2500 - 3000]	0.5		

IX

Slope	Vegetation cover	Value
≤ 8 %	-	1
(8 - 31]	High	0.95
	Low	0.9
(31 - 76]	High	0.85
	Low	0.8
> 76 %	-	0.75

Distance to sinking stream (ds)

VIII

Distance to sinking stream	Value
< 10 m	0
10 - 100 m	0.5
> 100 m	1*

*: Also 1 when no sinking stream is present

C SCORE = dh · ds · sv

SCENARIO 2 — **Rest of the area**

Surface features (sf) / Slope and Vegetation (sv)

X

Karstic features	Surface layers: Absence	Permeable	Impermeable
Developed karst	0.25	0.5	0.75
Scarcely developed or dissolution features	0.5	0.75	1
Fissured carbonate	0.75	0.75	1
Non karstic terrains	1	1	1

XI

Slope	Vegetation cover	Value
≤ 8 %	-	0.75
(8 - 31]	High	0.8
	Low	0.85
(31 - 76]	High	0.9
	Low	0.95
> 76 %	-	1

C SCORE = (sf) · (sv)

XII

C SCORE	Reduction of protection
[0 - 0.2]	Very High
(0.2 - 0.4]	High
(0.4 - 0.6]	Moderate
(0.6 - 0.8]	Low
(0.8 - 1.0]	Very Low

→ **C MAP**

P FACTOR (Precipitation)

$[P_Q]$ Quantity

XIII

Rainfall * (mm/year)	Value
> 1600	0.4
(1200 - 1600]	0.3
(800 - 1200]	0.2
(400 - 800]	0.3
< 400	0.4

*: Average rainfall for wet years. Wet year ≥ (0.15 · $\bar{x}$) + $\bar{x}$

$[P_I]$ Temporal distribution

Temporal distribution = P (mm/year) / N° rainy days

XIV

Temporal distribution (mm/day)	Value
< 10	0.6
(10 - 20]	0.4
> 20	0.2

P SCORE = $[P_Q]$ + $[P_I]$

XV

P SCORE	Reduction of protection
0.4 - 0.5	Very High
0.6	High
0.7	Moderate
0.8	Low
0.9 - 1	Very Low

→ **P MAP**

COP Index = C SCORE · O SCORE · P SCORE

XVI

COP Index	Vulnerability classes
[0 - 0.5]	Very High
(0.5 - 1]	High
(1 - 2]	Moderate
(2 - 4]	Low
(4 - 15]	Very Low

→ **COP Map**

GW Vulnerability Mapping
EPIK & COP

- Geology ► geological mapping
- Karst features ► karst feature mapping
- Soil ► soil mapping

➢ Groundwater Vulnerability Map

+ groundwater travel time (tracer tests)
➢ Groundwater Protection Zones

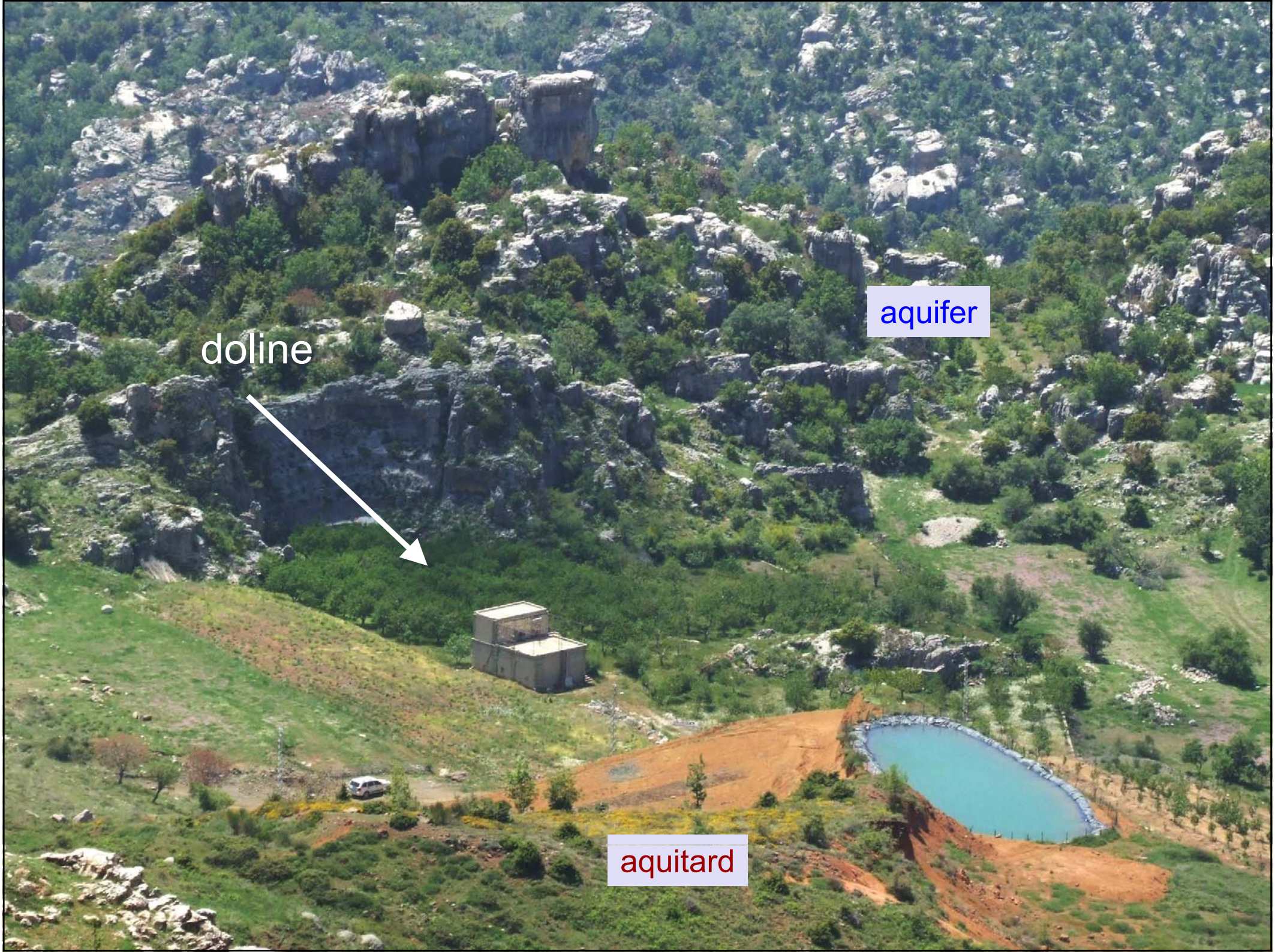
Modified COP Method

Each method must be adapted to the local conditions.

Factors that needed to be changed in the current COP method:

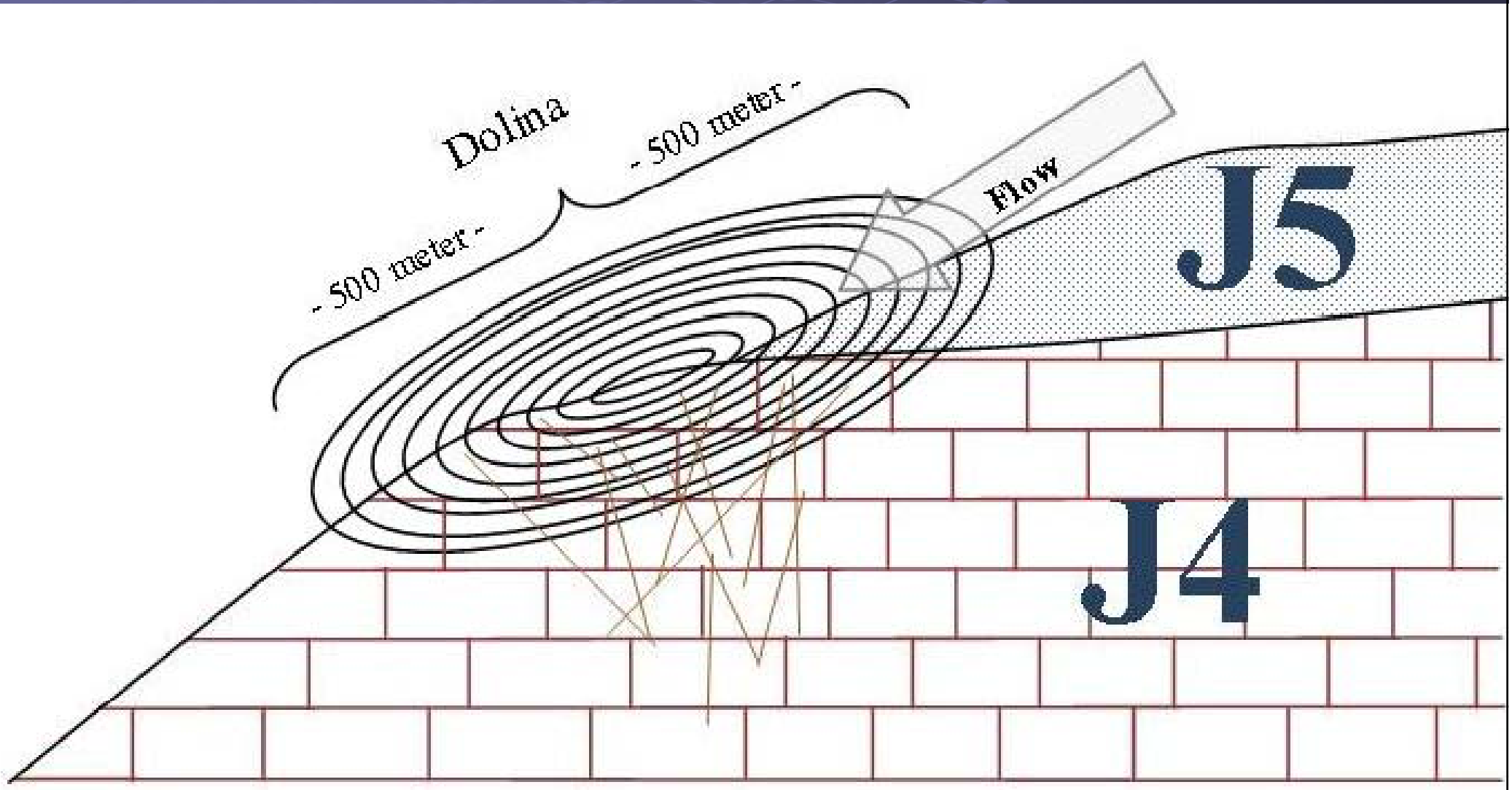
- **drainage from aquitards towards aquifers** (karst features): the COP method considers not only direct groundwater recharge but also flow concentration (surface water drainage) towards karst features with high infiltration. This flow concentration can also be generated in geological units overlying the J4 unit, namely the J5. Flow towards dolines, located near the contact of the J4 and J5, was therefore also considered in the vulnerability assessment.
- The **range of influence of concentrated flow towards dolines**
  > was reduced to 500 m (before 5,000 m)
- The **range of influence of riverbed infiltration** (sinking streams) was modified: now 0-500 m, before 0-100 m
- drainage from aquitards near identified infiltration zones (introduction of S-factor)
- fast flow component (underground river)

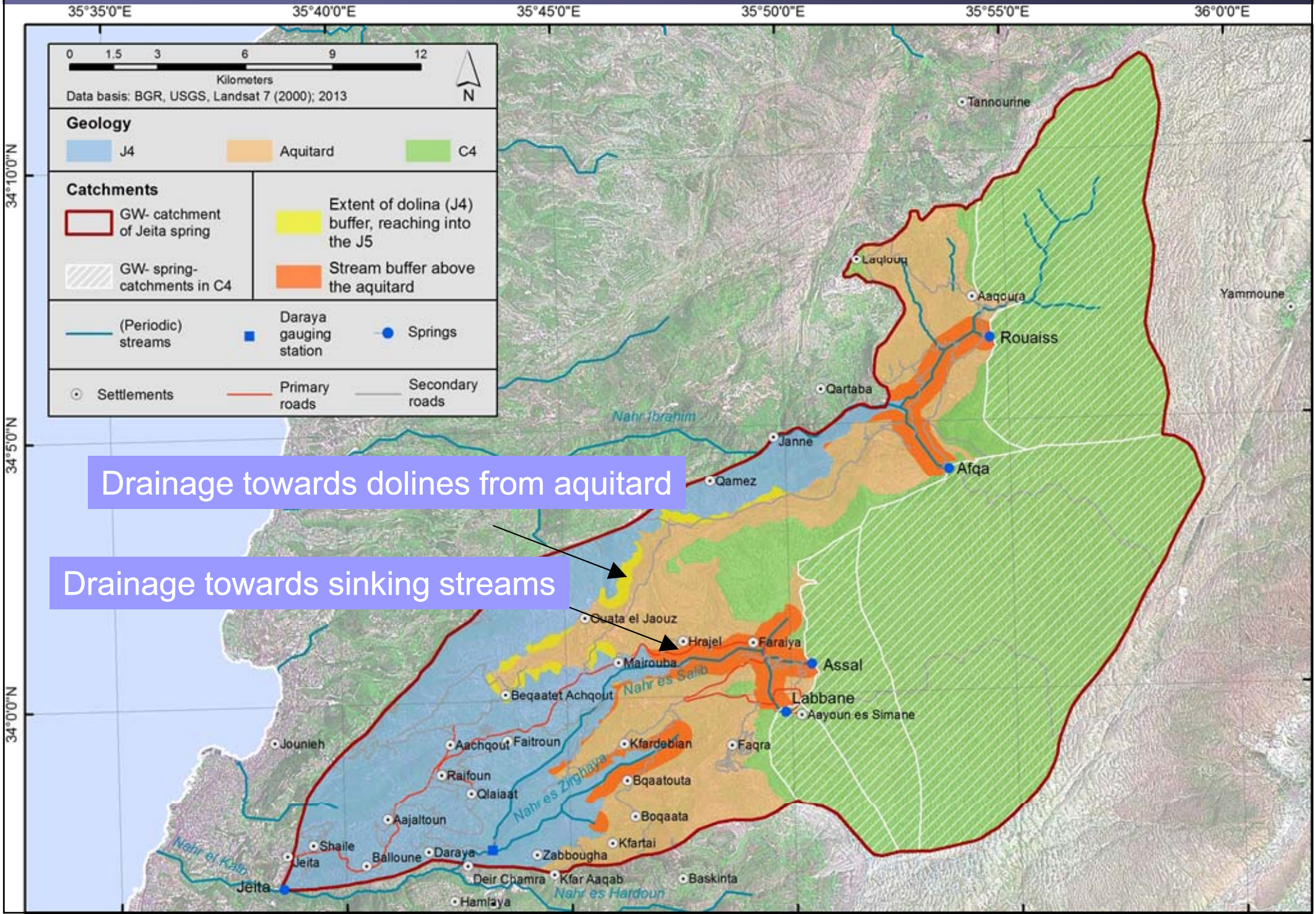
Modified COP Method


doline
aquifer
aquitard

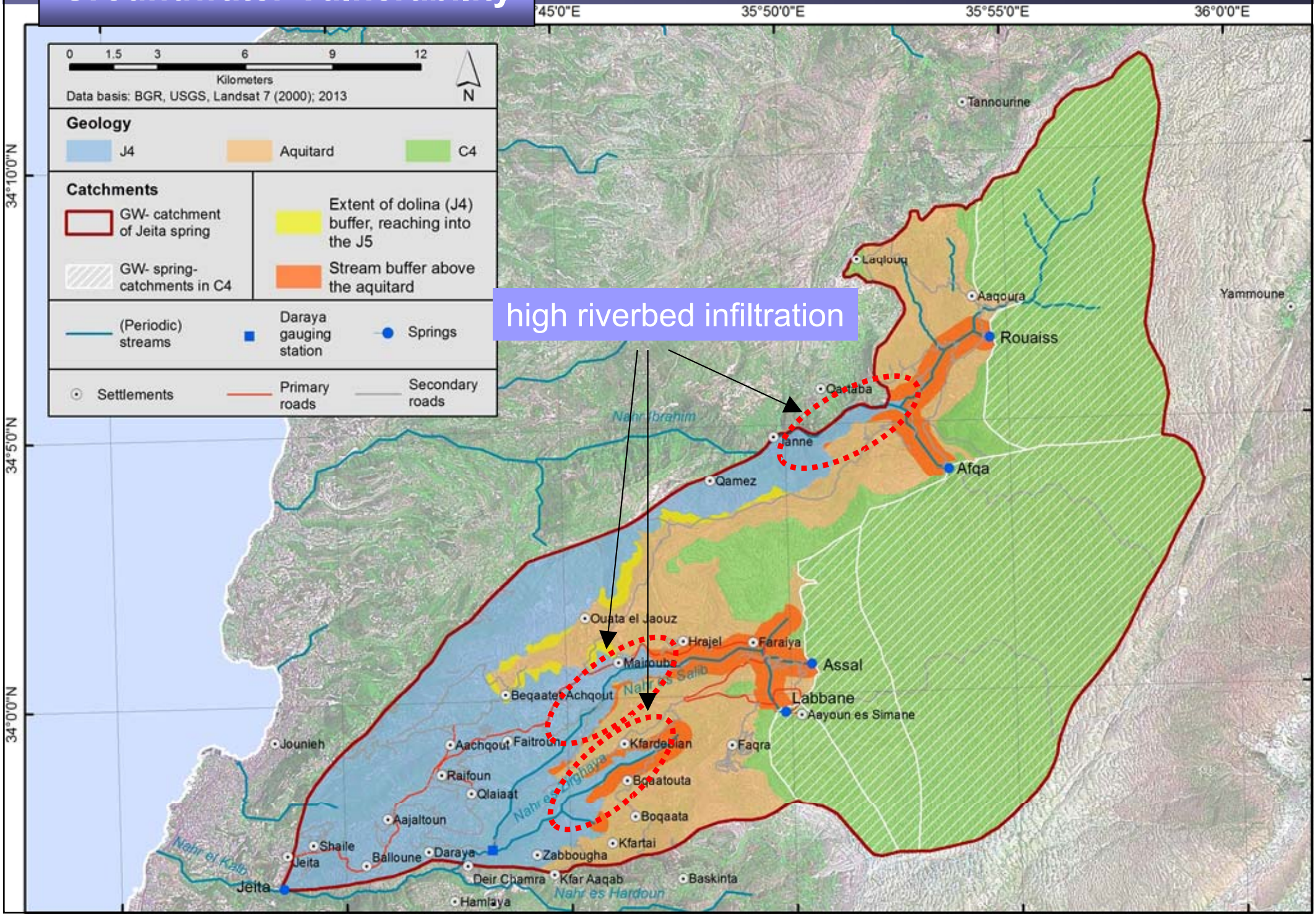
Modified COP Method

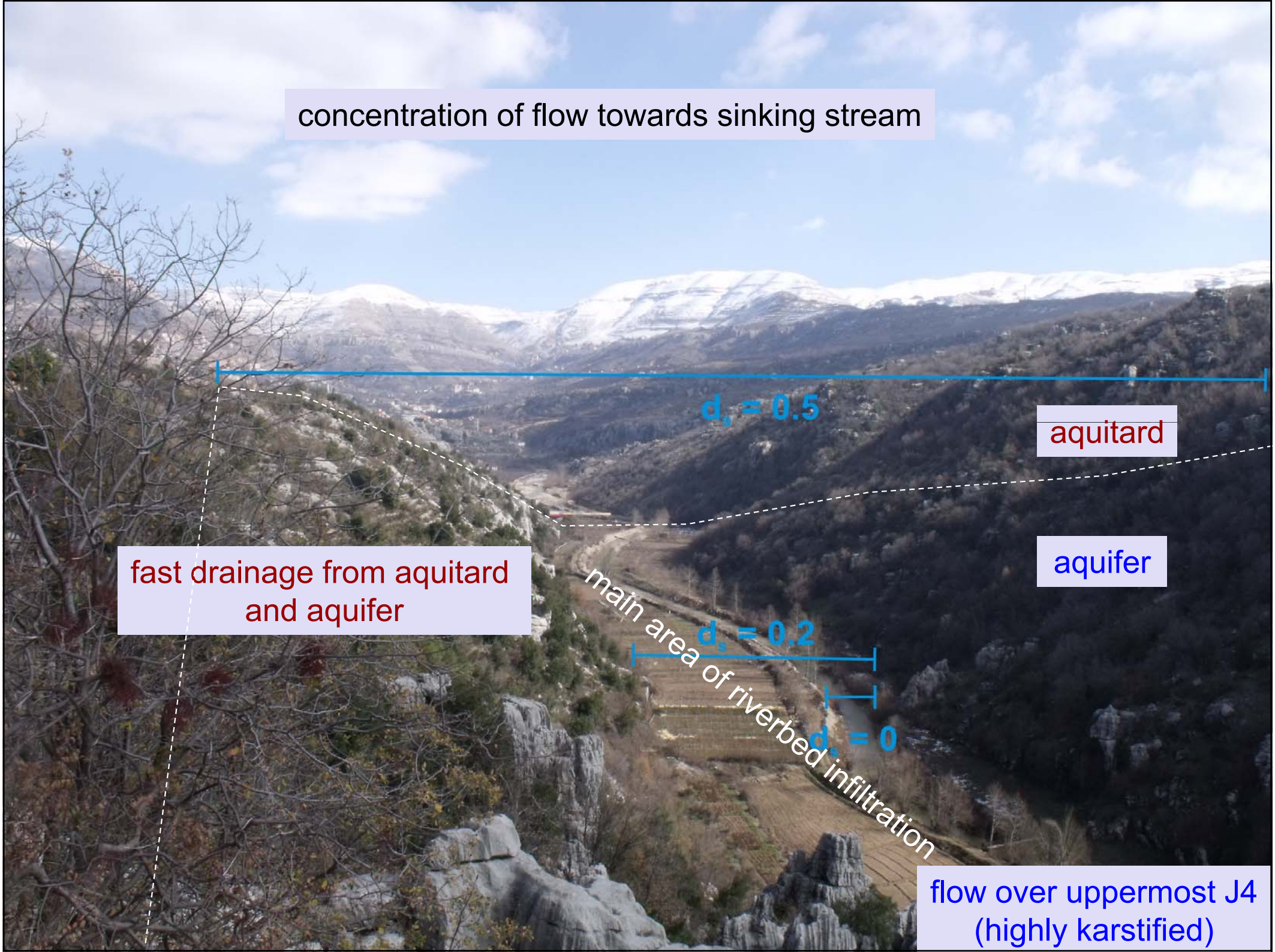
Vulnerability on aquitards




35°35'0"E
35°40'0"E
35°45'0"E
35°50'0"E
35°55'0"E
36°0'0"E
34°10'0"N
34°5'0"N
34°0'0"N
0 1.5 3 6 9 12
Kilometers
Data basis: BGR, USGS, Landsat 7 (2000); 2013
N
Geology
J4
Aquitard
C4
Catchments
GW- catchment of Jeita spring
GW- spring-catchments in C4
Extent of dolina (J4) buffer, reaching into the J5
Stream buffer above the aquitard
(Periodic) streams
Daraya gauging station
Springs
Settlements
Primary roads
Secondary roads
Drainage towards dolines from aquitard
Drainage towards sinking streams
Tannourine
Laqloug
Aaqoura
Yammoune
Rouaiss
Qartaba
Nahr Ibrahim
Janne
Afqa
Qamez
Ouata el Jaouz
Hrajel
Faraiya
Mairouba
Assal
Nahr es Salib
Beqaatet Achqout
Labbane
Aayoun es Simane
Jounieh
Aachqout
Faitroun
Kfardebian
Faqra
Raifoun
Nahr es Zirghaya
Bqaatouta
Qlaiaat
Aajaltoun
Boqaata
Nahr el Kalb
Shaile
Jeita
Balloune
Daraya
Zabbougha
Kfartai
Deir Chamra
Kfar Aaqab
Baskinta
Jeita
Nahr es Hardoun
Hamlaya

Groundwater Vulnerability




concentration of flow towards sinking stream
d_s = 0.5
aquitard
aquifer
fast drainage from aquitard and aquifer
main area of riverbed infiltration
d_s = 0.2
d_s = 0
flow over uppermost J4 (highly karstified)

Modified COP Method

Range of influence of dolines reduced

Range of influence of sinking streams changed

O FACTOR (Overlying layers)

[Os] Soil

I

Clayey	> 30% clay
Silty	> 30% silt
Sandy	Sand > 70%
	Clay ≤ 15%
Loam	Rest

II

$[O_s]$ +

Thickness			Texture (os) Clayey	Silty	Sandy	Loam
	> 1 m	2	5	4	3	
	0.5 -1 m	1	4	3	2	1
	< 0.5 m	0	3	2	1	0

* 0 when no soil is present

$[O_L]$ Lithology

III

Lithology and fracturation	ly
Clays	1500
Igneous rocks	
Cemented or non fissured conglomerates and breecias	100
Sandstones	60
Scarcely cemented or fissured conglomerates and breccias	40
Sands and gravels	10
Permeable basalts	5
Fissured carbonate rocks	3
Karstic rocks	1

UZ

V

Confined conditions (cn)	cn

(ly) (m) (cn)

Layer Index (ly.m)

IV

Layer Index	ly.m
(0-250]	1
(250-1000]	2
(1000-2500]	3
(2500-10000]	4
>10000	5

Value Layer Index . cn

$[O_L]$

C FACTOR (Concentration of flow)

Scenario 1 [C_1]: Swallow hole recharge area

Distance to swallow hole (dh)

VII

Distance to swallow hole	dh
≤ 500	0
(50-100]	0.025
(100-150]	0.05
(150-200]	0.075
(200-250]	0.1
(250-300]	0.125
(300-350]	0.15
(350-400]	0.175
(400-450]	0.2
(450-500]	0.225
> 500	1

Slope and Vegetation (sv)

IX

Slope	Vegetation	sv
≤ 8%	-	1
(8-31] %	Yes	0.95
	No	0.9
(31-76] %	Yes	0.85
	No	0.8
> 76%	-	0.75

C_1 SCORE = [dh] . [ds] . [sv]

VIII

Distance to sinking stream	ds
< 10 m	0
10-100 m	0.2
100-500 m	0.5
> 500 m	1

*1 when no sinking stream is present

Scenario 2 [C_2]: Non-swallow hole recharge area

Surfaces features (sf)

X

sf	Absence	Permeable	Imp
Dev. Karst	0.25	0.5	0.75
Scarcely developed or dissolution features	0.5	0.75	1
Fissured karst	0.75	0.75	1
Absence of karst features	1	1	1

Slope and Vegetation (sv)

XI

Slope	Vegetation	sv
≤ 8%	-	0.75
(8-31] %	Yes	0.8
	No	0.85
(31-76] %	Yes	0.9
	No	0.95
> 76%	-	1

C_2 SCORE = [sv] . [sf] . [ds]

(sf) (sv) (ds)

P FACTOR (Precipitation)

P_Q Quantity

XIII

Rainfall (mm/year)	pq
> 1600	0.4
(1200-1600]	0.3
(800-1200]	0.2
(400-800]	0.3
≤ 400	0.4

P_I Intensity

$$\text{Intensity} = \frac{\text{P (mm/year)}}{\text{N of rainy days}}$$

XIV

Intensity (mm/day)	pi
≤ 10	0.6
(10-20]	0.4
> 20	0.2

[P] Score

P SCORE = $[P_Q] + [P_I]$

XV

P score	Reduction of Protection
0.4-0.5	Very high
0.6	high
0.7	Moderate
0.8	Low
0.9-1	Very low

[O] Score

O SCORE= $[O_L] + [O_s]$

VI

O score	Protection value
1	Very low
2	Low
(2 - 4]	Moderate
(4 - 8]	High
(8 - 15]	Very high

[C] Score

1) C_1 SCORE = [dh] . [ds] . [sv] or 2) C_2 SCORE = [sv] . [sf] . [ds]

XII

C score	Reduction of Protection
(0 - 0.2]	Very high
(0.2 - 0.4]	high
(0.4 - 0.6]	Moderate
(0.6 - 0.8]	Low
(0.8 - 1]	Very low

[COP] Score

COP Index = [C] . [O] . [P]

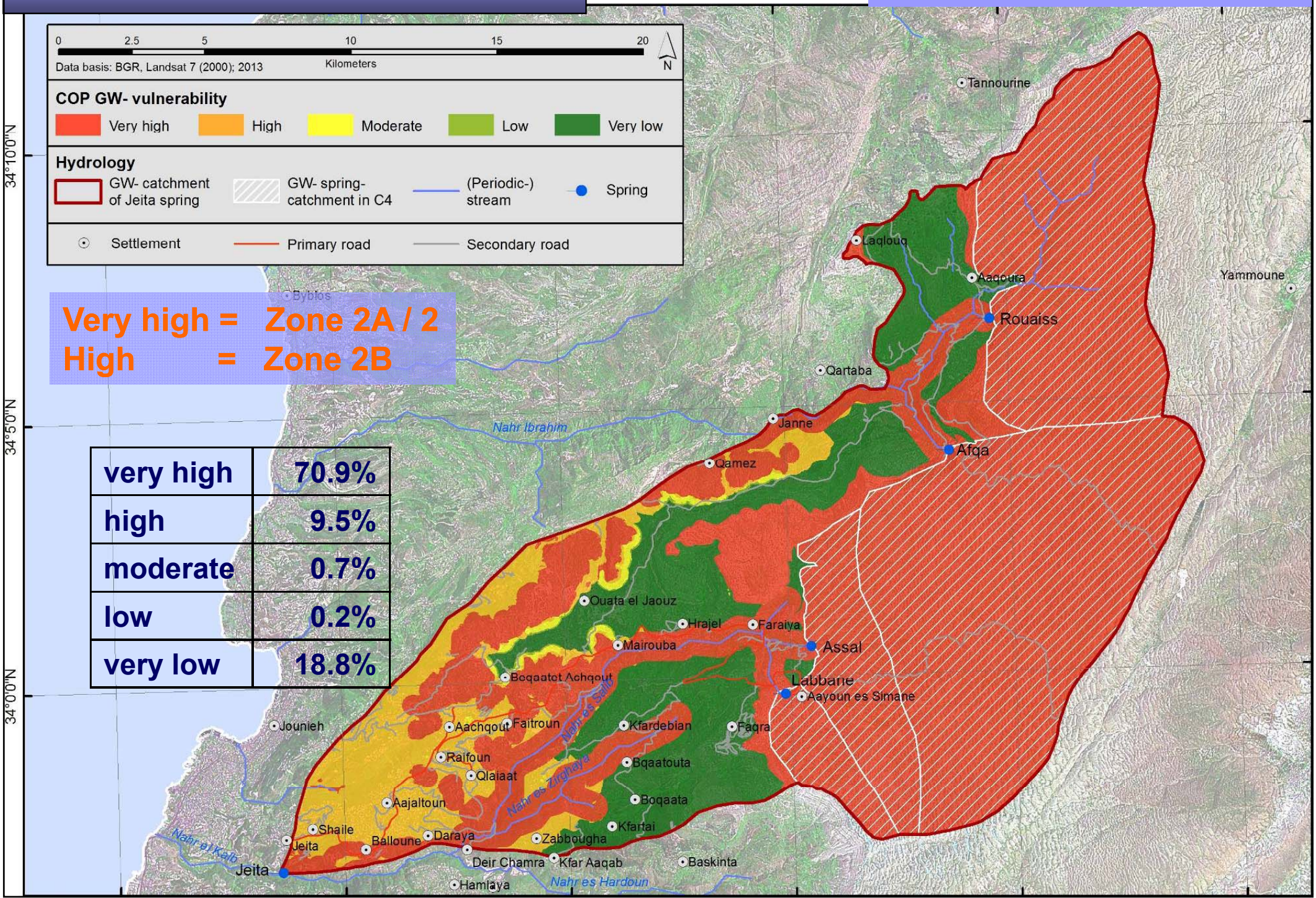
XVI

COP Index	Vulnerability classes
(0 - 0.5]	Very high
(0.5 - 1]	high
(1 - 2]	Moderate
(2 - 4]	Low
(4 - 15]	Very low

Groundwater Vulnerability

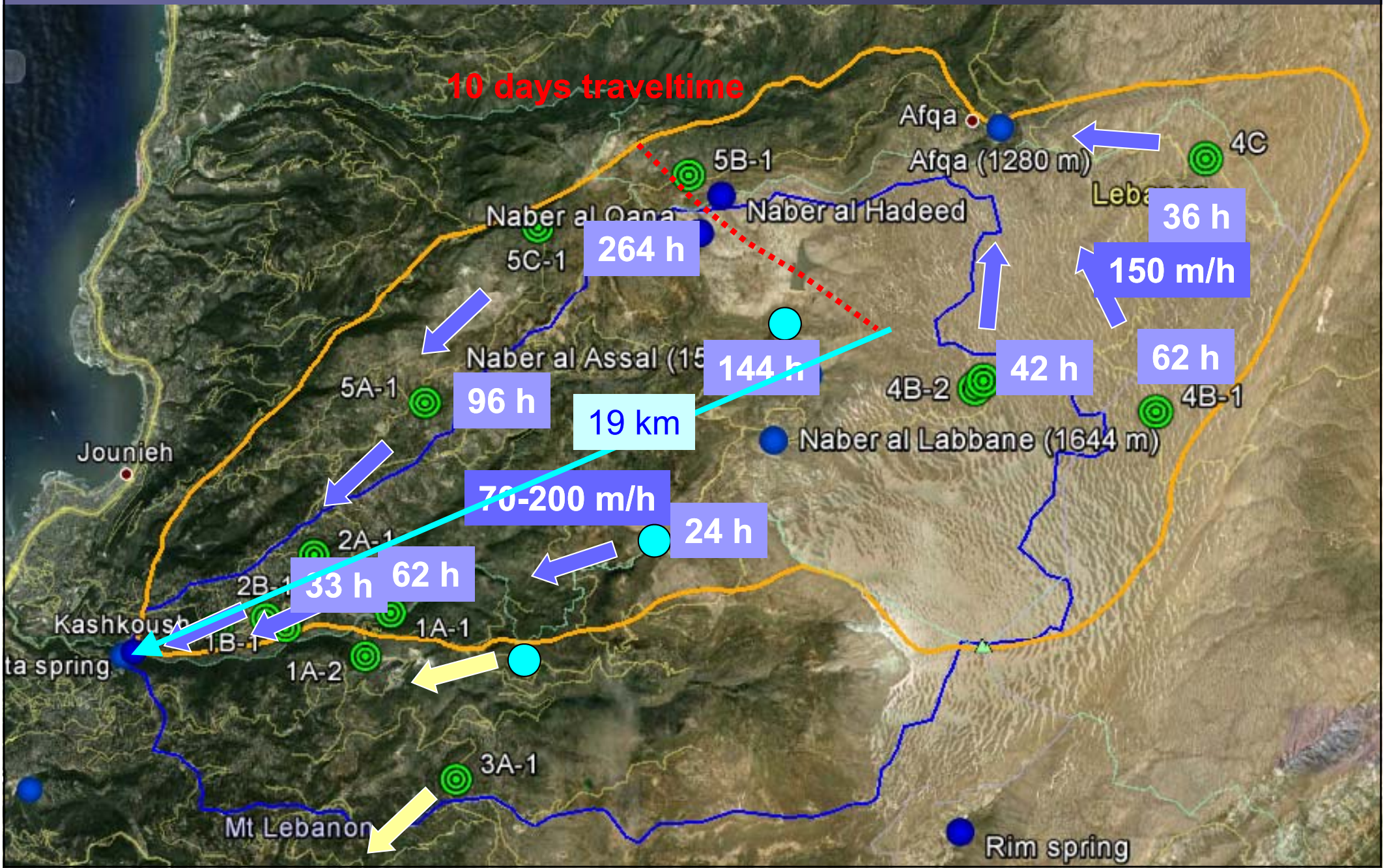
Groundwater Protection Zones

Groundwater Vulnerability COP Method (modified)



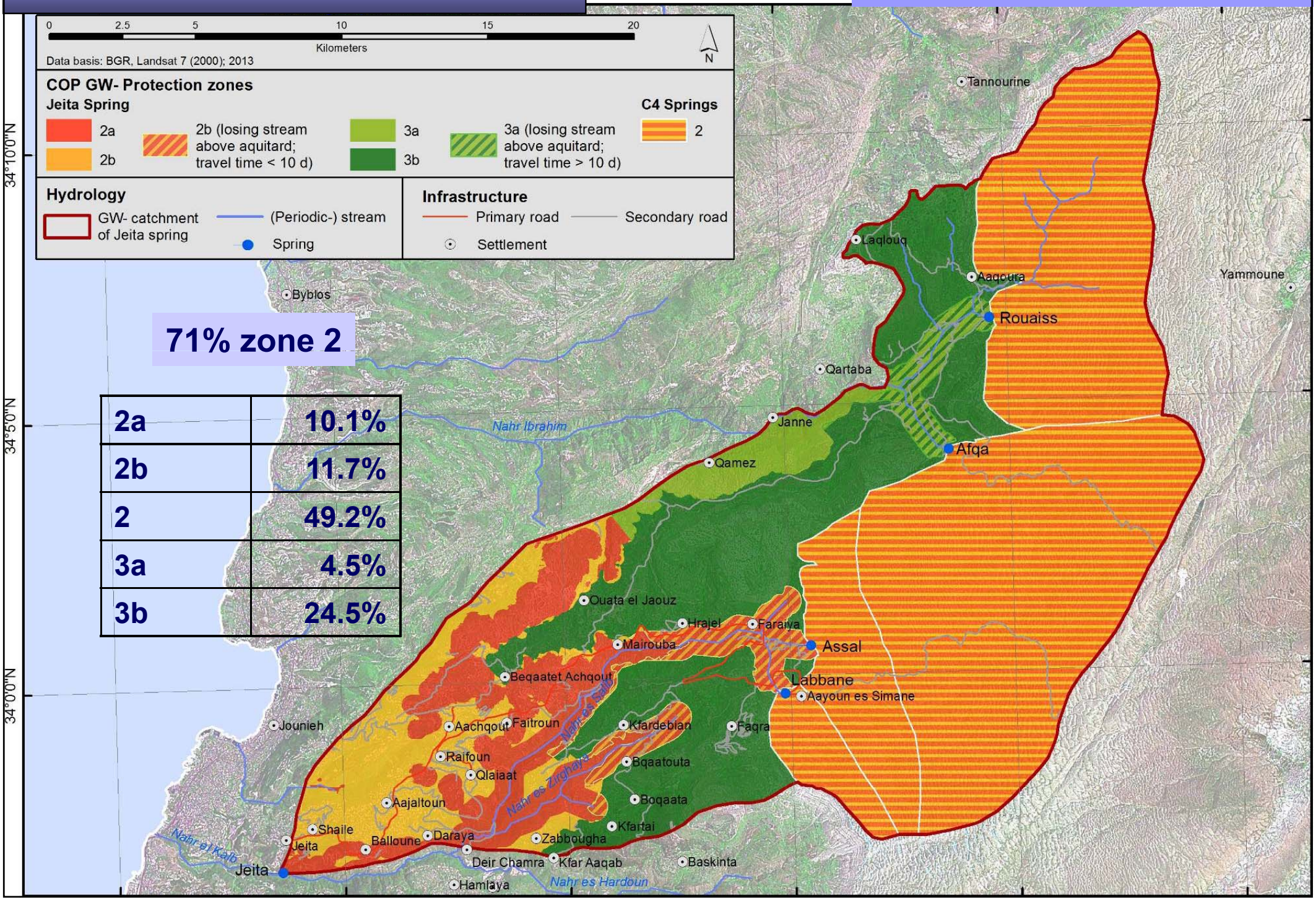
Groundwater Flow

Mean travel times



Groundwater Protection Zones

for Jeita, Afqa, Rouaiss, Assal and Labbane springs



Groundwater Protection Zones

zone 1: 50 m upstream, 15 m to each side, 10 m downstream of the spring and 10 m to each side of related water infrastructure, e.g. conveyor line, reservoir, etc. until entry into the actual water supply infrastructure; Zone 1 includes the area over the cave and underground river with a rock cover of less than 100 m;

zone 2A: groundwater travel time < 10 days, very high groundwater vulnerability, possible direct infiltration into underlying Jeita underground river: buffer zone 250 m from projected course;

zone 2B: groundwater travel time < 10 days, high groundwater vulnerability;

zone 3A: groundwater travel time > 10 days, very high groundwater vulnerability and

zone 3B: all other parts of the groundwater catchment.

New residential buildings should not be allowed to be built downgradient of the new wastewater collector line (escarpment collector).

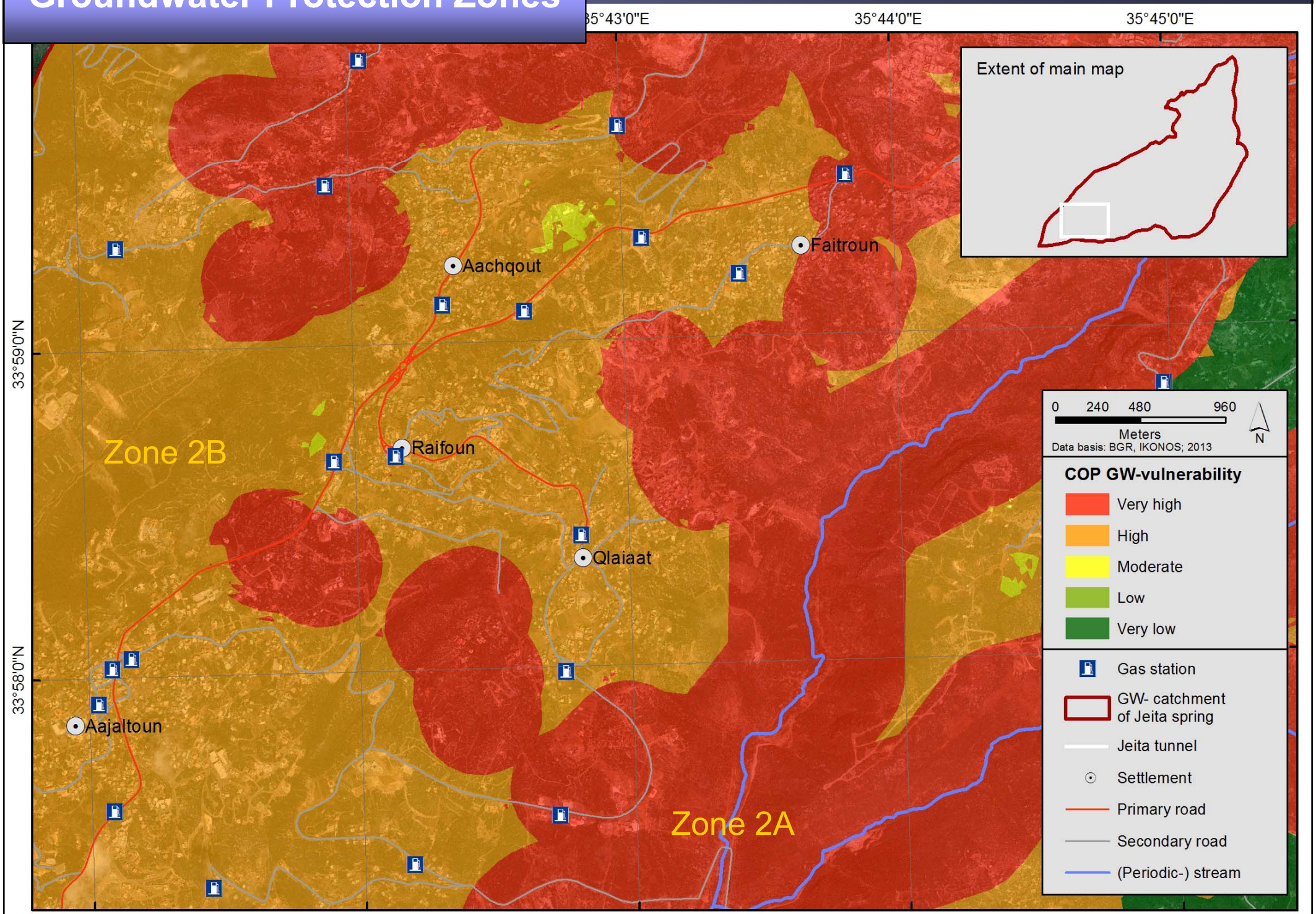
The **stormwater drainage along the main road** (Jeita - Faraiya highway) **should be enlarged** to ensure that all stormwater can be drained to a location outside protection zone 2A.

The following activities shall **not be allowed in zones 2A and 2B**:

- Gas stations,
- Industrial sites,
- Commercial businesses using hazardous substances,
- Quarries, rock cutting facilities, brick factories,
- Dumping of waste,
- Animal farms,
- Slaughterhouses,
- Application of pesticides and chemical fertilizers.

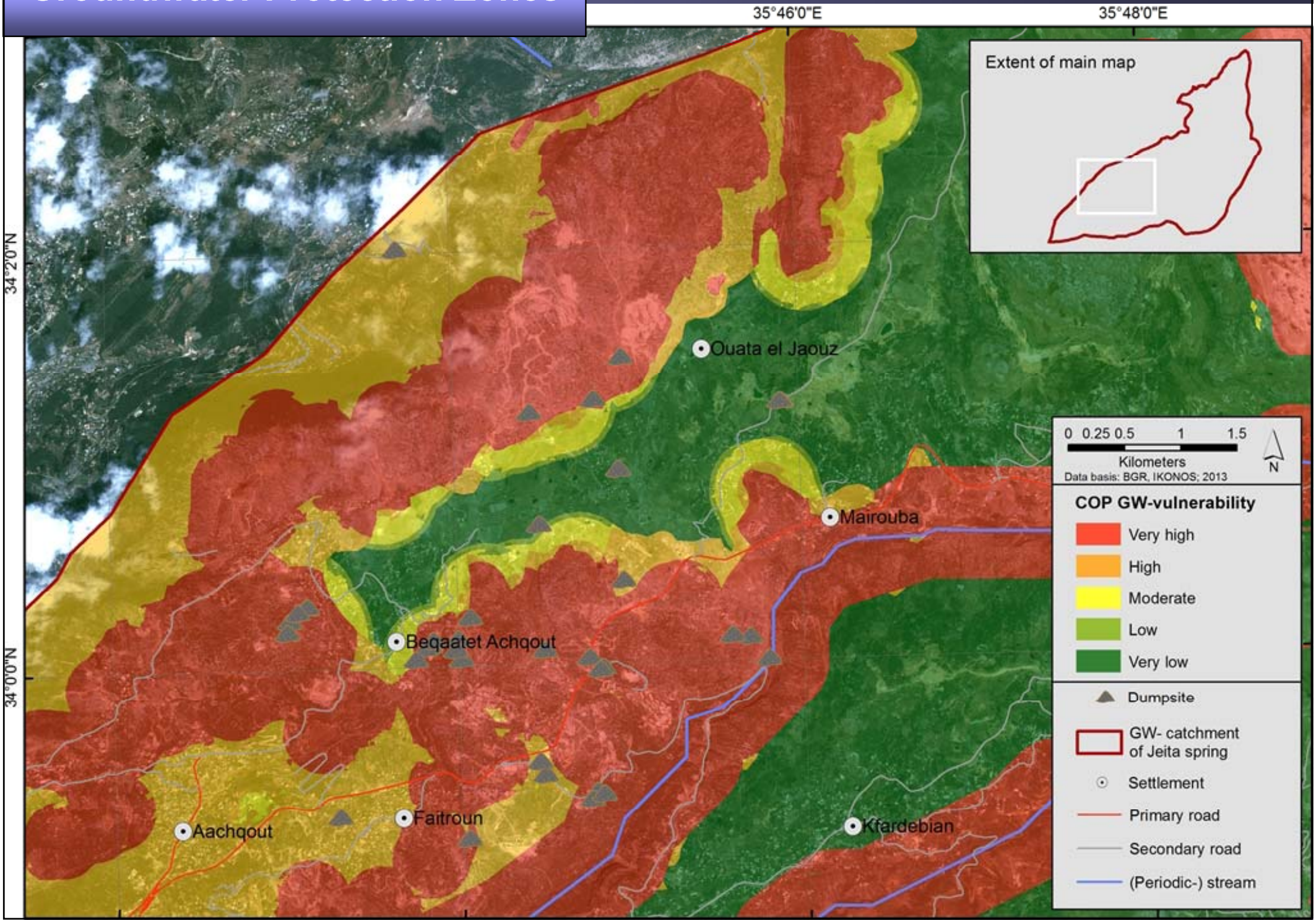
Groundwater Protection Zones

Impact of Gas Stations



Groundwater Protection Zones

Impact of Dump Sites



Thank you for your kind attention

www.bgr.bund.de/jeita

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