WATER HARVESTING IN THE DRY AREAS: Diversity and impact assessment

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CONTENT

- **General introduction**
- **Basic principles of WH and classification of WH types**
- **Main objectives/roles of WH**
- **Impact assessment**
  - ***Concept, Why ?***
  - ***Main methods***
- **Case applications and issues**
  - ***Crop production***
  - ***Fodder production***
  - ***Groundwater recharge***
  - ***Drinking/Watering***
  - ***Flood spreading / prevention***
  - ***Landscaping, ecotourism and cultural heritage***
  - ***Combined effects***
- **Conclusions**
- **Further readings**

INTRODUCTION

The dry areas are characterized by:

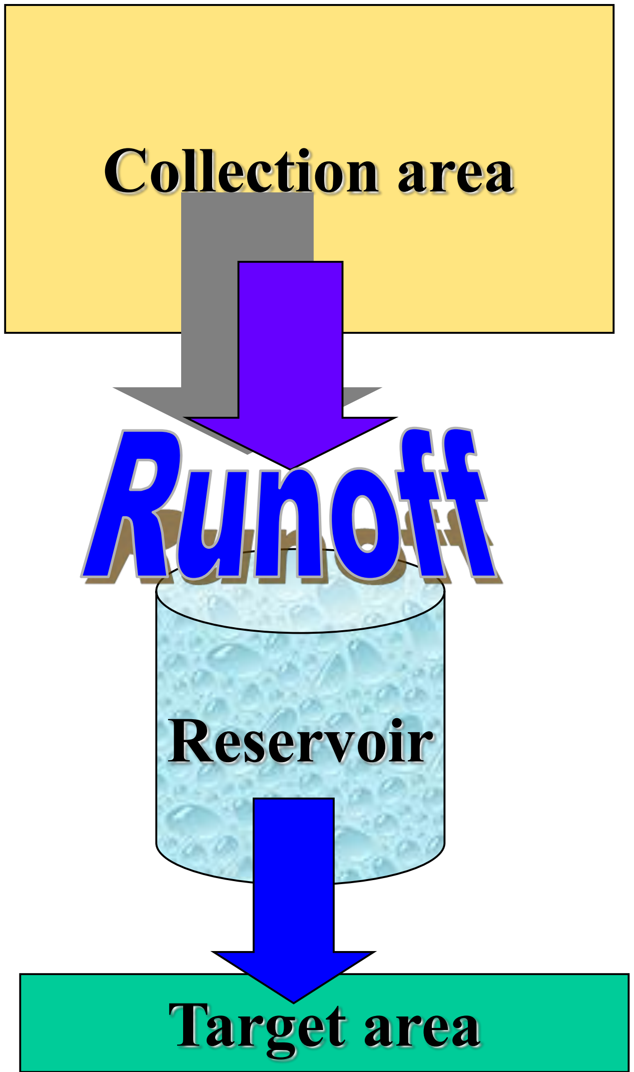
- **rainfall is *rare, variable and torrential***
  - ***Insufficient to meet the basic needs for crop production,***
  - ***Poorly distributed over the growing season ➔ risky farming***
  - ***Runoff can cause erosion and be lost later by evaporation from swamps 'salt sinks",***
- **High temperature ➔ evapotranspiration**
- **Shallow and poor soils ➔ degradation, moisture stress ➔ desertification**
- **Dominating rainfed agriculture**
- **An increasing competition (drinking, industry, tourism, agriculture, etc.) vis-à-vis the water resources**

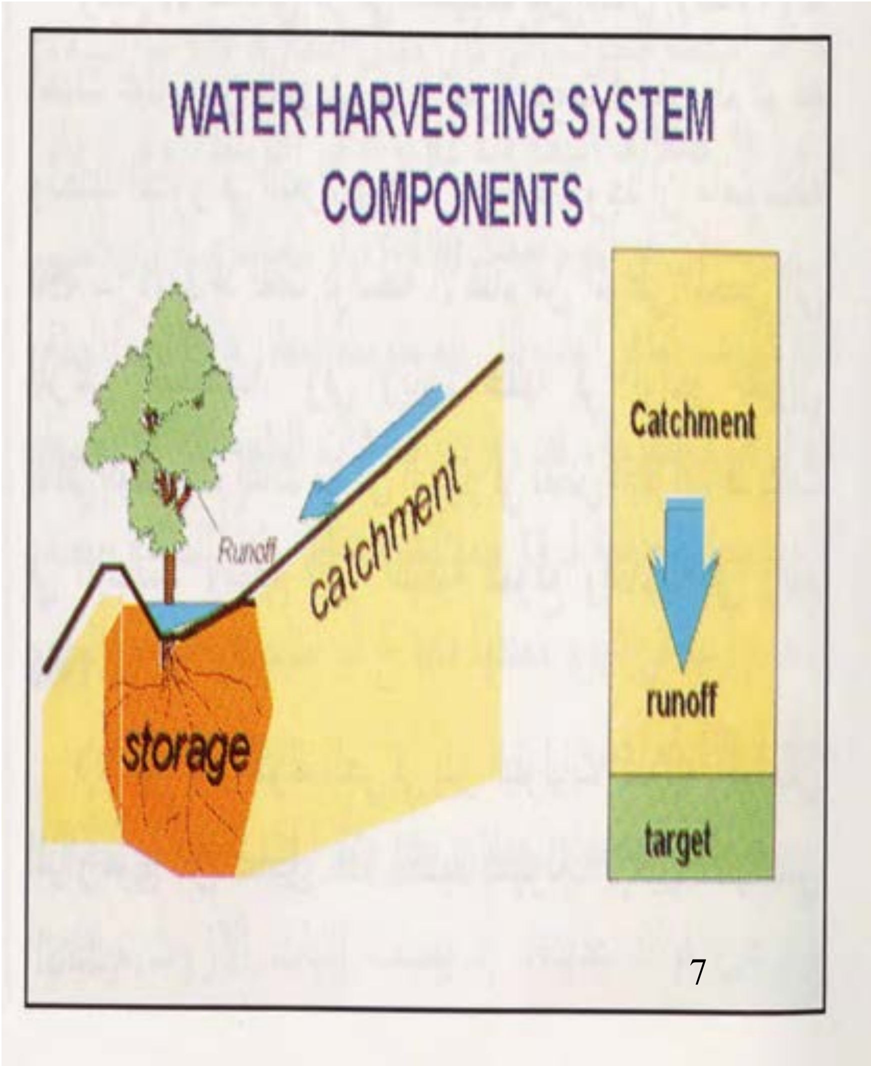
BASIC PRINCIPLE

&

CLASSIFICATION

***Depriving* part of the land of its share of rain, which is usually small and non productive, and *adding* it to the share of another part in order to bring the available water amount closer to the *water requirements* of crops (Oweis et al., 2001)**



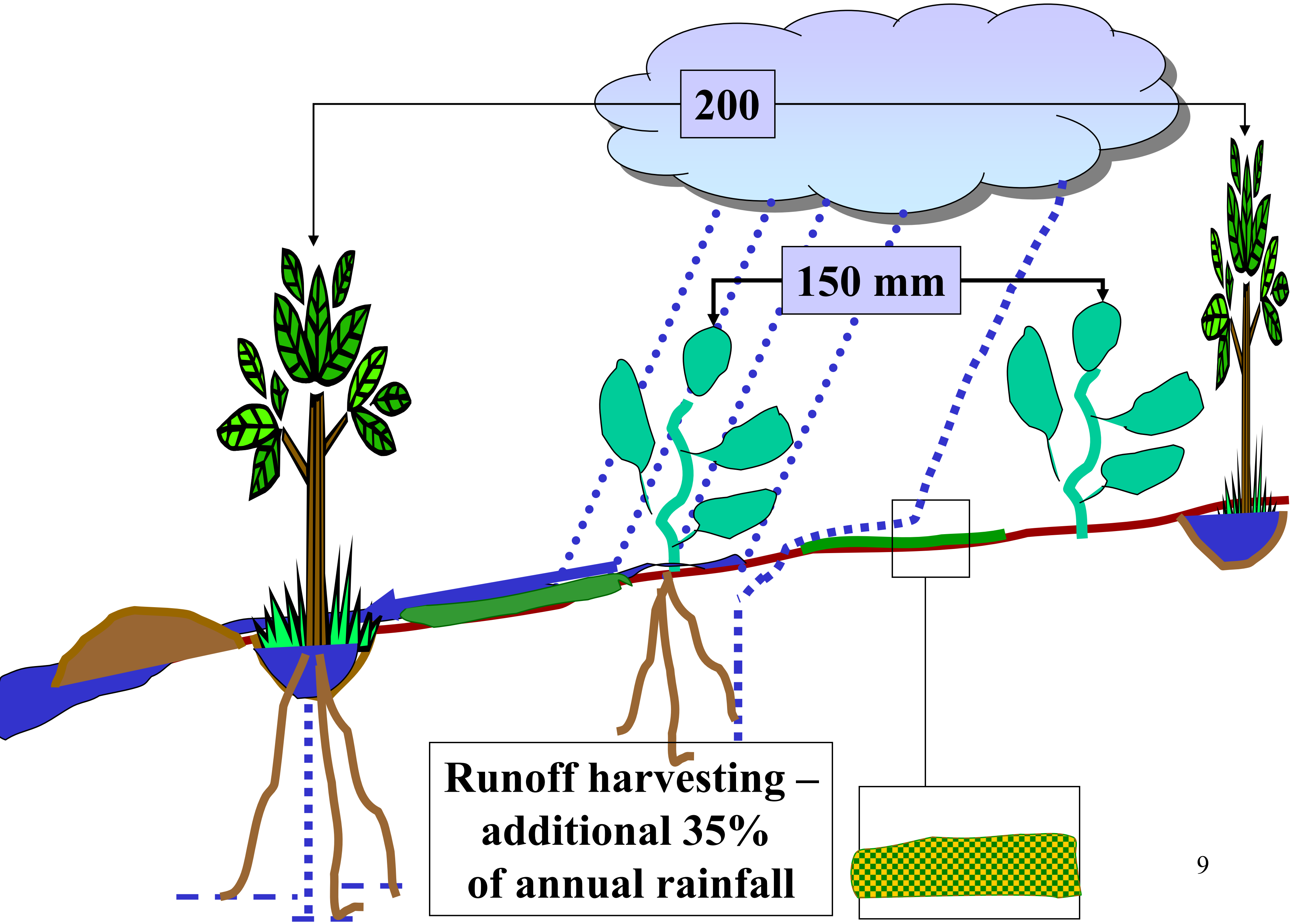


DEFINITIONS

- **WH is the practice of collecting water from an area treated to increase runoff from rainfall or snowmelt (Meyers, 1975)**

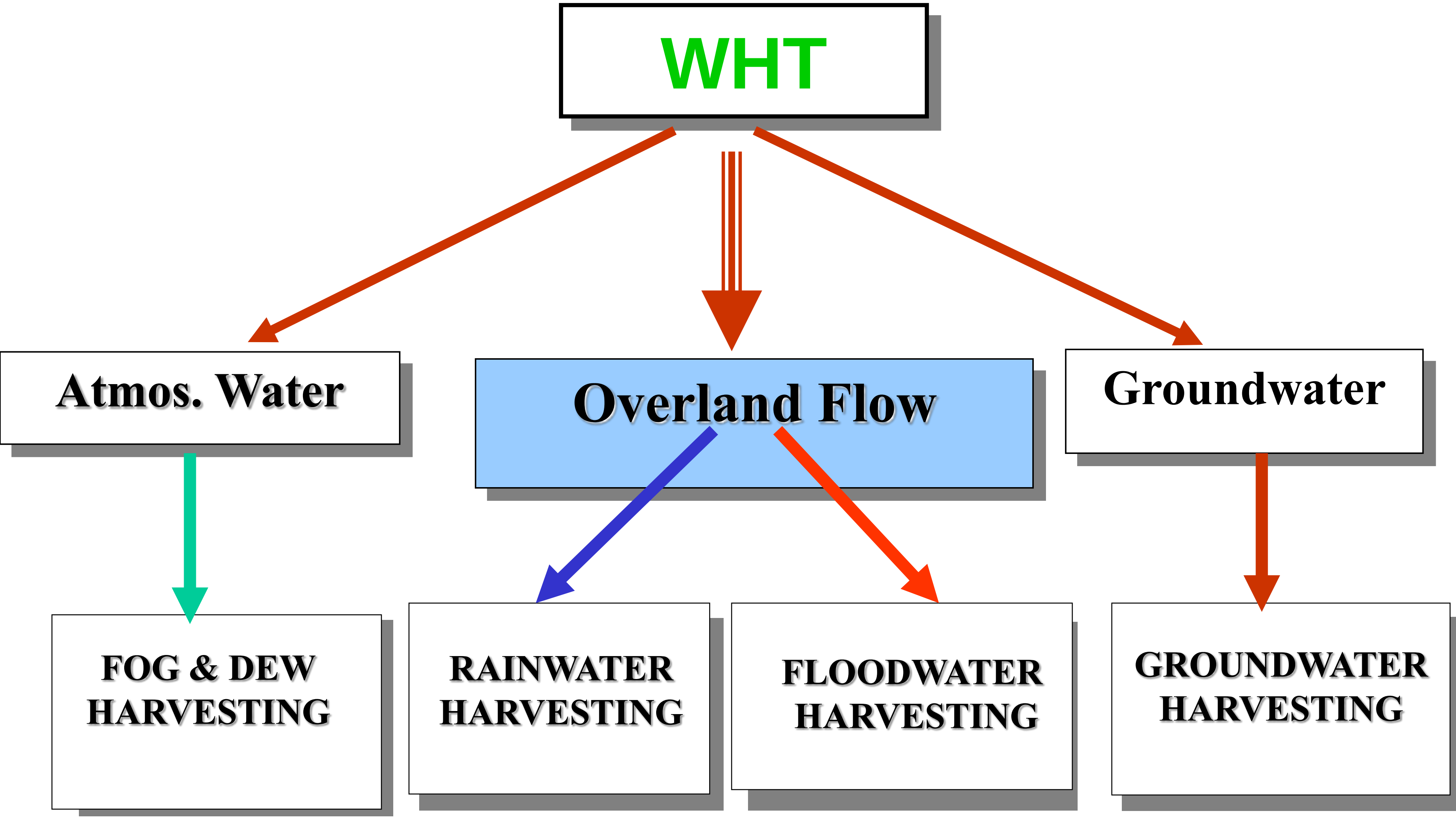
- **WH is a method to induce, collect, and conserve local surface runoff for agriculture in arid and semi arid regions (Boers & Ben-Asher, 1982)**

- **WH is the process of concentrating precipitation, through runoff and storage, for beneficial use (Oweis et al., 2001)**



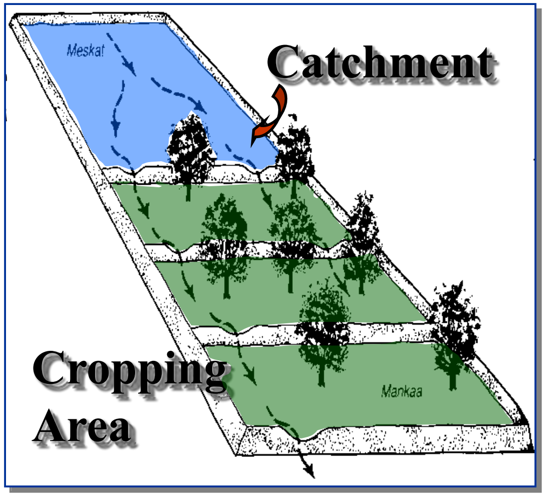
Runoff harvesting – additional 35% of annual rainfall

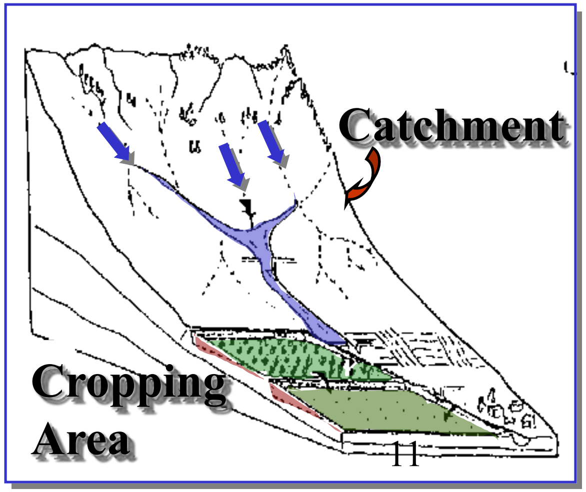
CLASSIFICATION (Prinz, 1994. Oweis et al., 2012)



RAINWATER HARVESTING

Rooftop & Courtyard Water Harvesting	Micro-catchment Water Harvesting	Macro-catchment Water Harvesting





Development of WH

- **As long as the people have inhabited the dry areas and made cultivation, they have harvested water.**
- **In southern Jordan early WH structures are believed to have been constructed around 5000 years ago,**
- **Southern Mesopotamia: 4500 BC,**
- **Negev desert: 1000 BC,**
- **Yemen (Tihama): spreading system dating 1000 years BC**
- **Pakistan (Balauchistan): Khuskaba and salaiba systems**
- **Tunisia: Jessour, meskat and cisterns,**
- **Egypt (North west and Sina): wadi bed systems and cisterns,**
- **Moroccco, Syria, Iran, Oman, : Groundwater galleries (fouggara, falej, …).**

IMPACT ASSESSMENT

Why ?/ Objectives

- Evaluation of efficiency (technical, socio-economic, environmental, etc..) of undertaken works
- Recommend adjustments (choice of techniques, design, implementation, etc.)

How ?/ Methodologies

- Technical monitoring (scientific)
- Surveys
- Modeling

Soil erosion and runoff traps

Infiltrometer:

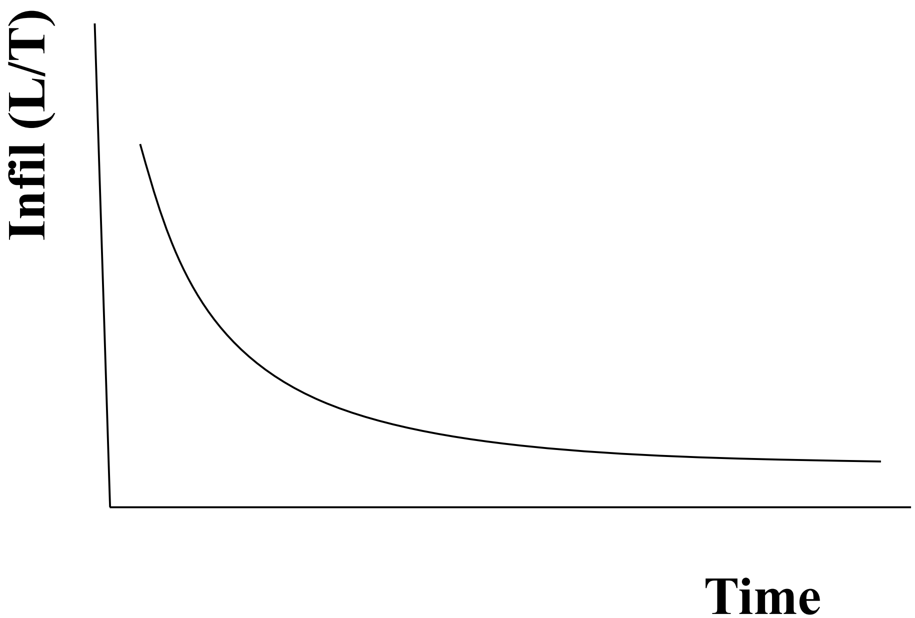
Infiltration

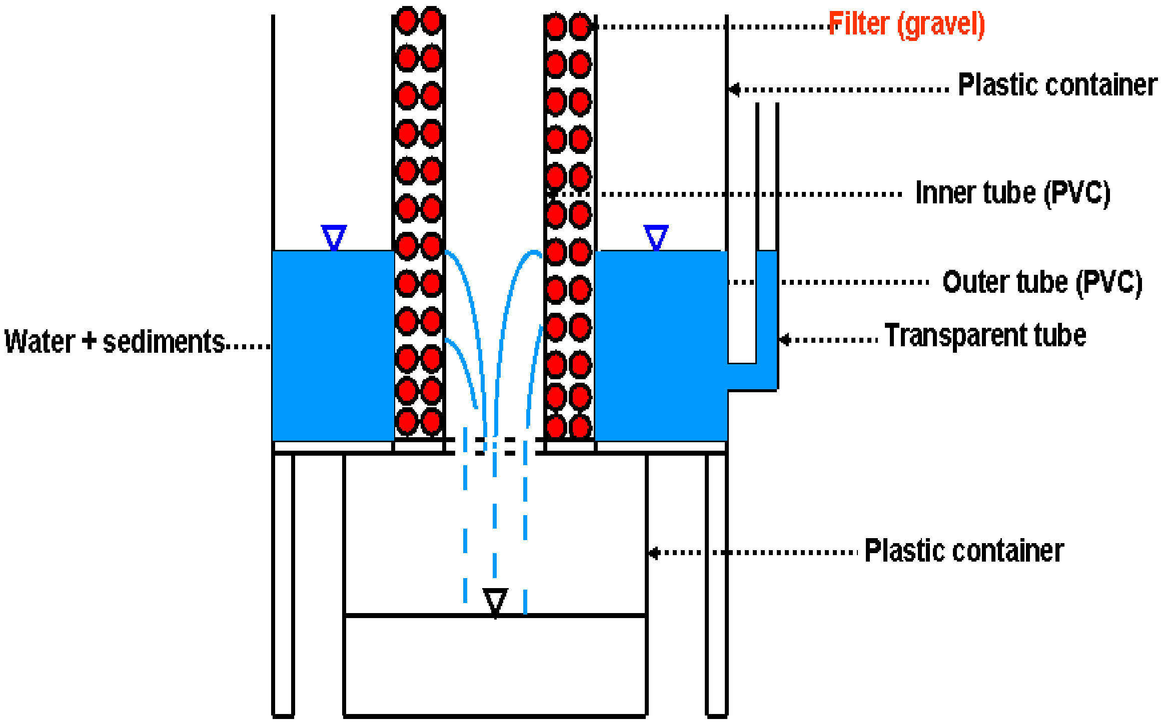
Rainfall simulation:
Infiltration = Rain-Runoff
Erosion

Gauging stations


TDR TRIME

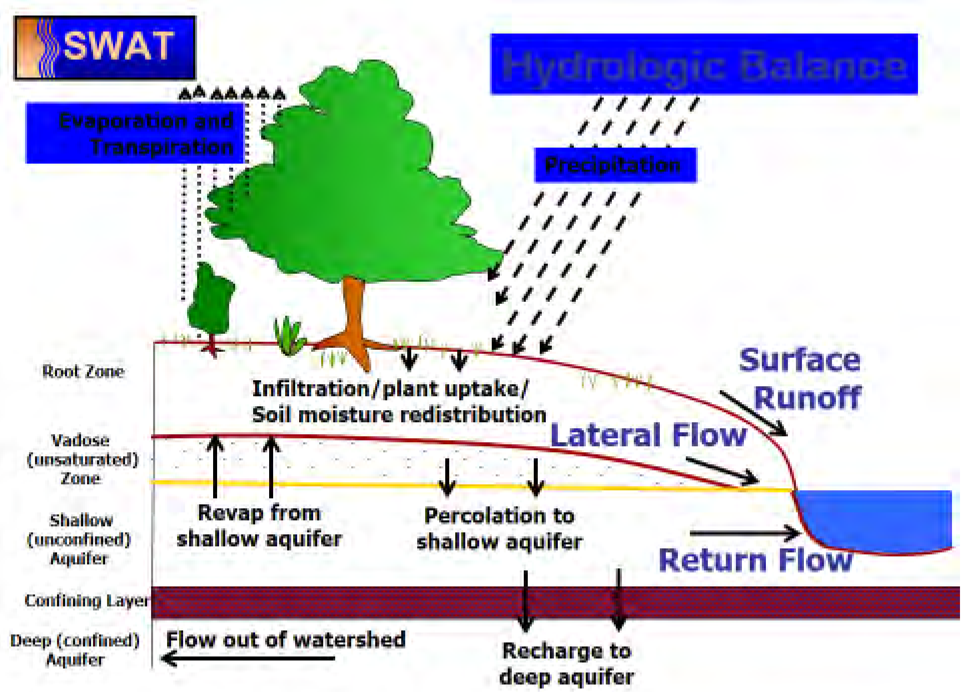
Double ring infiltrometer

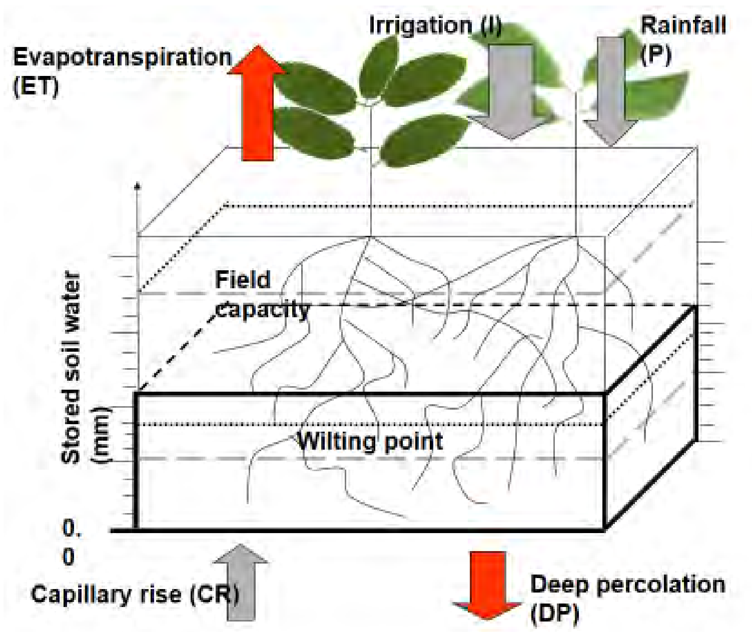




Recharge well Laboratory prototype experiment

Modelling


SWAT
Hydrologic Balance
Evaporation and Transpiration
Precipitation
Root Zone
Vadose (unsaturated) Zone
Shallow (unconfined) Aquifer
Confining Layer
Deep (confined) Aquifer
Infiltration/plant uptake/ Soil moisture redistribution
Surface Runoff
Lateral Flow
Revap from shallow aquifer
Percolation to shallow aquifer
Return Flow
Flow out of watershed
Recharge to deep aquifer


Irrigation (I)
Rainfall (P)
Evapotranspiration (ET)
Field capacity
Wilting point
Stored soil water (mm)
0.
0
Capillary rise (CR)
Deep percolation (DP)

Field surveys/questionnaire

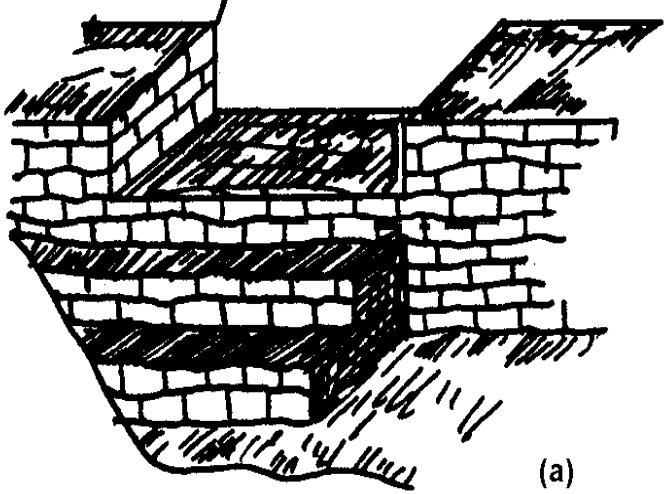
CASE APPLICATIONS

RAIN WATER HARVESTING

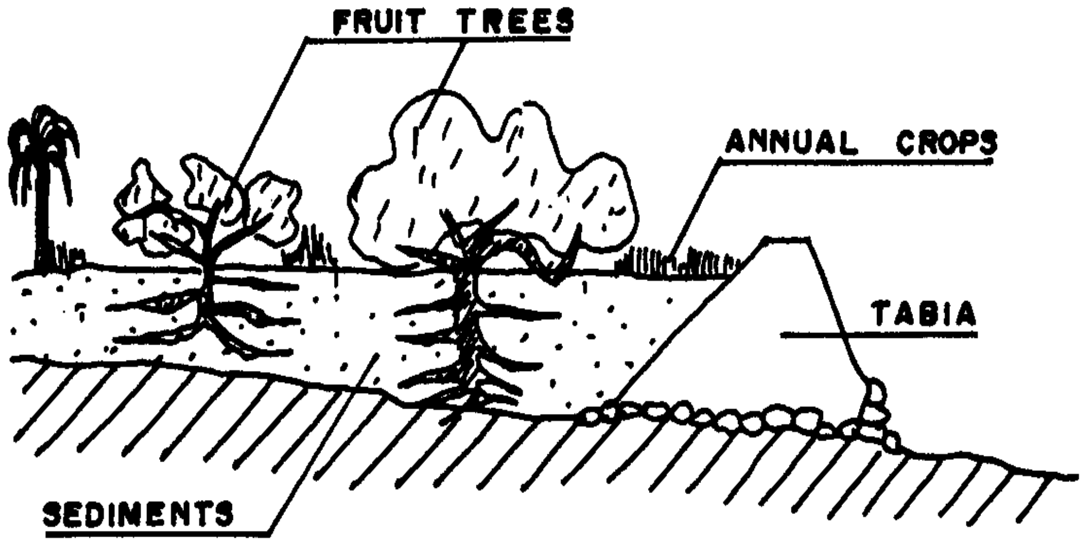
RAIN-WATER USE FOR LIFE

Crop production

Jessour in Southern Tunisia



(a)



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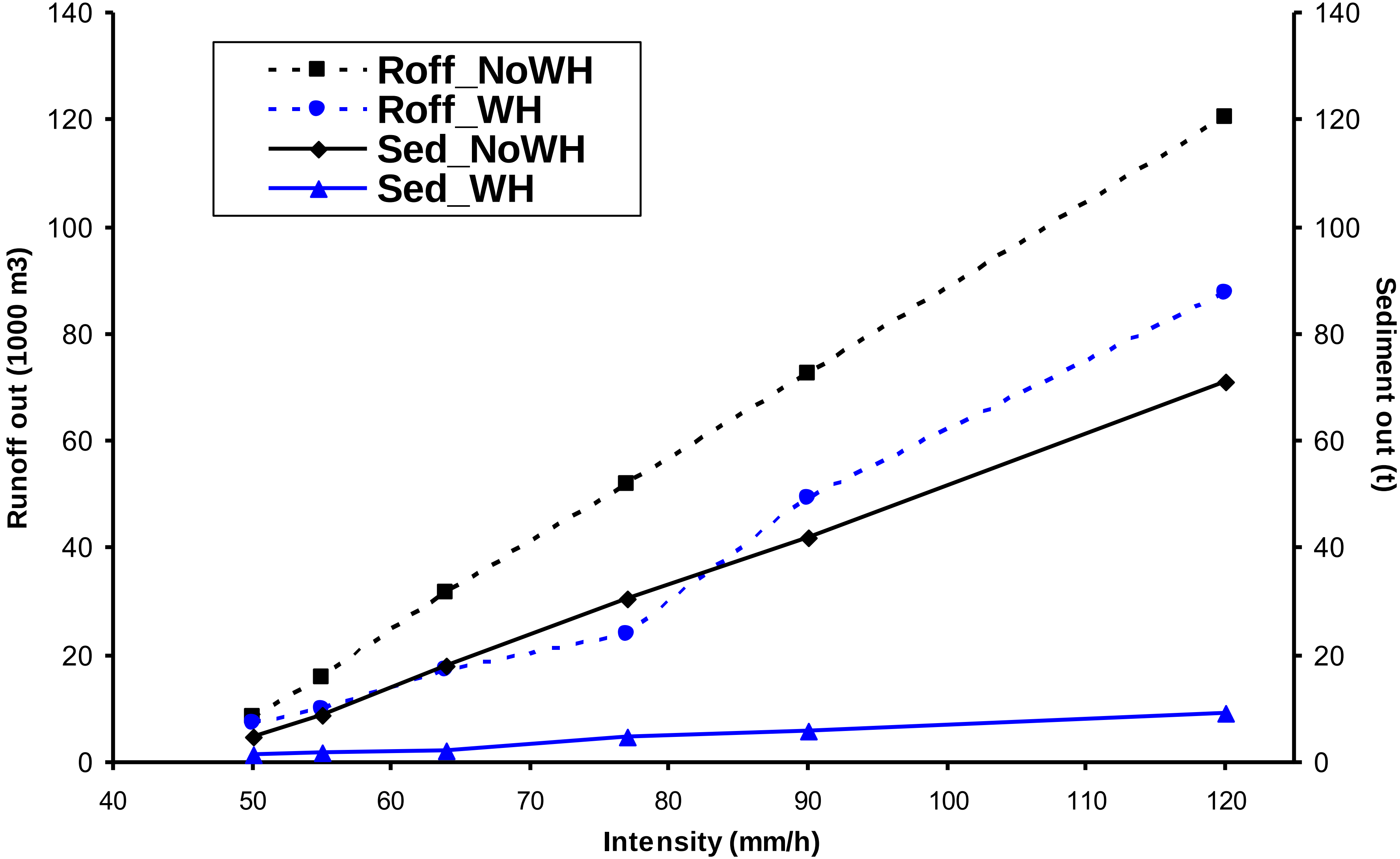
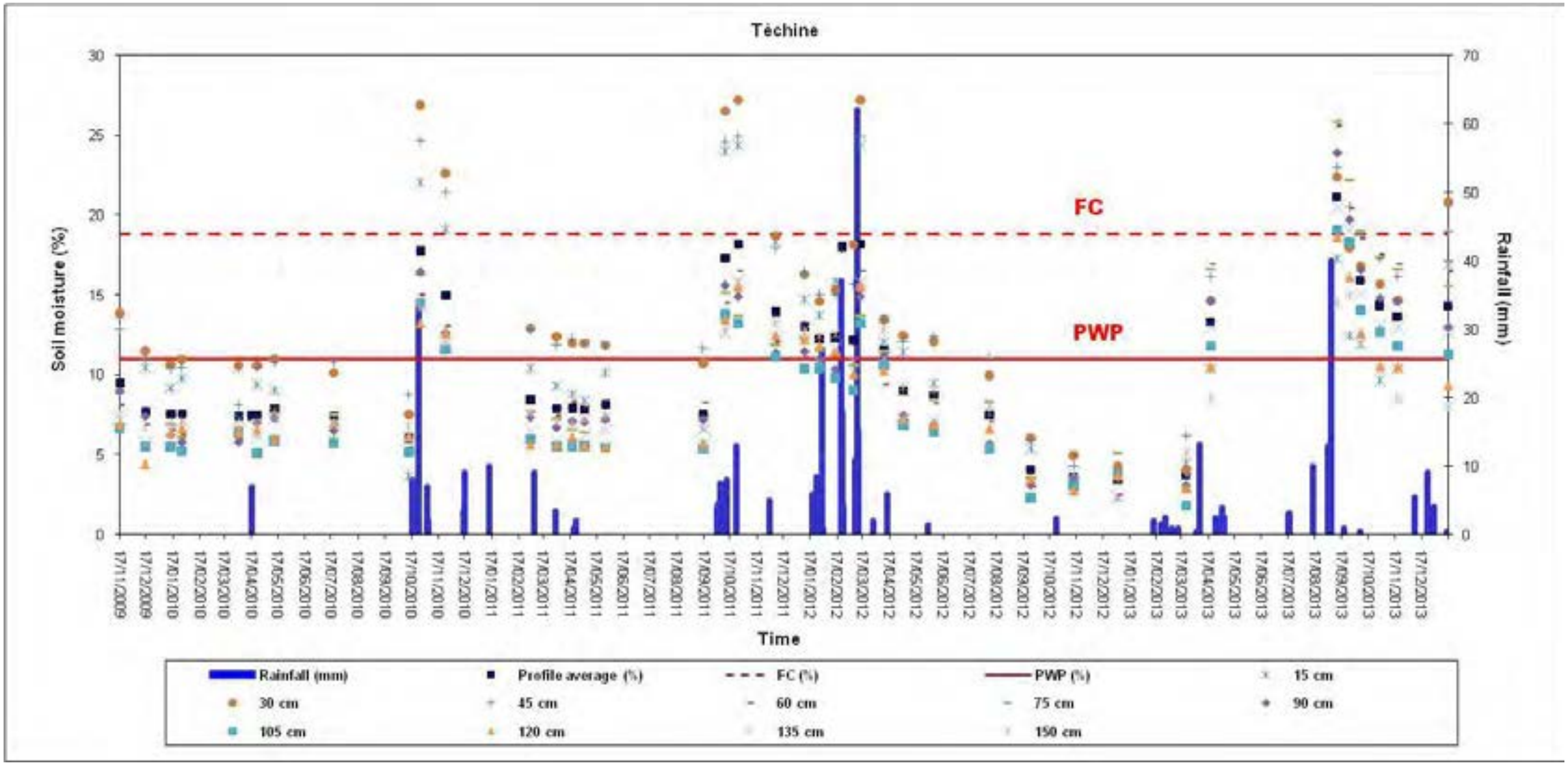


Ouessar, 2007

Ouessar, 2007

Hyd. Year	ET_{rel} (2/1)	ET_{rel} (3/1)	ET_{rel} (3/2)
Wet	1.1	-	-
Dry	2.3	2.5	1.1
Very dry	**12.0**	**15.6**	**1.3**

Hyd. Year: type of the hydrological year
ETrel: relative ETa
1: ETa with only rainfall on the terrace
2: ETa with rainfall and runoff on the terrace
3: ETa with rainfall, runoff and supplemental irrigation



Variation of average soil moisture (% vol.) at different depths in the *jesr* of Techine.

Abdelli et al., 2016

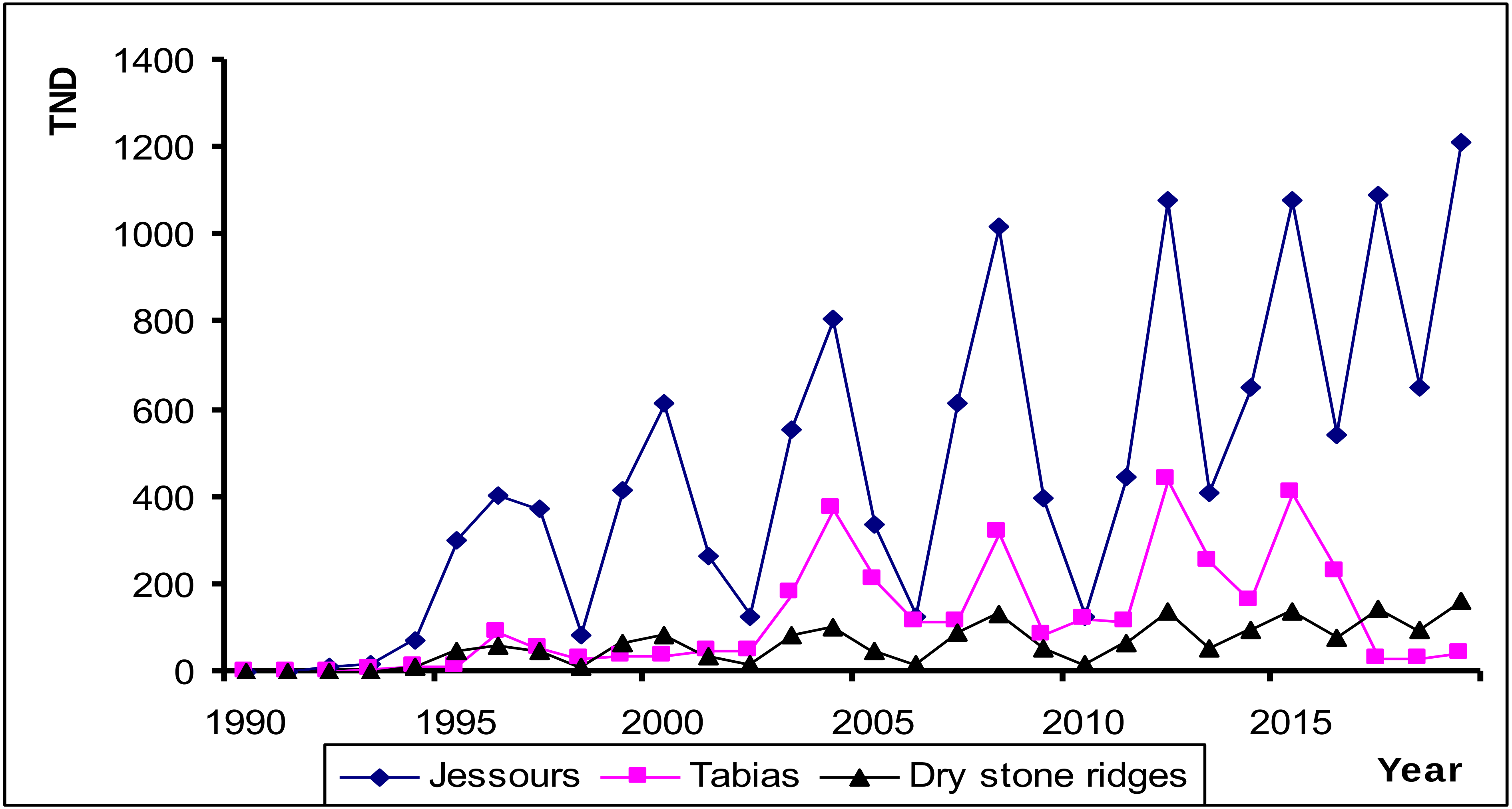
Farmers appreciation of the WH works impacts in the SWS (Sghaier et al., 2003).

Group	WH impacts[a]					
	Yield ↑	Erosion ↓	Recharge ↑	Runoff ↓	Flooding ↓	Diversification ↑
Beneficiaries of WH works	56%	100%	100%	33%	100%	100%
Irrigators on borehole wells	87%	100%	100%	38%	75%	88%
Irrigators on surface wells	100%	100%	100%	50%	75%	100%
Herders	Rangelands degradation	Rangelands area ↓	Species disappearance	Runoff ↓	Flooding ↓	Diversification ↑
	80%	60%	0%	75%	100%	-
Fishing men	Clovis ↓	Erosion ↓	Recharge	Runoff ↓	Flooding ↓	Diversification ↑
	50%	100%	100%	75%	100%	-

a: expressed as percentage of inquired farmers in favour of the statement.

↑: increase

↓ : decrease



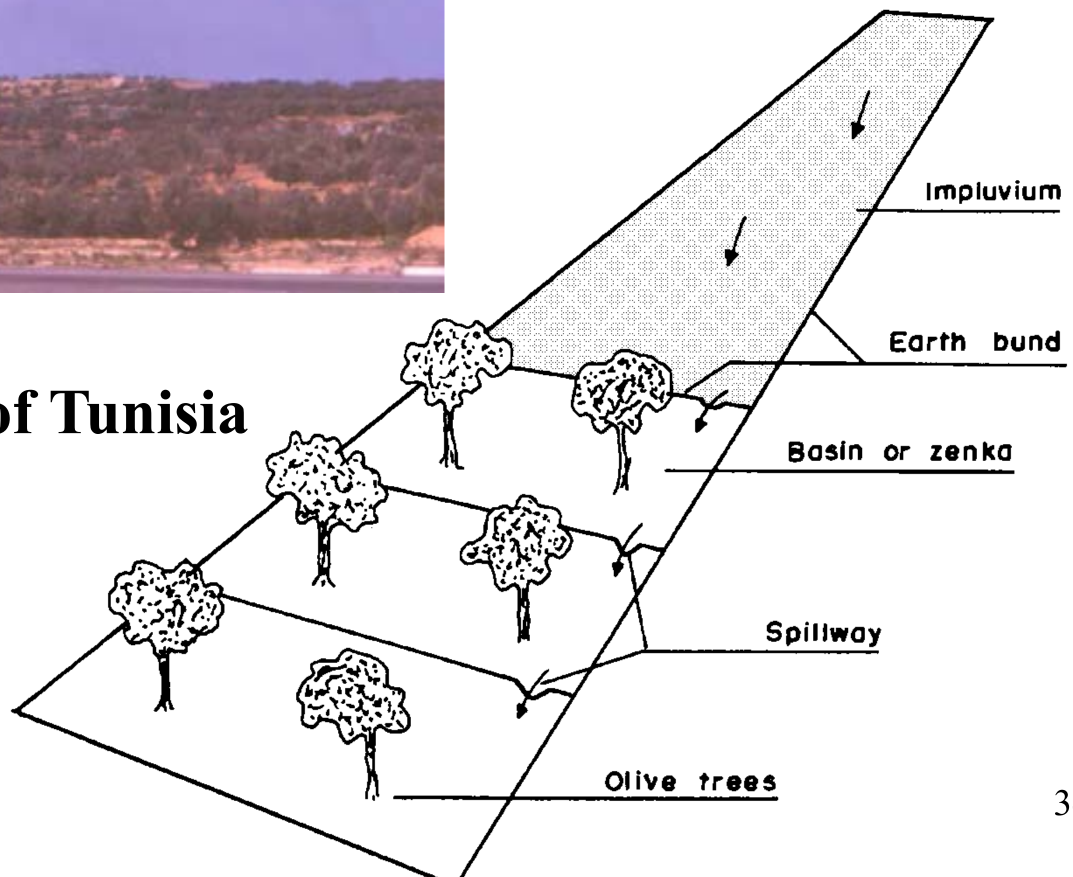
Gross production value per hectare, by type of structure and by year (case of newly installed plantations) (After Sghaier *et al*., 2002).

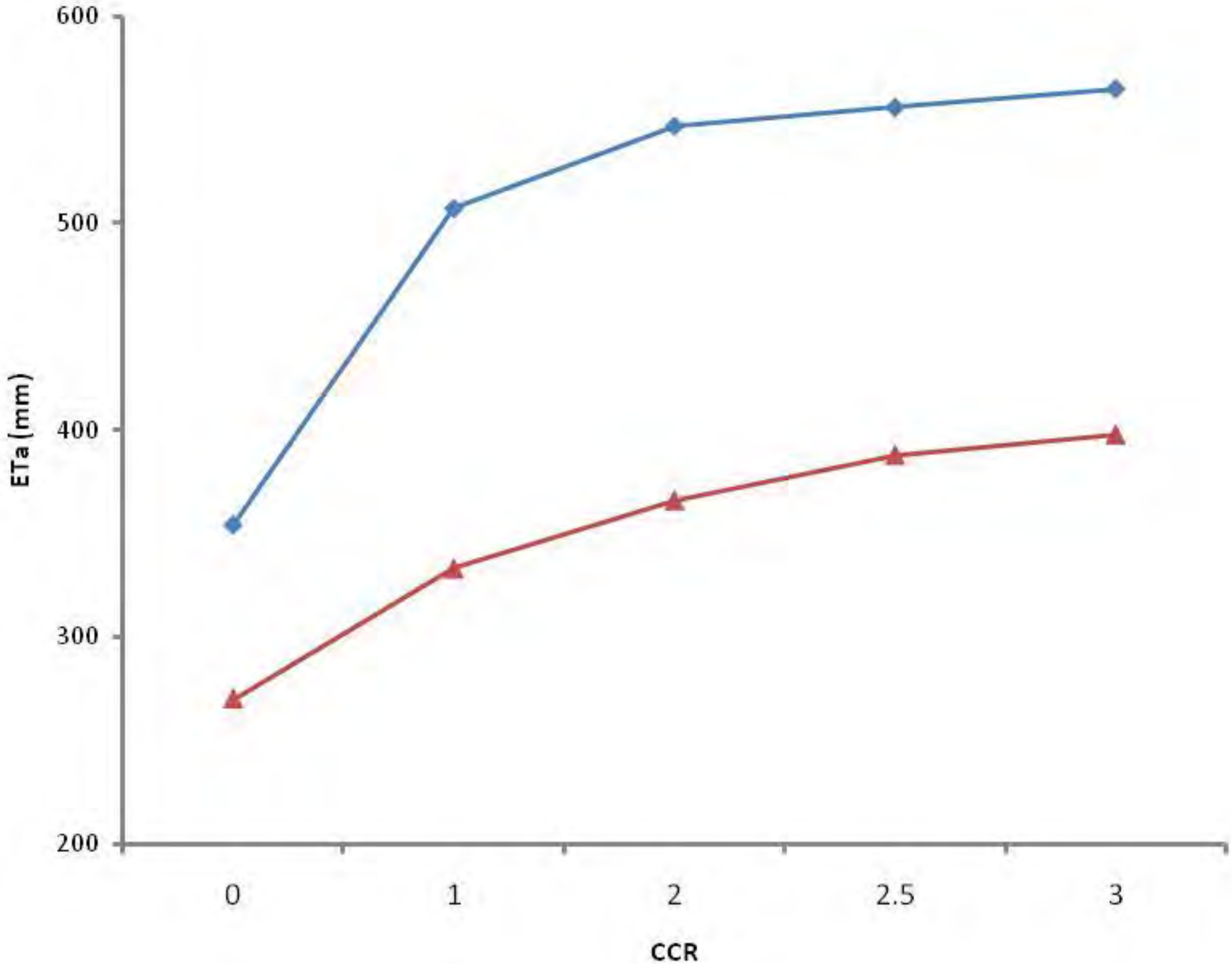
	NPV			IRR (%)
Discounting rate	10.8	8	13.8	
Financial analysis	-1.065	-0.703	-1.194	5.47
Conventional economic analysis	0.285	0.934	-0.048	13.25
Extended economic analysis I	0.798	1.677	0.13	18.43
Extended economic analysis II	1.049	1.97	0.521	25.98
Social economic analysis	1.15	2.166	0.576	27.8

Sghaier et al., 2002).

Recurrent droughts and need for SI

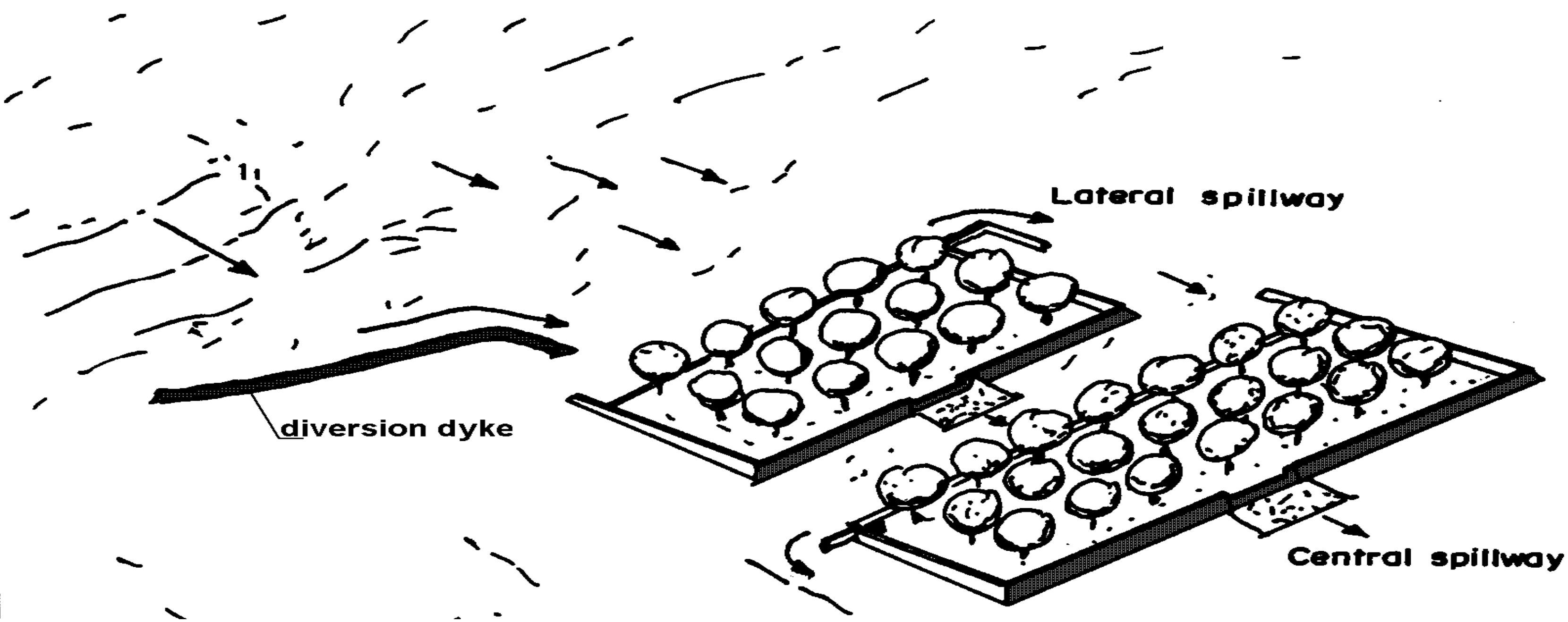
Meskat in the Sahel of Tunisia

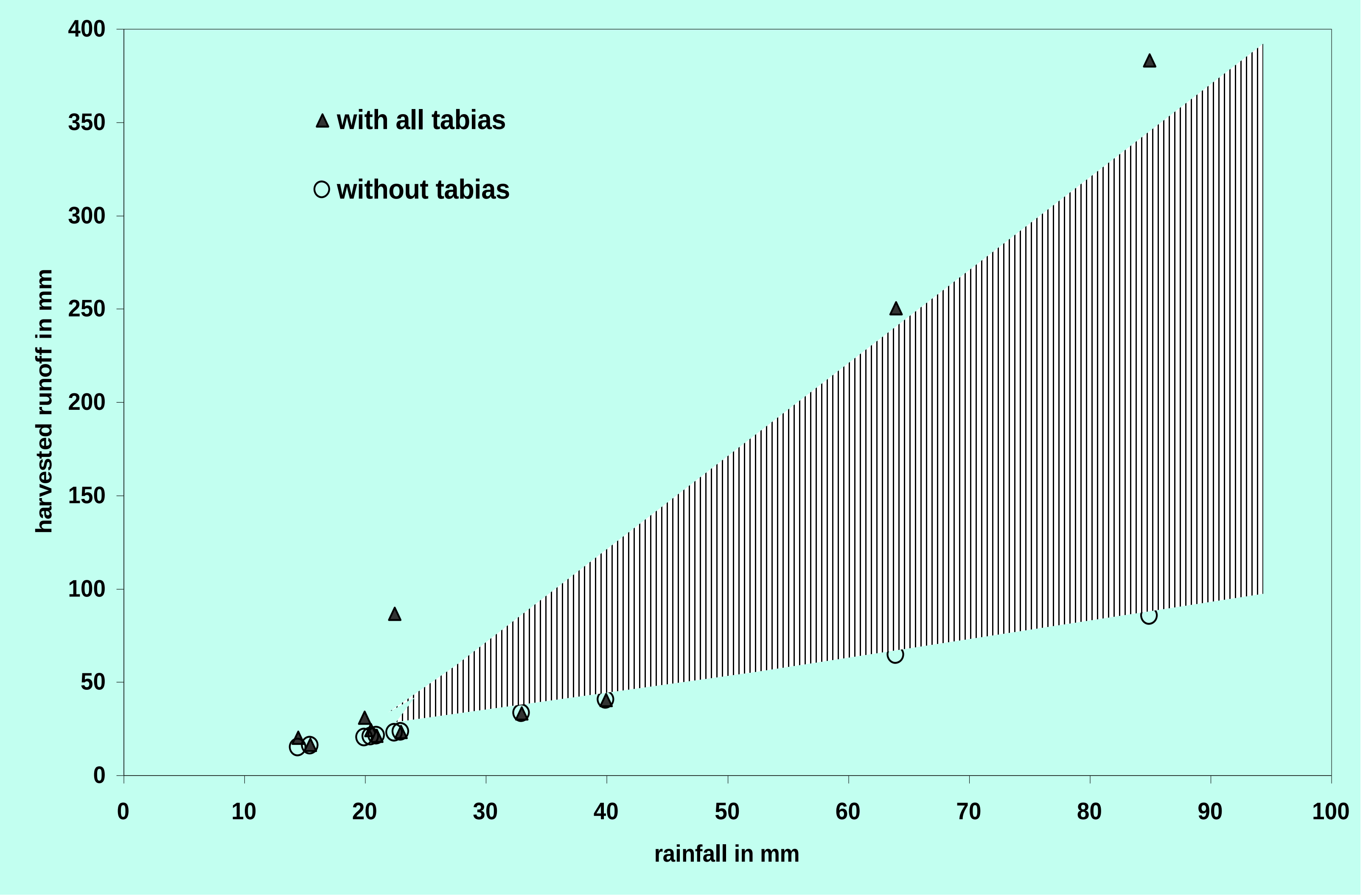




ETa in a Meskat system for different CCR and annual rainfall (green: 413 mm; Red: 290 mm)

Tabia with natural impluvium in Central Tunisia



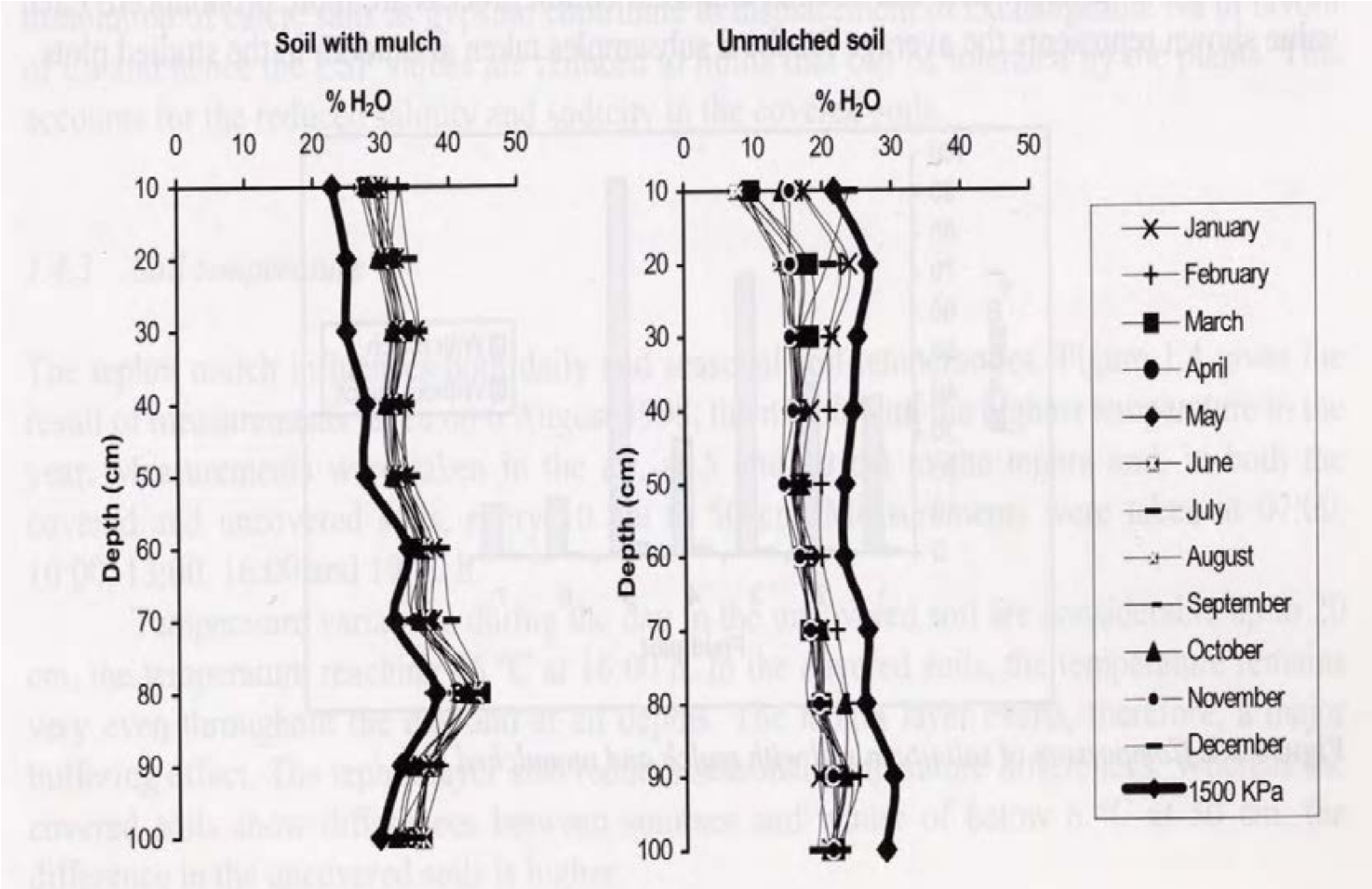


Nasri et al., 2004

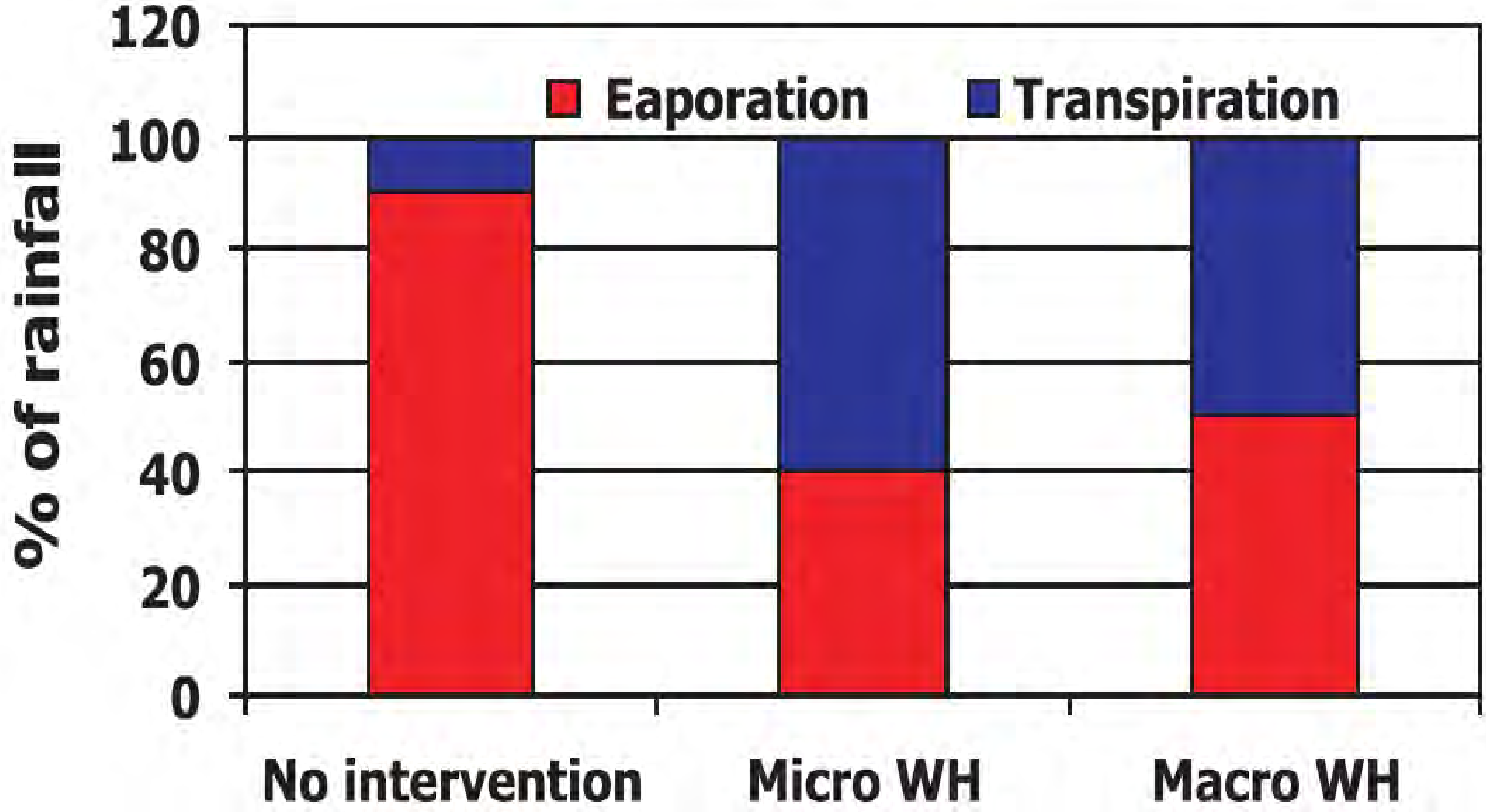
Fruit trees

Annual crops

System of *arenados* at the Islands of Lanzarote (Canaries)



Source: Tejedor et al. (2002)



Role of water harvesting in shifting nonproductive water evaporation into beneficial transpiration.

(Oweis et al., 1999; Oweis, 2006)

Fodder production

Table 3.15. Vegeation cover and plant height increase for *Atriplex* and *Salsola* species in the Vallerani experiment at different spacing treatments (catchment areas) during the 2005/06 growing season (until June).

Catchment area	*Atriplex* spp.		*Salsola* spp.	
	Cover (%)	Height (cm)	Cover (%)	Height (cm)
Control	17 b	13 b	17 c	7 b
5 m (14 m^2)	85 a	25 b	78 a	33 a
10 m (28 m^2)	82 a	42 a	62 b	35 a

Karrou et al., 2011

Table 6. Forages and fodder productivity improvement in watershed treated with rainwater and soil conservation measure in India

Watershed	State	Productivity (t/ha)		
		Pre-treatment	Post treatment	% increase
Sukhomajri	Haryana	2.47	5.05	104
Bunga	Haryana	0.20	3.20	1500
Bazar Gunyar	Haryana	0.10	0.50	400
Chhajawa	Rajasthan	0.10	5.42	4420
Navamota	Gujarat	1.00	2.00	100
Chhinatekur	A.P.	0.88	11.60	1218
G.R.Halli	Karnataka	1.50	8.19	446
Fakot	Uttarakhand	3.90	12.0	208
Average		1.27	5.95	372

Samra, 2015

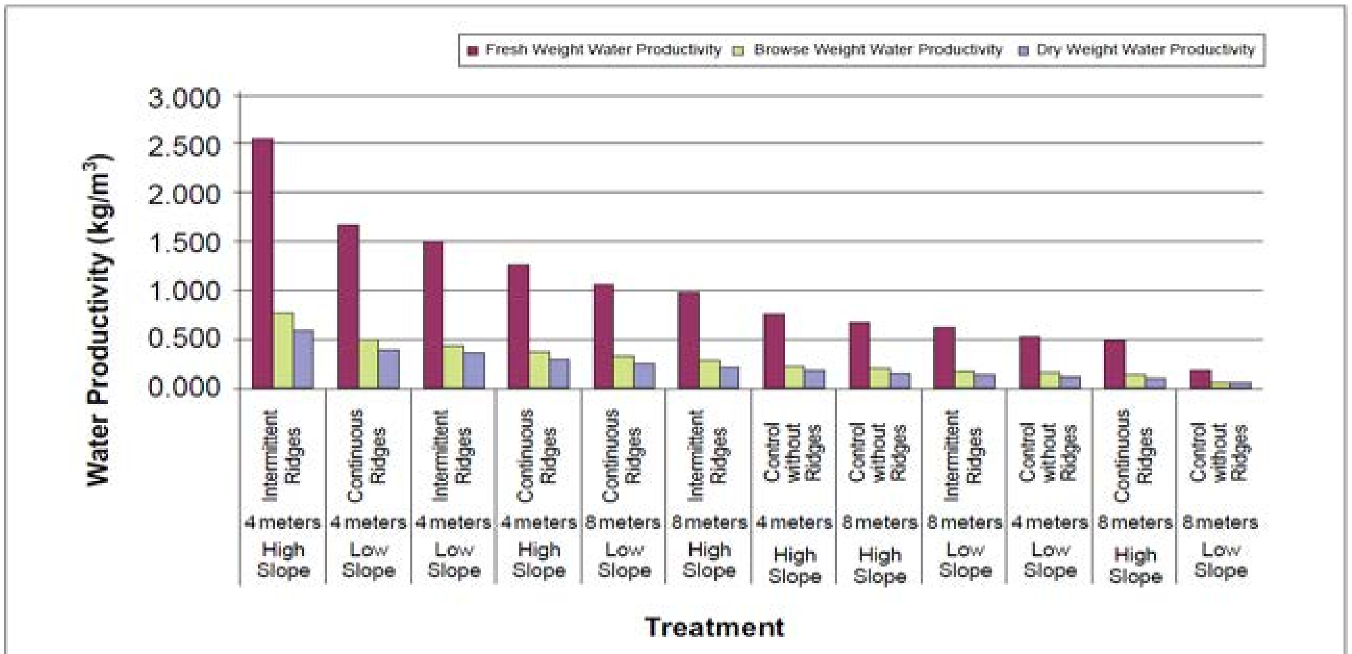


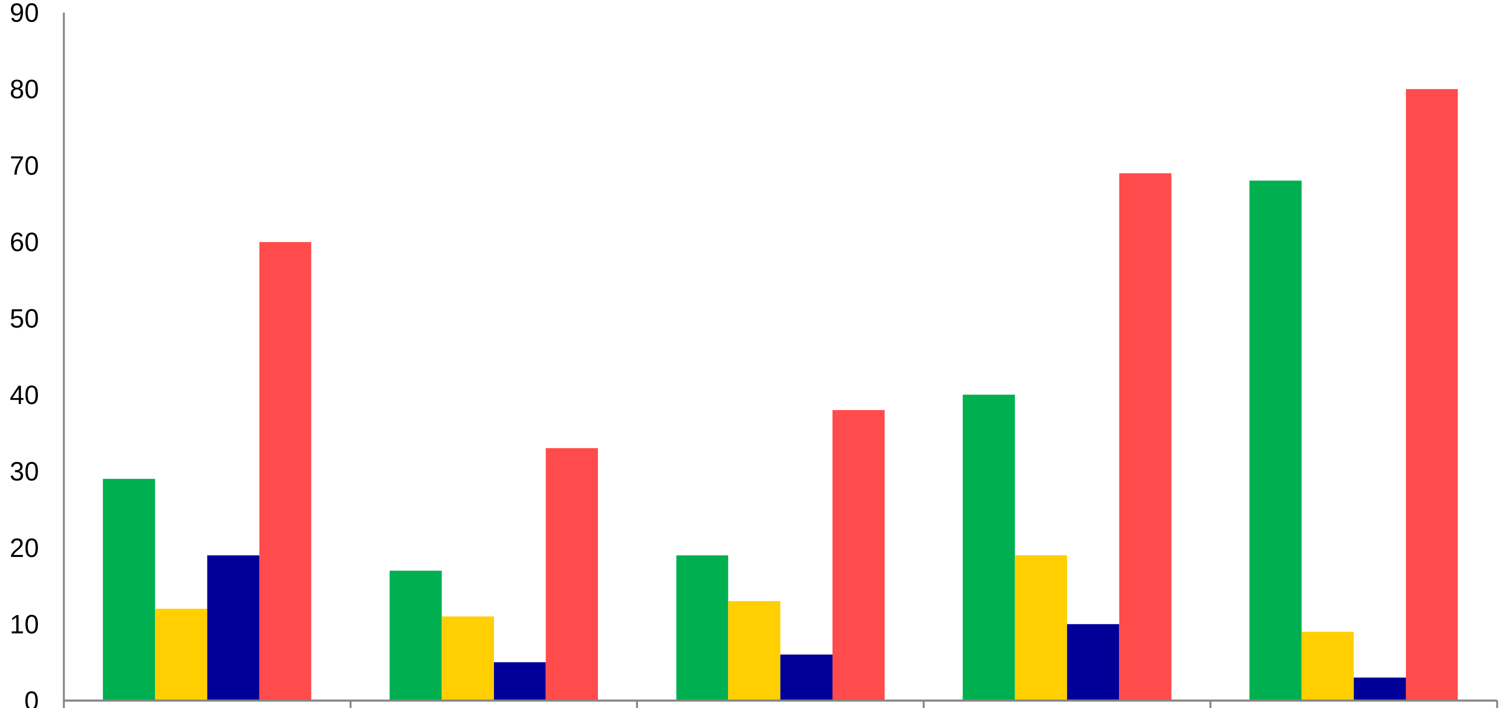
Figure 2.17. Water productivity of Atriplex shrubs as affected by WHT, spacing between contour ridges, and land slope (2006/07 season).

Mudabbar et al, 2011

Groundwater recharge

Gabion recharge structures

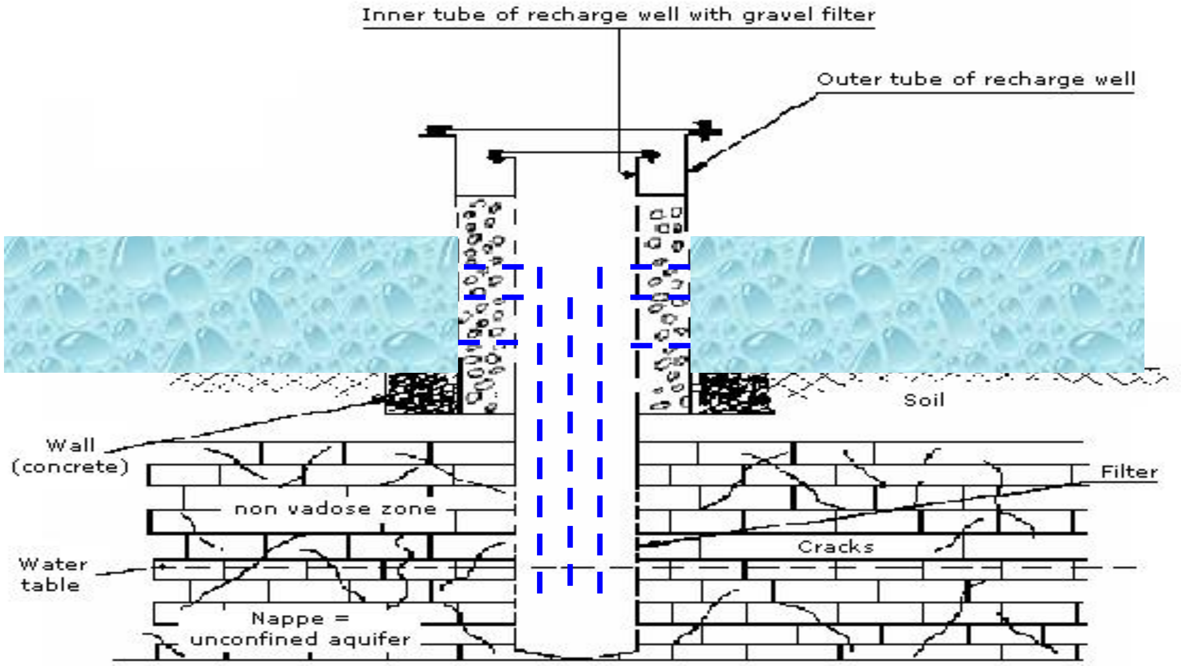
Loss in storage capacity



	0% - 10%	11% - 30%	31% - 50%	51% - 80%	81% - 100%
Amont	29	17	19	40	68
Centre	12	11	13	19	9
Aval	19	5	6	10	3
Total	60	33	38	69	80

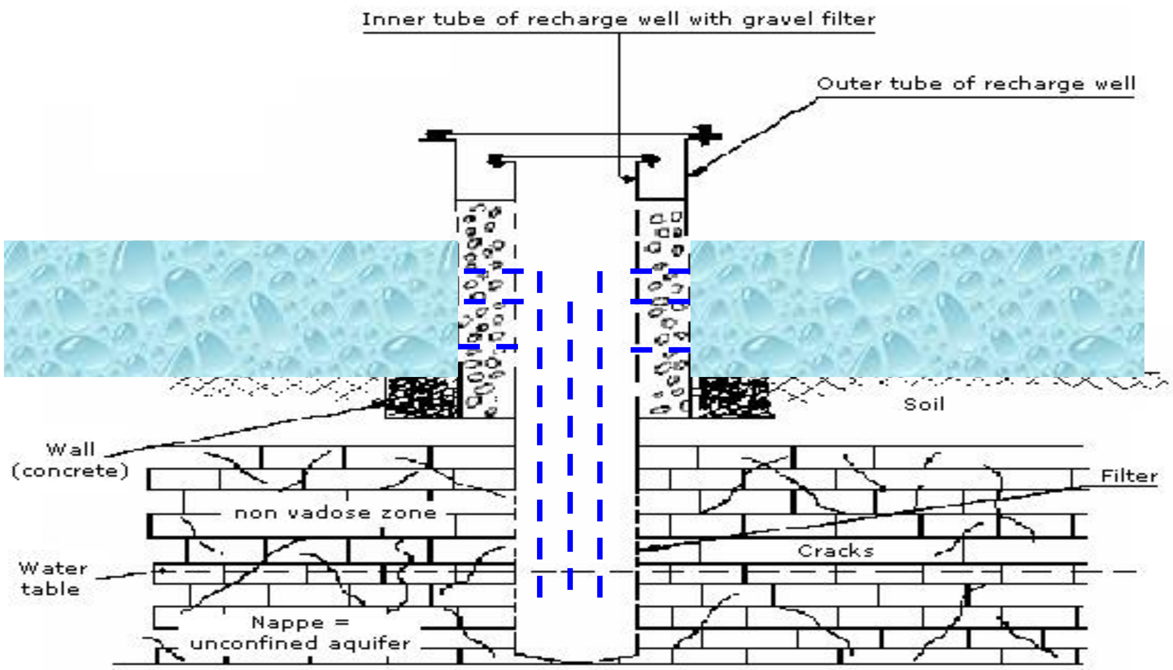
Nawab & Ouessar, 2013

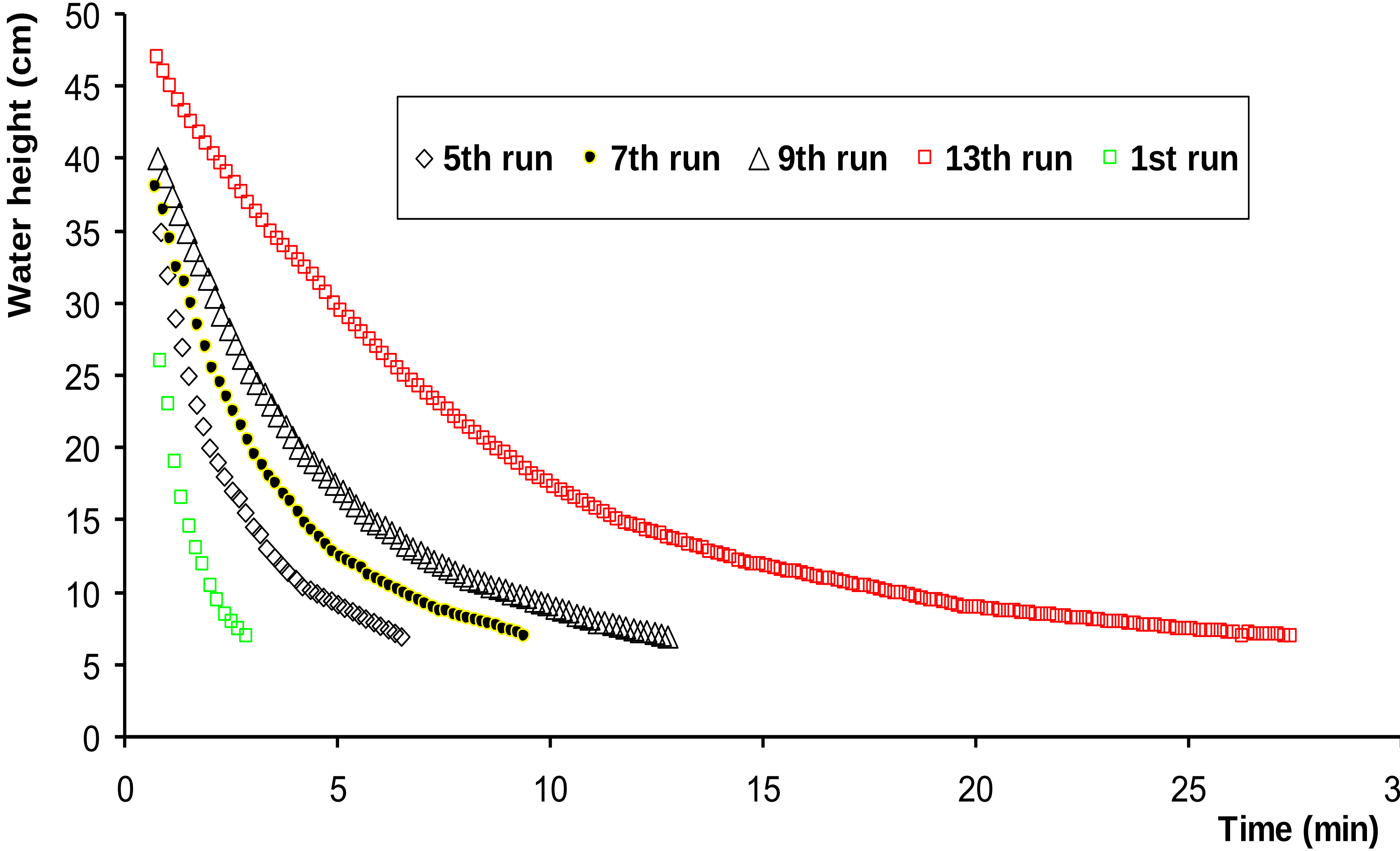
Groundwater recharge wells



Saudi Arabia

Recharge wells

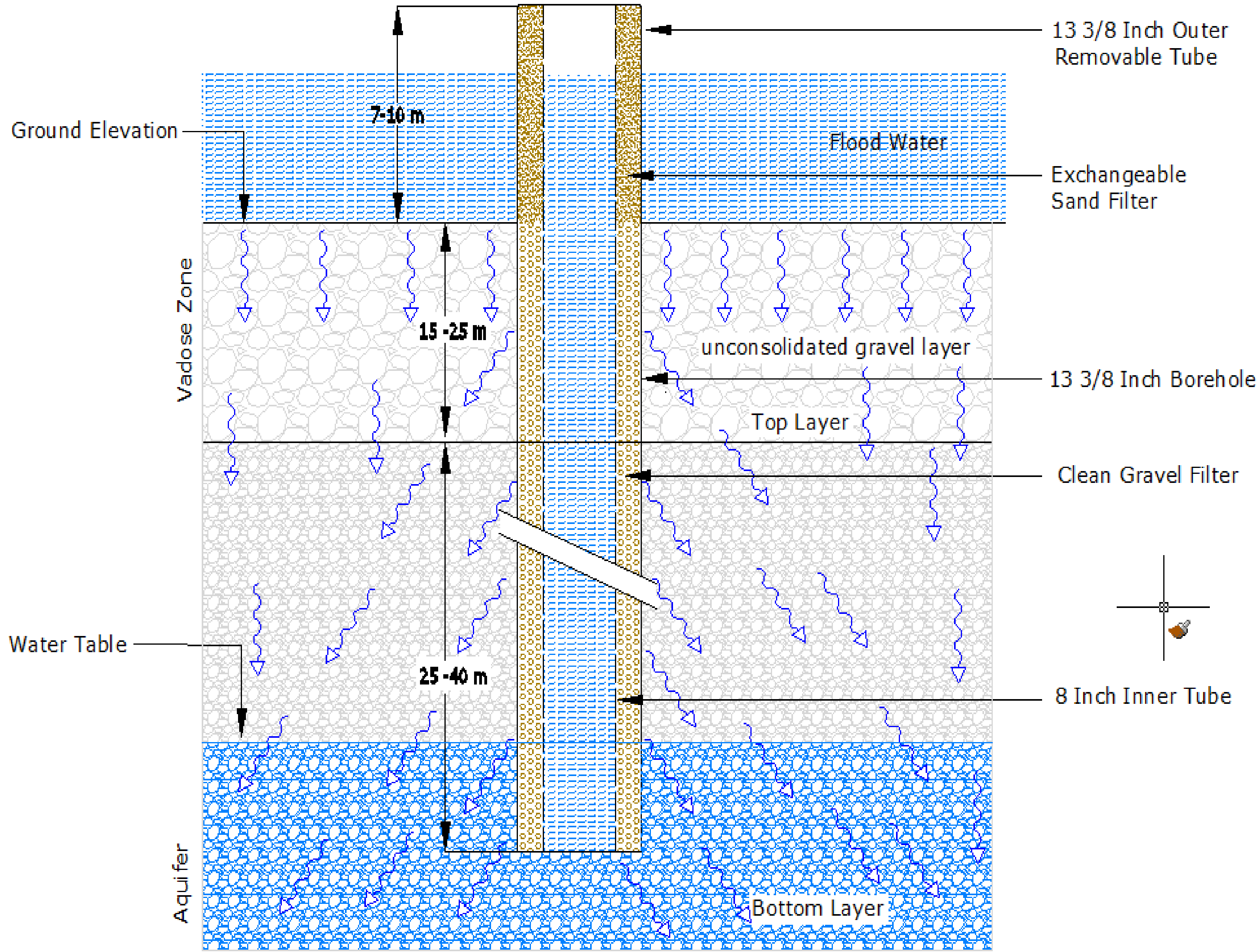




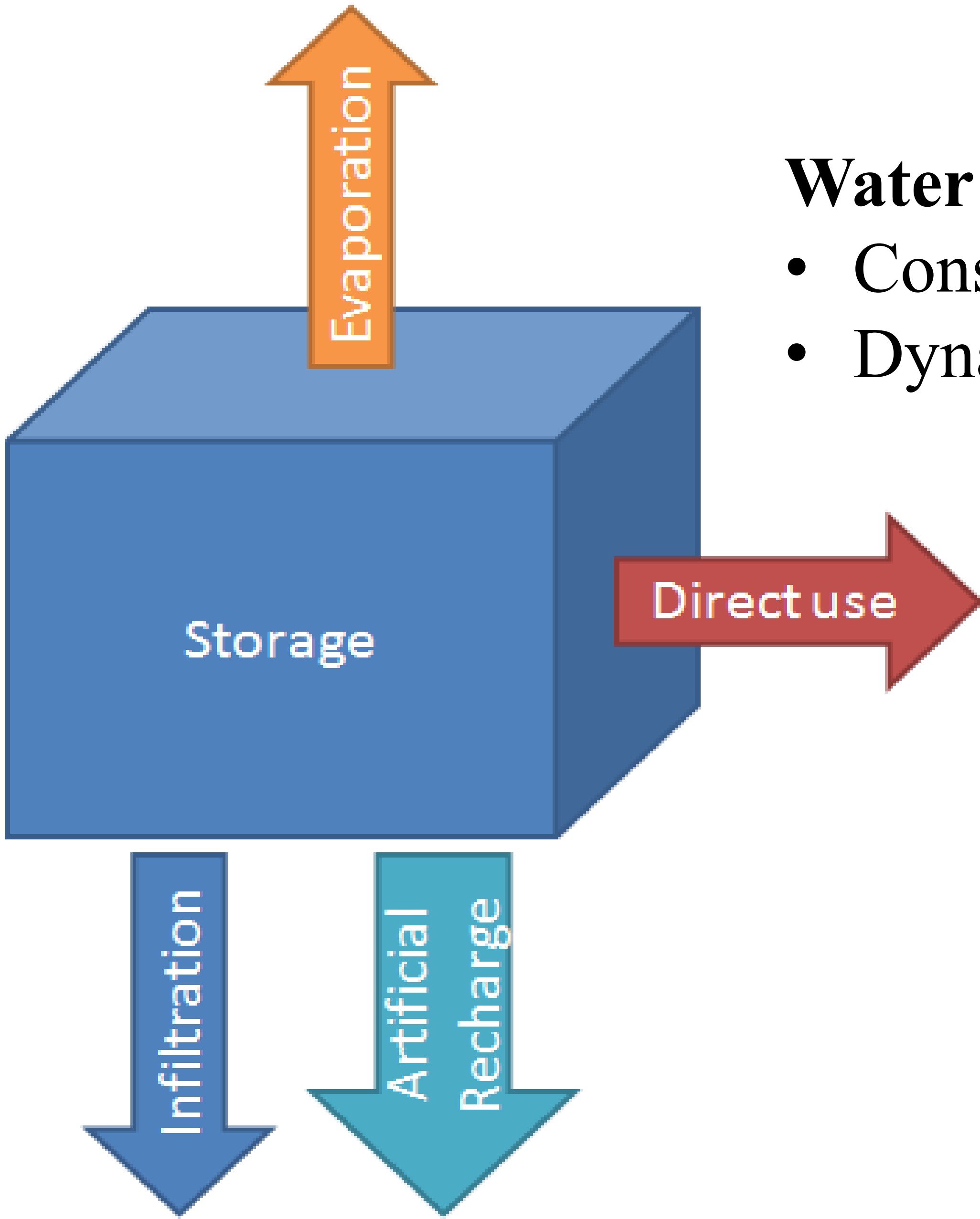
Water height fall as a function of time in the well prototype

Ouessar, 2007

Experience from UAE

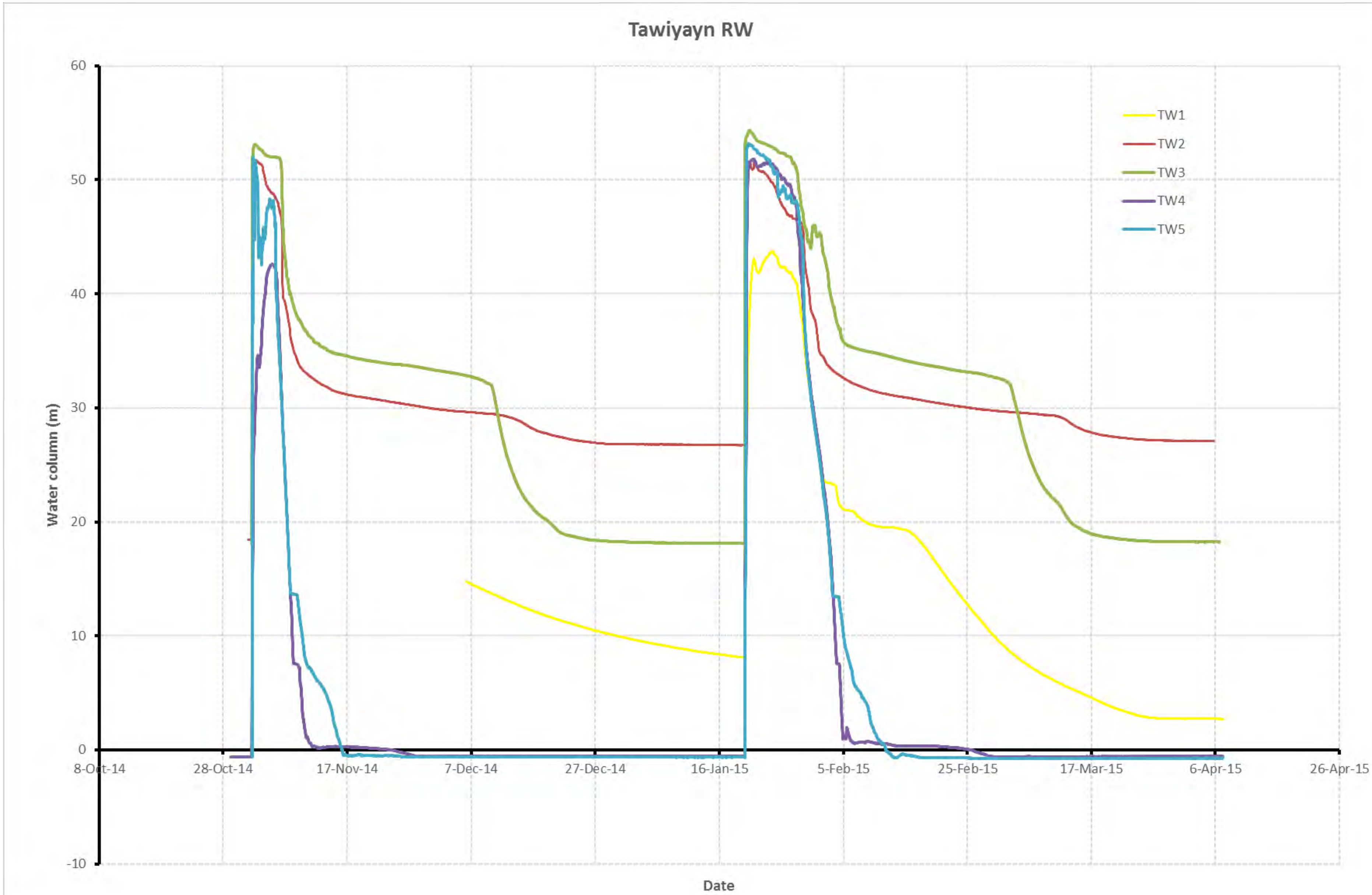


13 3/8 Inch Outer Removable Tube
Ground Elevation
7-10 m
Flood Water
Exchangeable Sand Filter
Vadose Zone
15 -25 m
unconsolidated gravel layer
13 3/8 Inch Borehole
Top Layer
Clean Gravel Filter
Water Table
25 -40 m
8 Inch Inner Tube
Aquifer
Bottom Layer

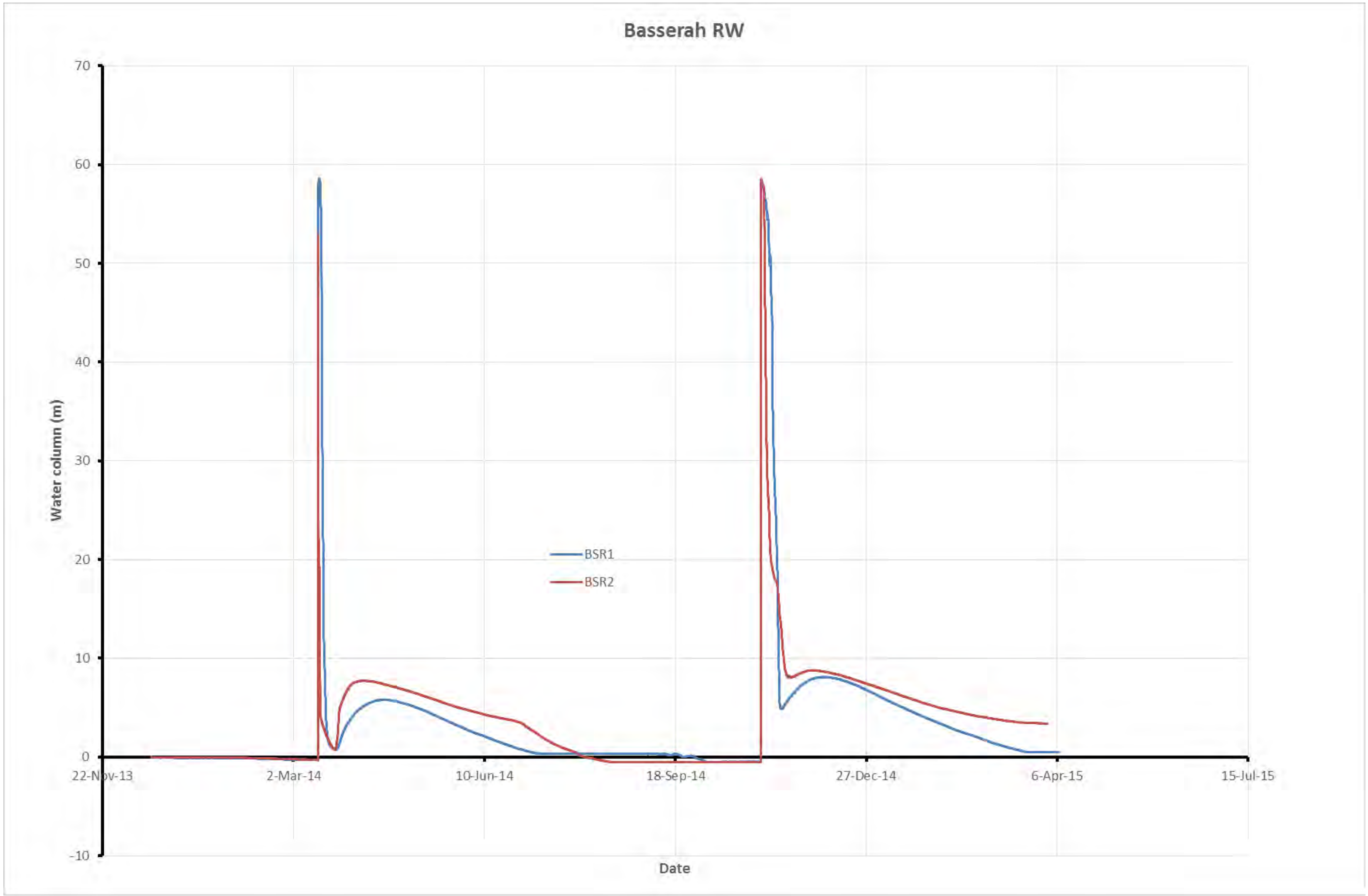


Water balance approach

- Constant head
- Dynamic head

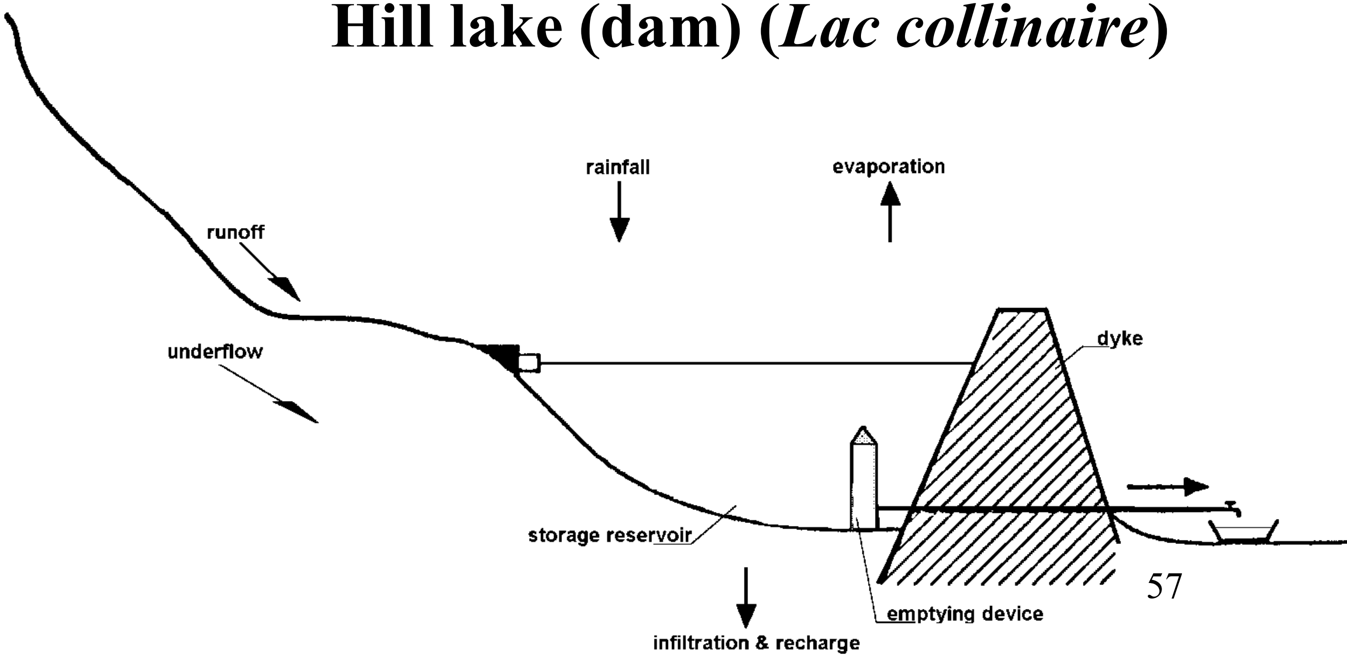


INWEH & MoEW, 2016



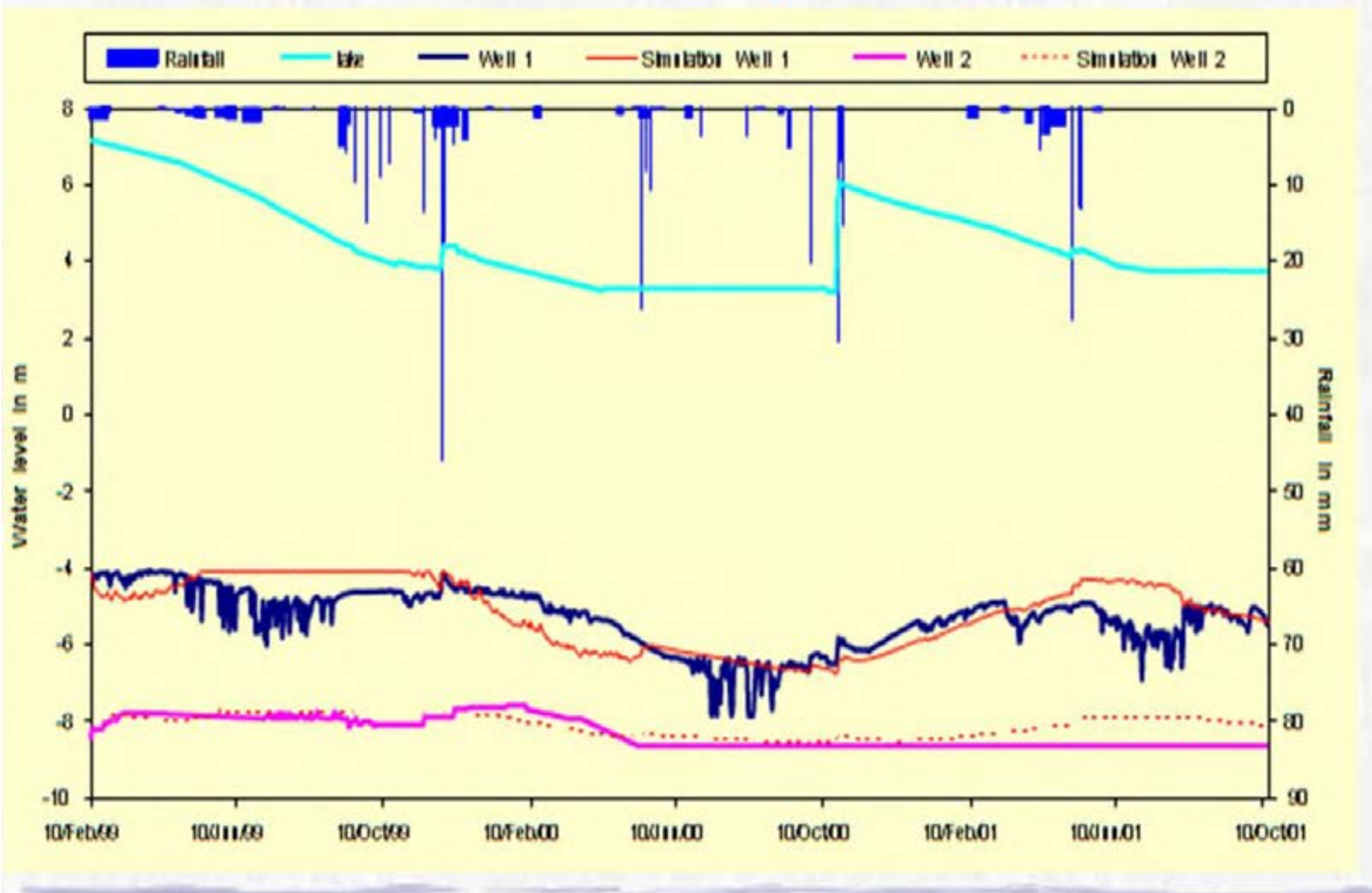
INWEH & MoEW, 2016

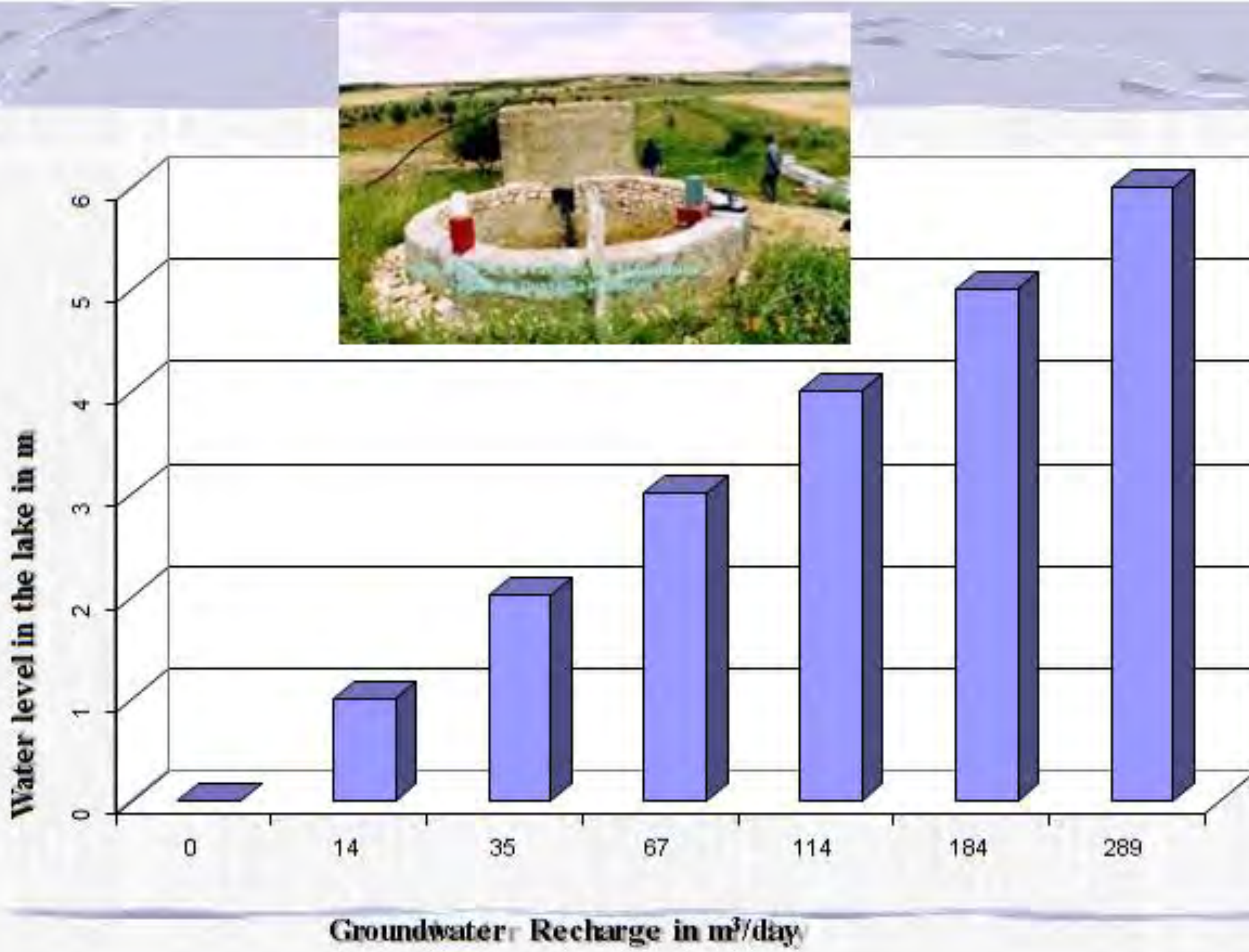
Hill lake (dam) (*Lac collinaire*)



Nasri, 2002

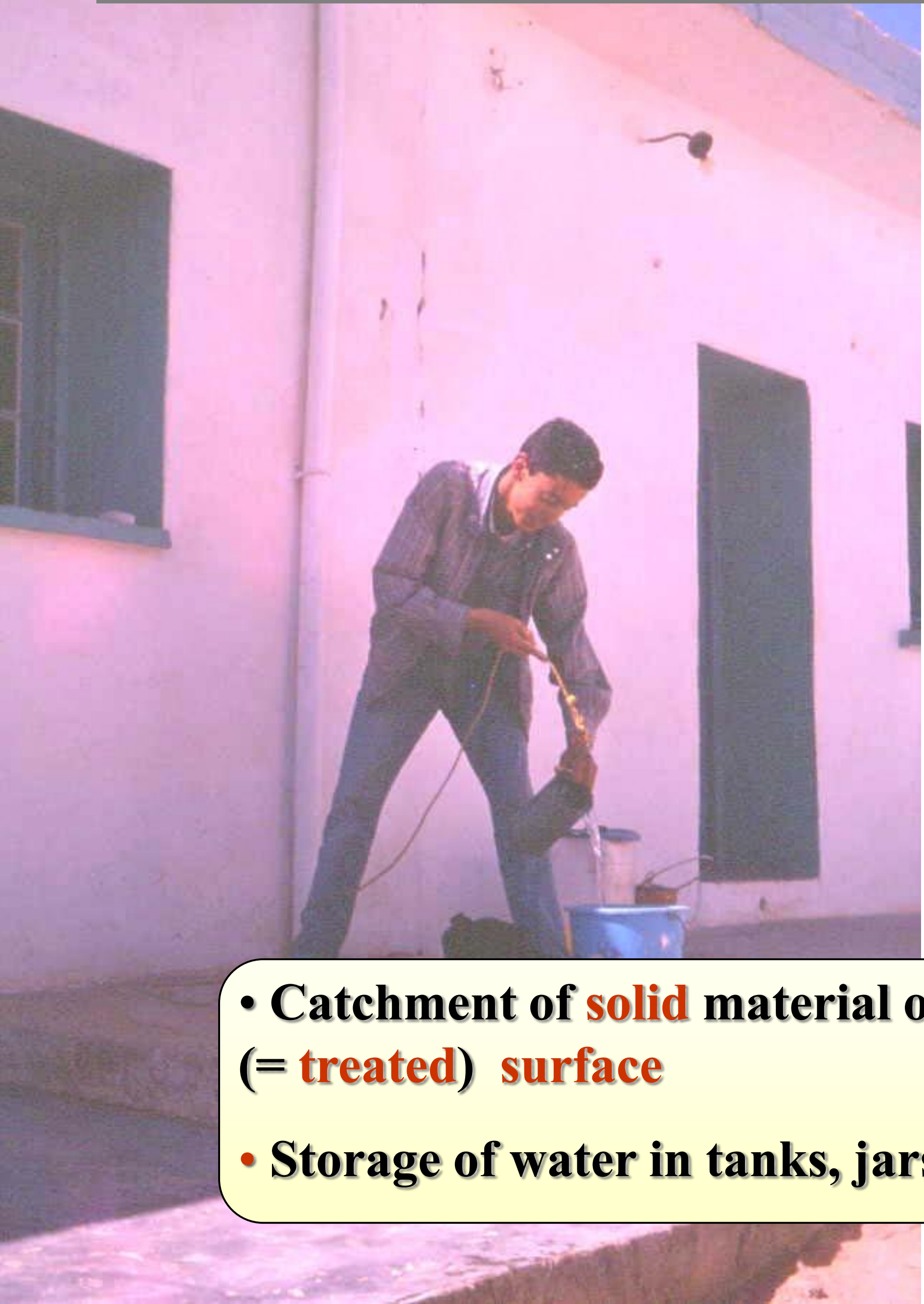

17
16
15
14
13
Well2


Rainfall
lake
Well 1
Simulation Well 1
Well 2
Simulation Well 2
Water level in m
Rainfall in mm
8
6
4
2
0
-2
-4
-6
-8
-10
0
10
20
30
40
50
60
70
80
90
10/Feb/99
10/Jun/99
10/Oct/99
10/Feb/00
10/Jun/00
10/Oct/00
10/Feb/01
10/Jun/01
10/Oct/01


Water level in the lake in m
0
1
2
3
4
5
6
0
14
35
67
114
184
289
Groundwater Recharge in m³/day

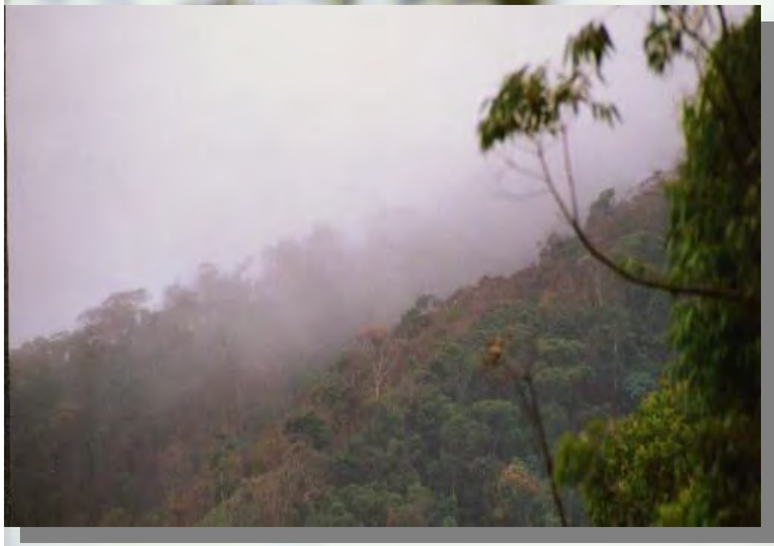
Watering / Drinking

Rooftop and Courtyard Water Harvesting



- Catchment of solid material or of paved, bituminized, compacted (= treated) surface
- Storage of water in tanks, jars, cisterns

FOG AND DEW HARVESTING (Prinz, 1994)



Fog drip is provoked by:

- Substantial heating during day time
- Clear skies or very light, high clouds at night
- No or very light wind
- A thermal inversion at moderate height
- A sufficiently high atmospheric humidity

Examples:

In South America: The desert along the coast of Chile and Peru

In Central and North America: Along the coast of the Californian peninsula in Mexico up to 34 ^{0} N, near Los Angeles

In Africa: Along the Atlantic coast of Namibia; Canary & Cape Verde Islands

In Asia: Arabian Peninsula, mainly Oman and Yemen

In El Tofo, Chile, (Atacama Desert) about 1000 mm of fog drip are captured per m³ per year (1 m³/m² x yr)

- There are two-dimensional and three dimensional fog collectors
- Strong differences between the seasons
- Well suited for tree establishment on mountain slopes

- In Oman, during the monsoon season, up to 50 litres per m² per day were measured
- On Table Mountain, South Africa, 3300 mm / yr were captured.

Namibia

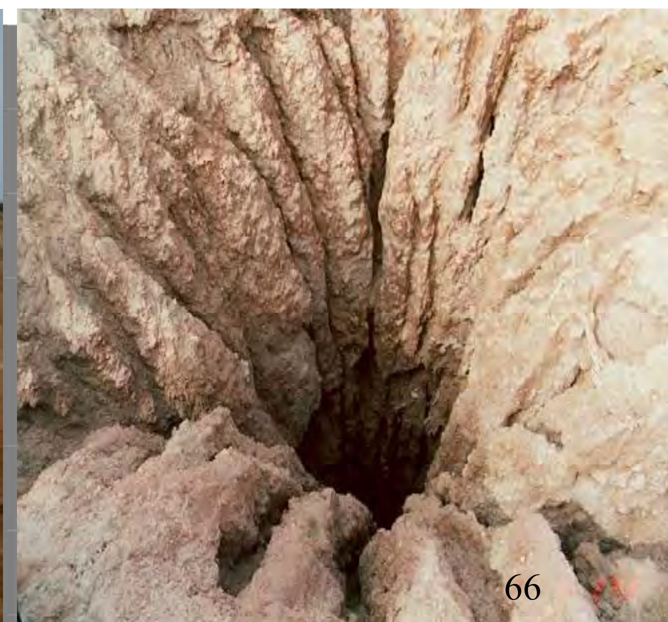
Syria

Cape Town

GROUNDWATER HARVESTING

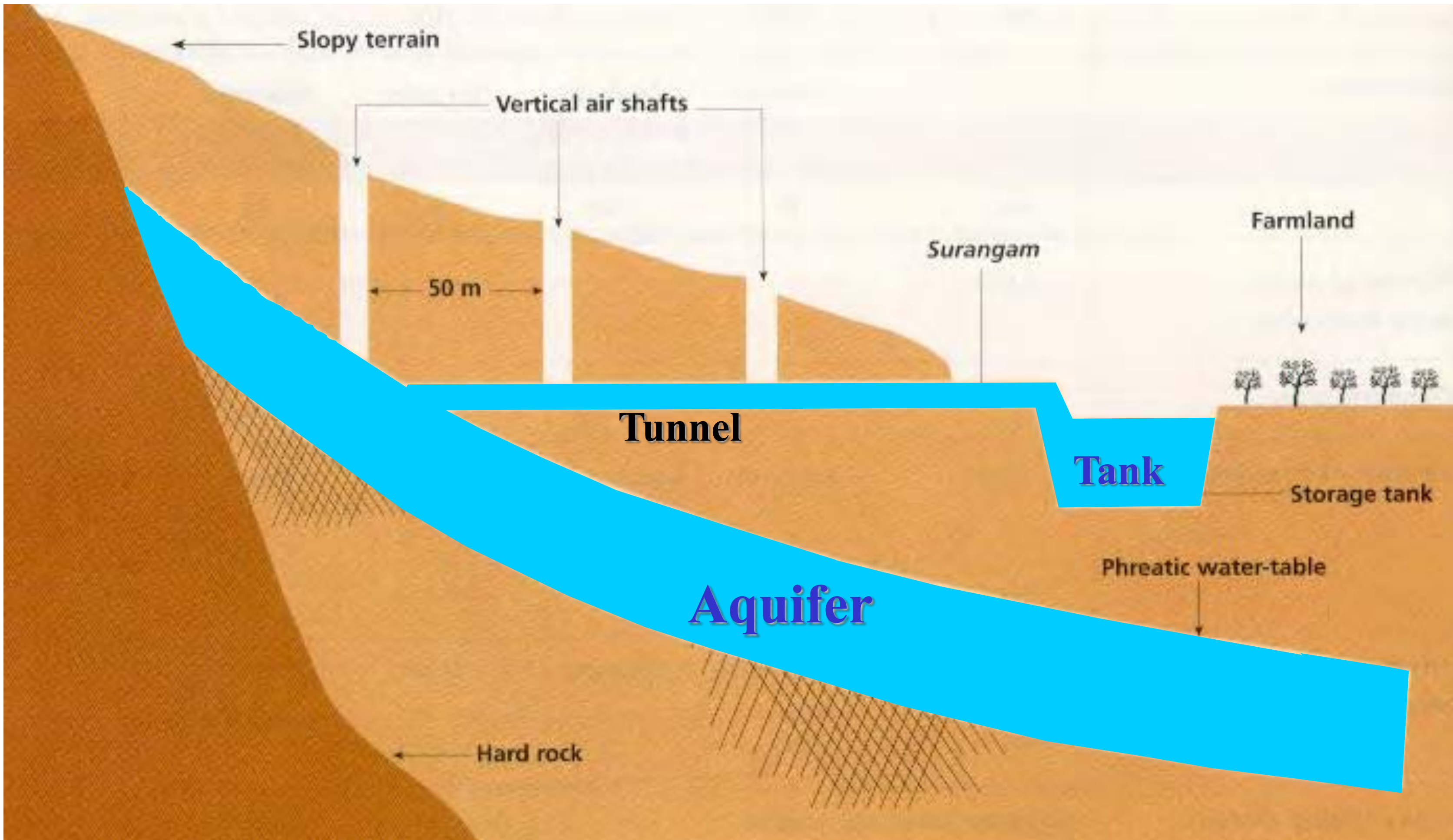
The term "Groundwater Harvesting" covers traditional and unconventional ways of groundwater extraction, e.g. by

- **'Qanats', (using groundwater without lifting it)**
- **Groundwater Dams, (catching subterranean flow)**
- **Special Types of Wells (Horizontal Wells, Artesian Wells)**

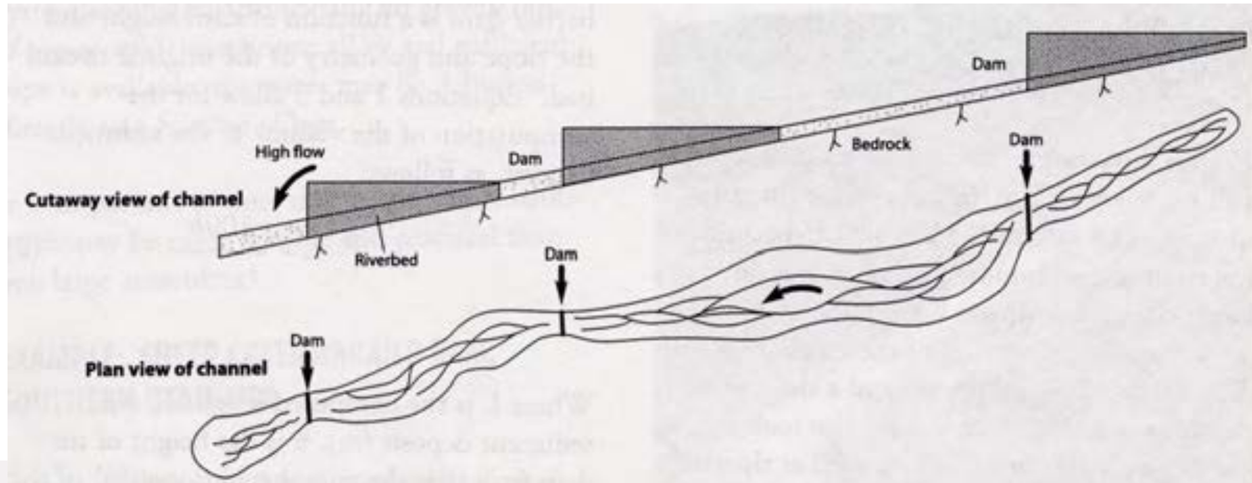


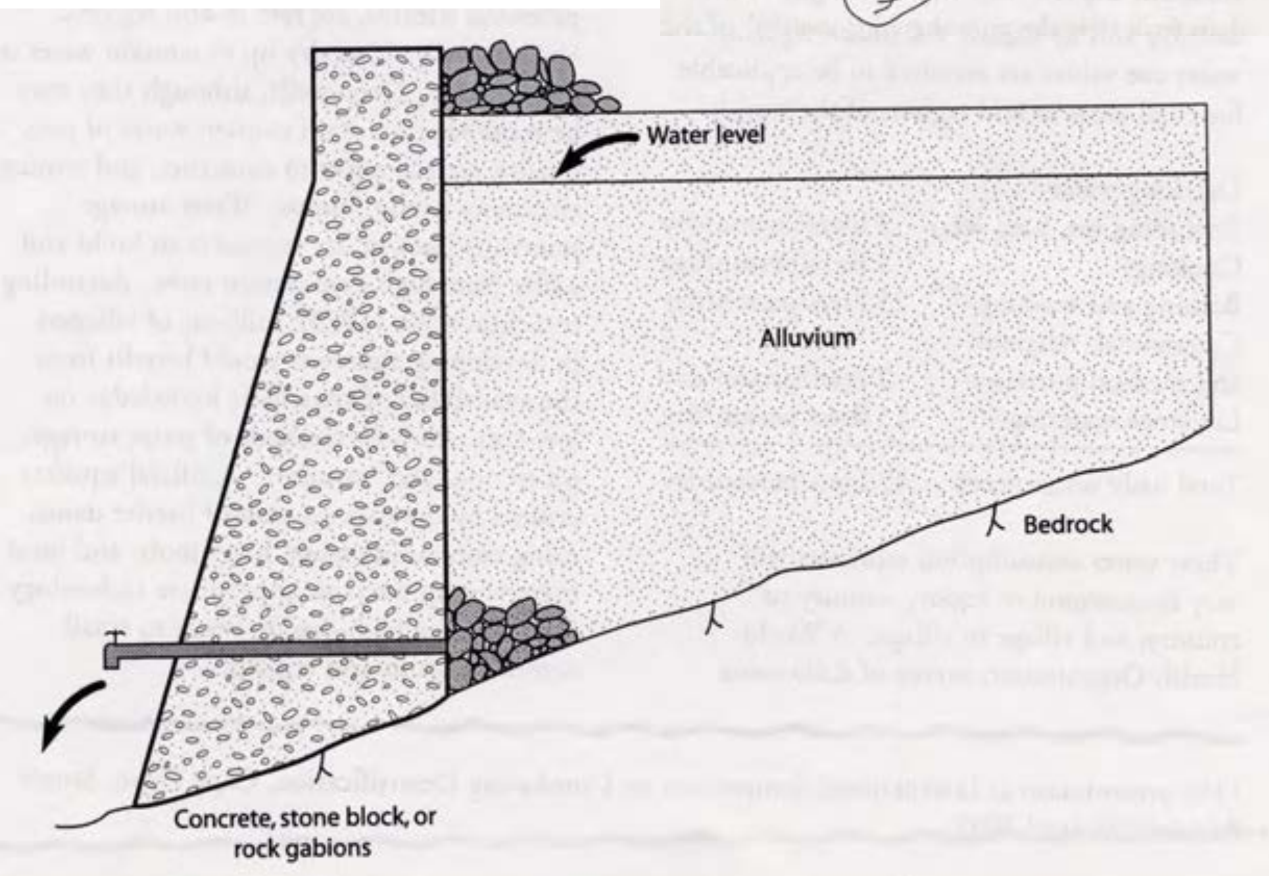
GROUNDWATER HARVESTING

QANATS convey water by gravity to the ground surface

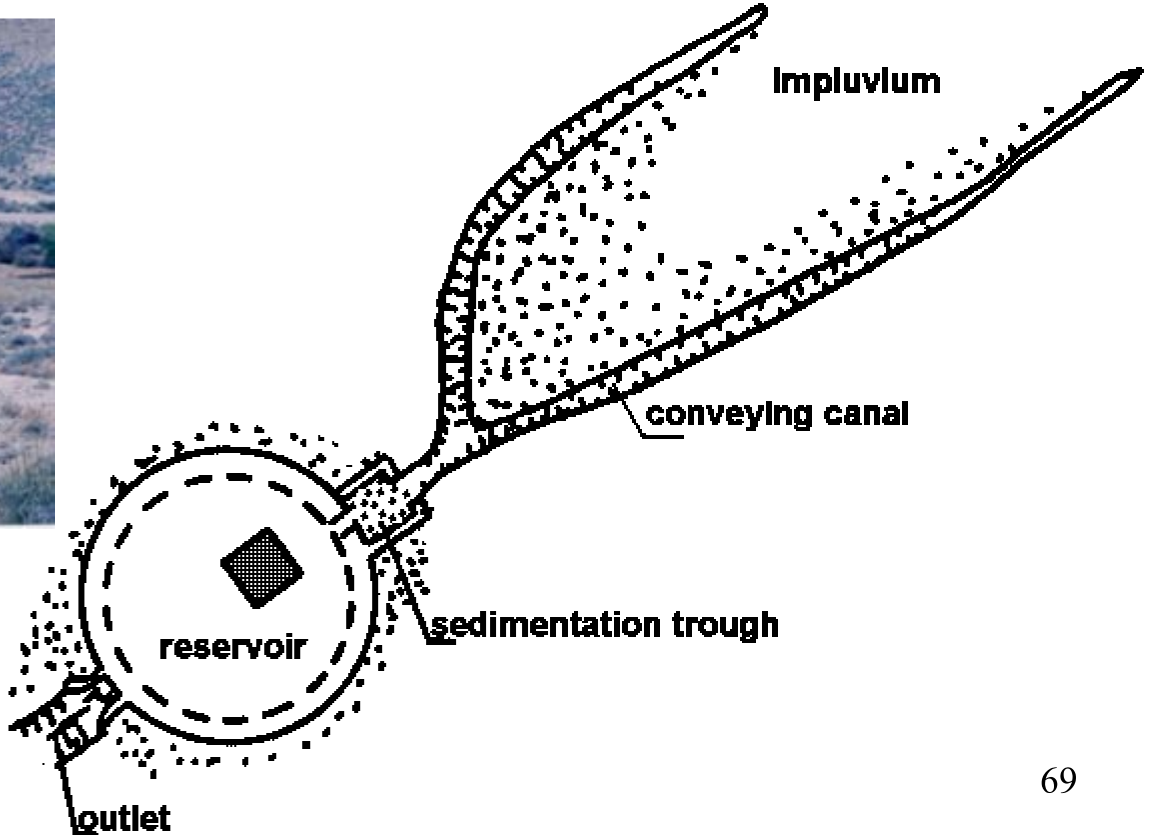


SOURCE: Agarwal & Narain : Dying Wisdom. State of India's Environment 4. New Delhi 1997


Dam
High flow
Dam
Bedrock
Dam
Cutaway view of channel
Riverbed
Dam
Dam
Plan view of channel

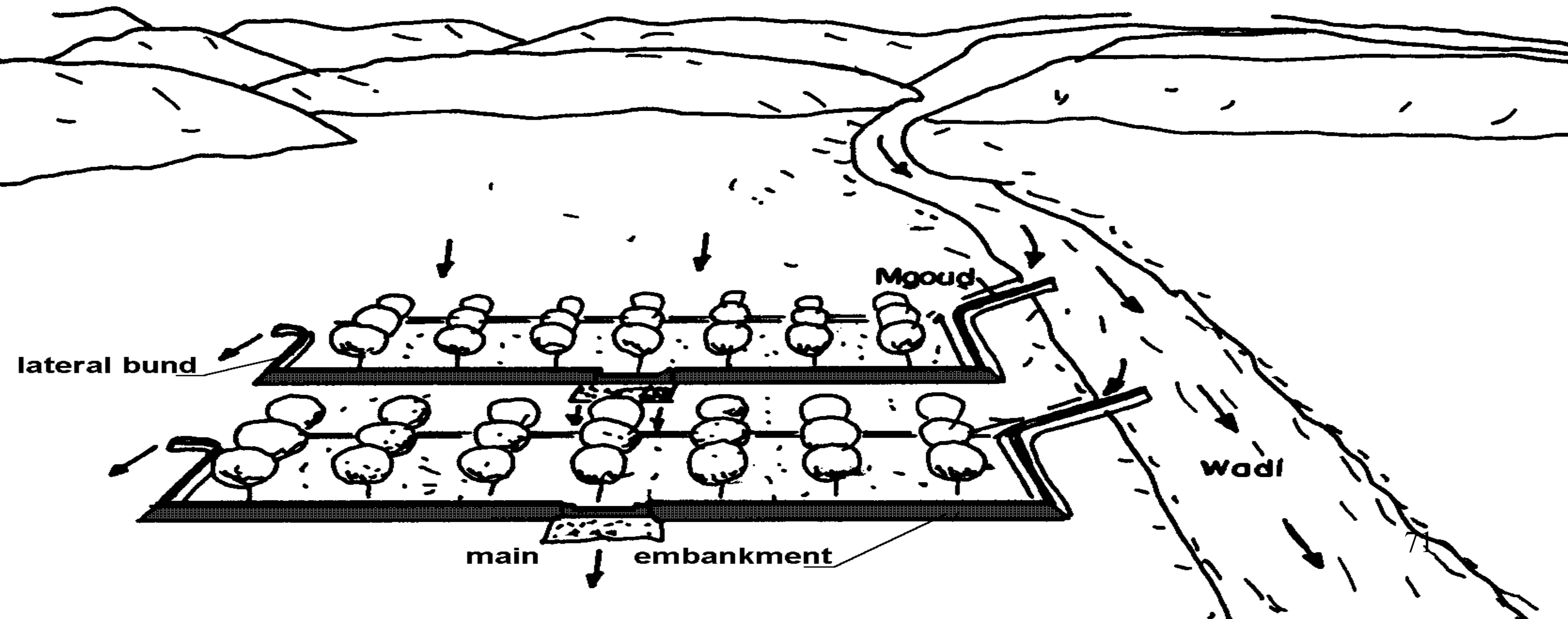

Water level
Alluvium
Bedrock
Concrete, stone block, or rock gabions

Cisterns


impluvium
conveying canal
sedimentation trough
reservoir
outlet

Flood spreading / prevention

Tabia on spreading system

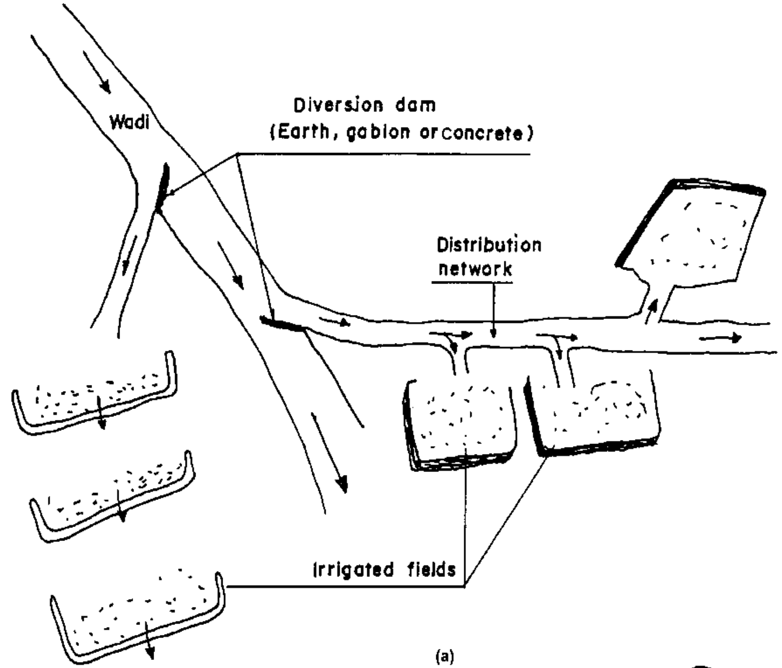


Canaries

Tunisia

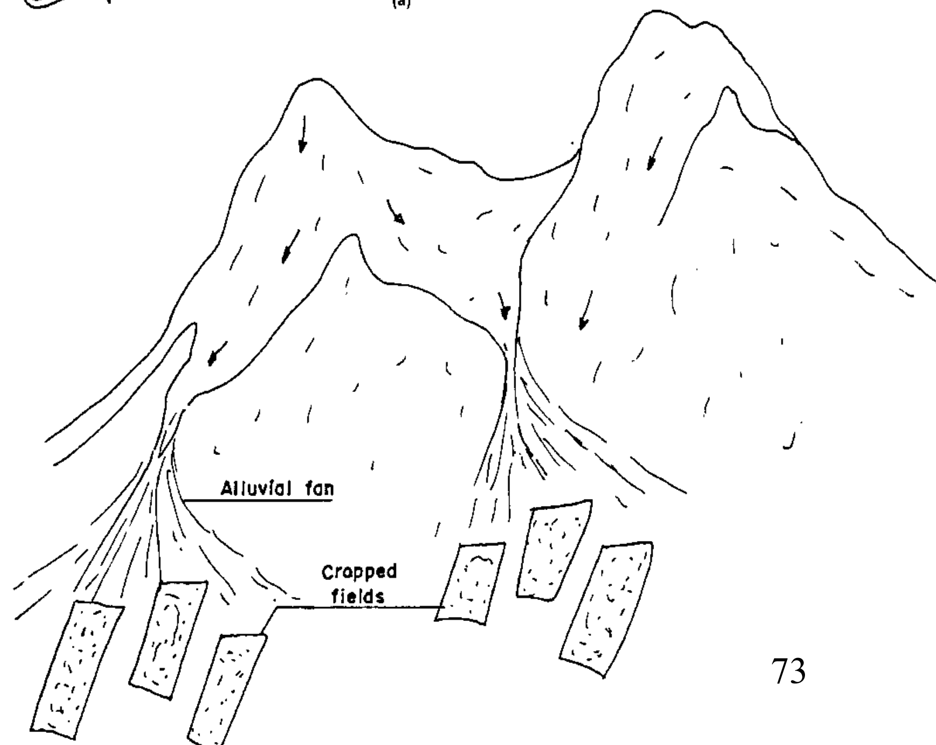
Floodwater diversion & spreading

Yemen



(a)

Flood spreading

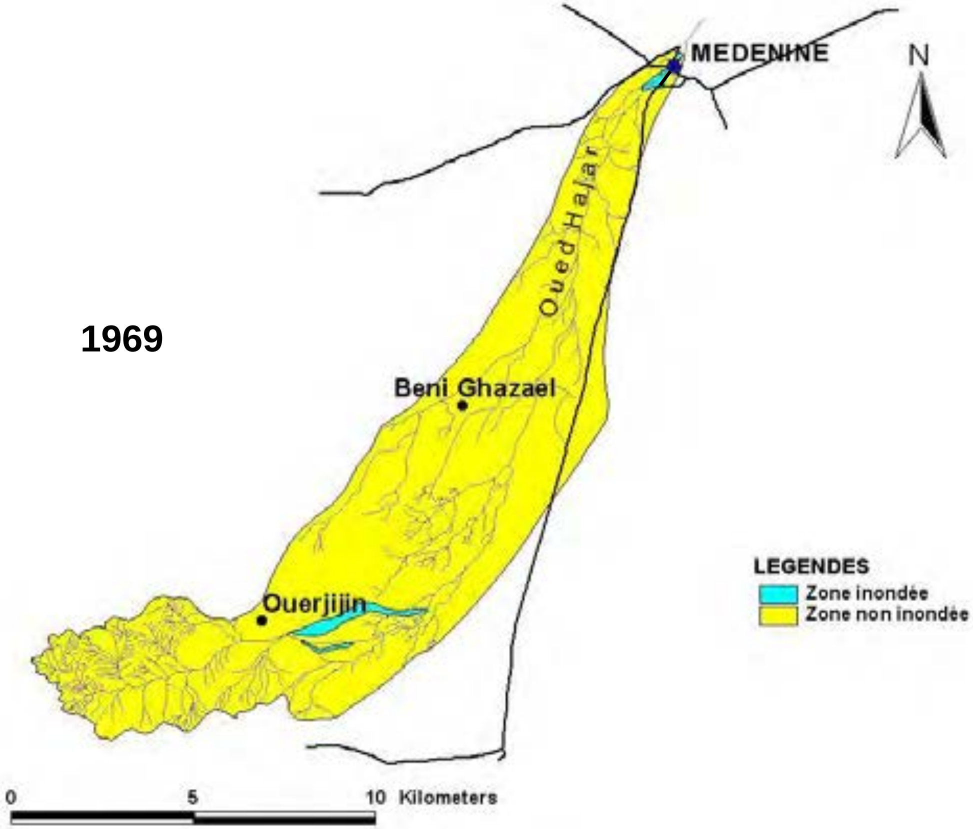


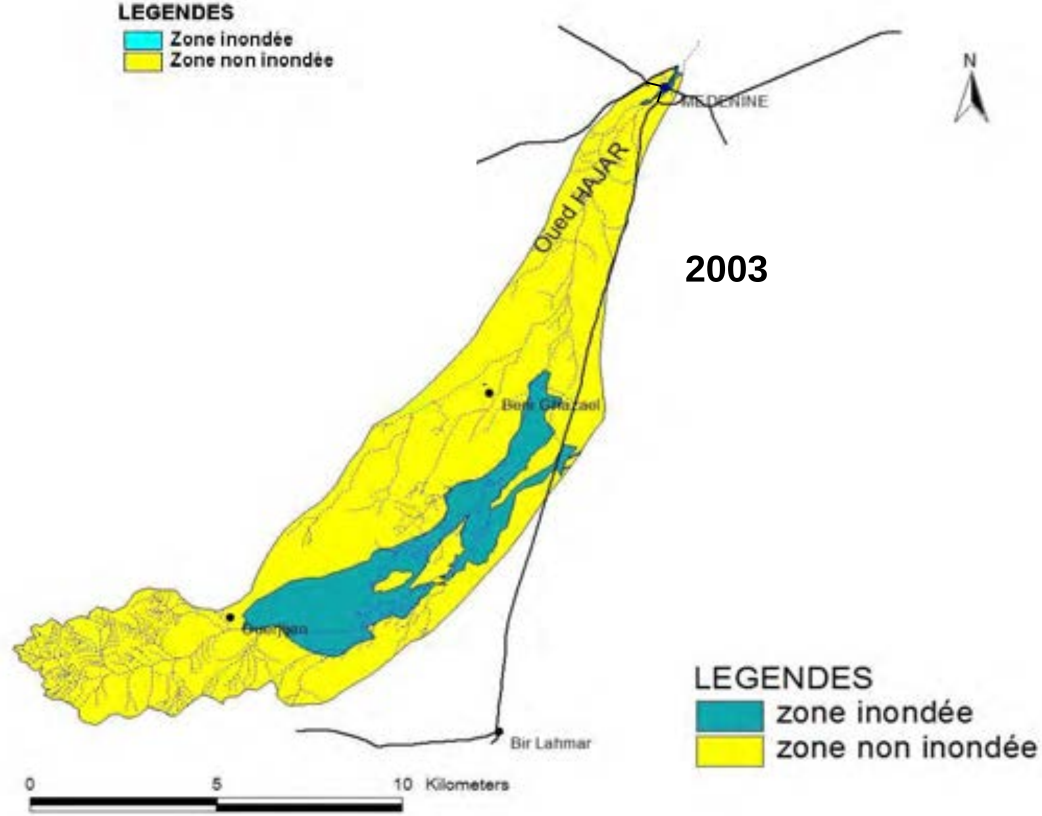
(b)

Flooding in Medenine, Tunisia





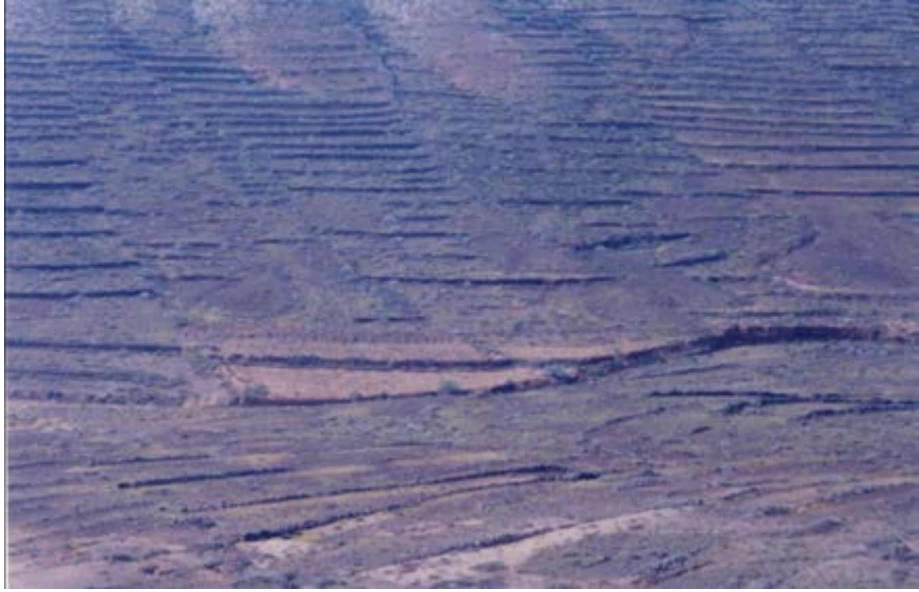





Chniter & Ouessar, 2006

Landscaping/ ecotourism & cultural heritage

Matmata, Tunisia



Canary Island, Spain

Yemen

.... for afforestations

... and fruit tree cropping

Beetle (Namibia)

Walvisia (Namibia)

Integration of the Zammour site (jessour) in some international alternative tourism circuits

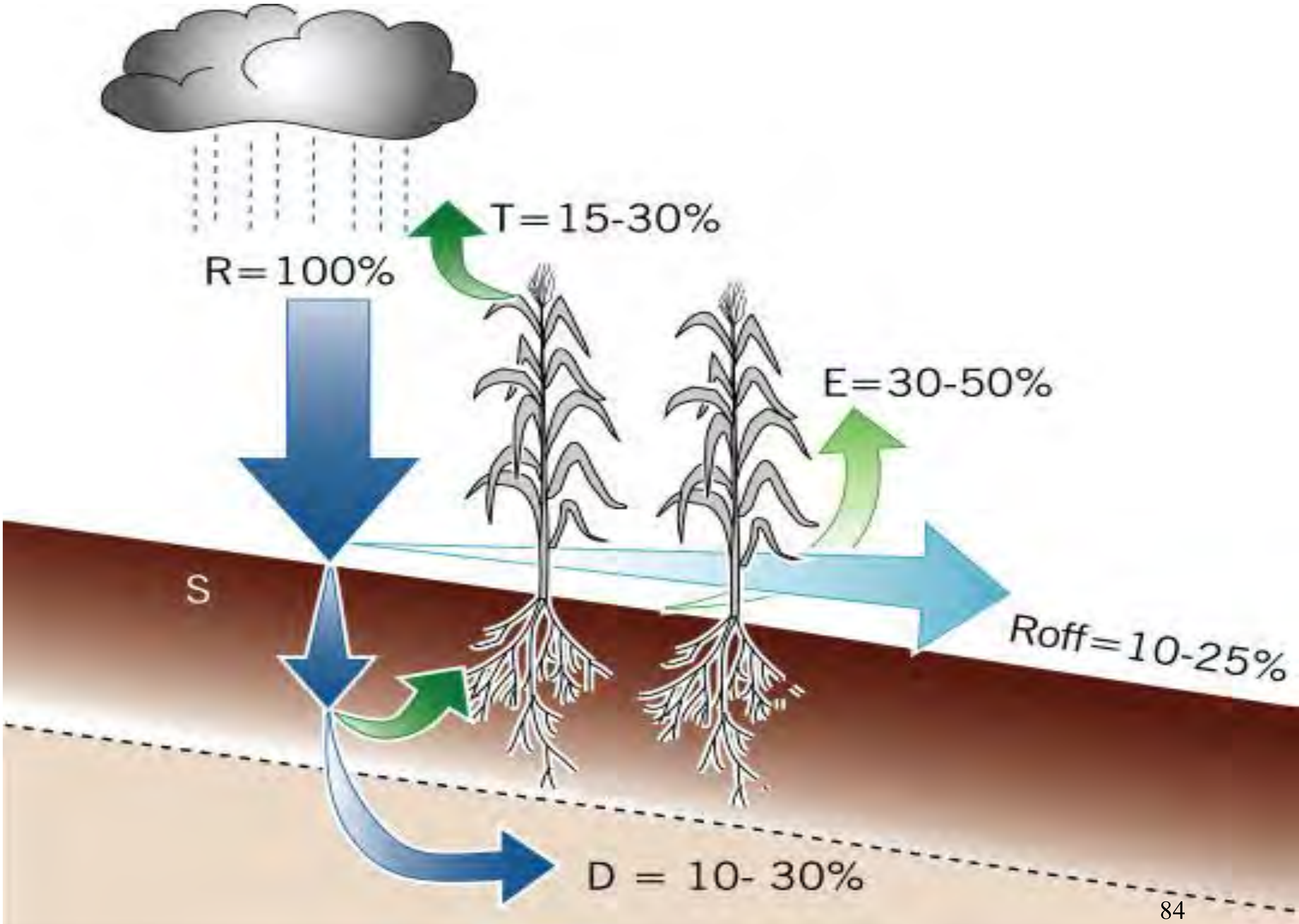
Ecotourism on Arenados, Lanzarote, Spain)


Aghlabit cistern, Kairouan, Tunisia

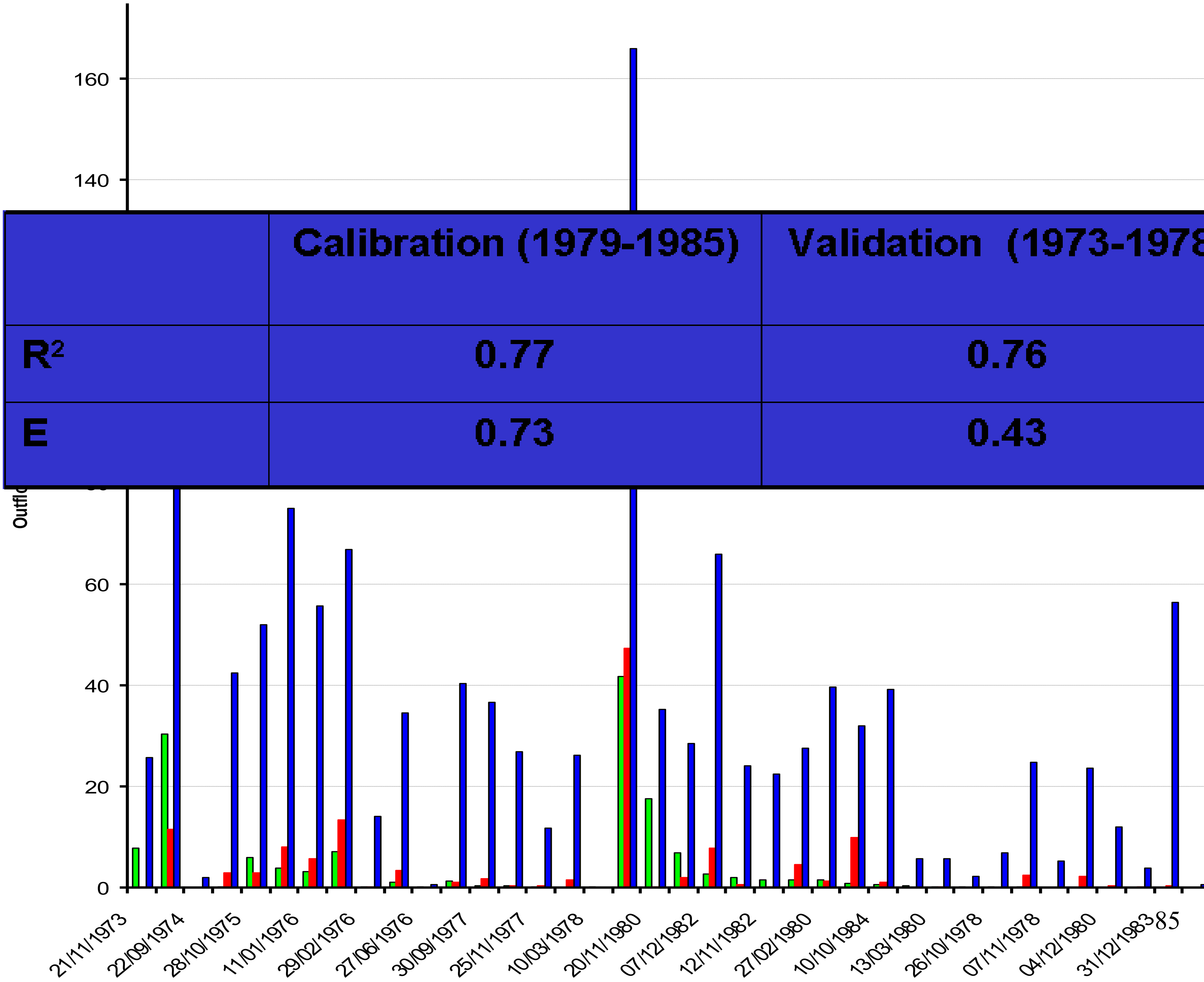

THE PERSIAN QANAT
The Water Supply System
Under The Desert


Ancient Ma'rib dam for flood spreading, Yemen

Combined effects



T=15-30%
R=100%
E=30-50%
S
Roff=10-25%
D = 10- 30%



	Calibration (1979-1985)	Validation (1973-1978)
R^2	0.77	0.76
E	0.73	0.43

Land use evolution before and after project

Landuse	Before project "1991"		After project "2004"		Changes (before/after)	
	ha	% (tot)	ha	% (tot)	ha	%
Halophyte ranges	949.4	2.7	949.4	2.7	0.0	0.0
Mountain ranges	12409.4	35.4	12409.4	35.4	0.0	0.0
Plain ranges	7105.2	20.3	2827.1	8.1	-4278.1	-12.2
Cereals	3947.3	11.3	1806.7	5.2	-2140.6	-6.1
Olives on jessour	8275.3	23.6	8275.3	23.6	0.0	0.0
Olives on tabias	2380.3	6.8	8799.0	25.1	6418.7	18.3

Scenarios

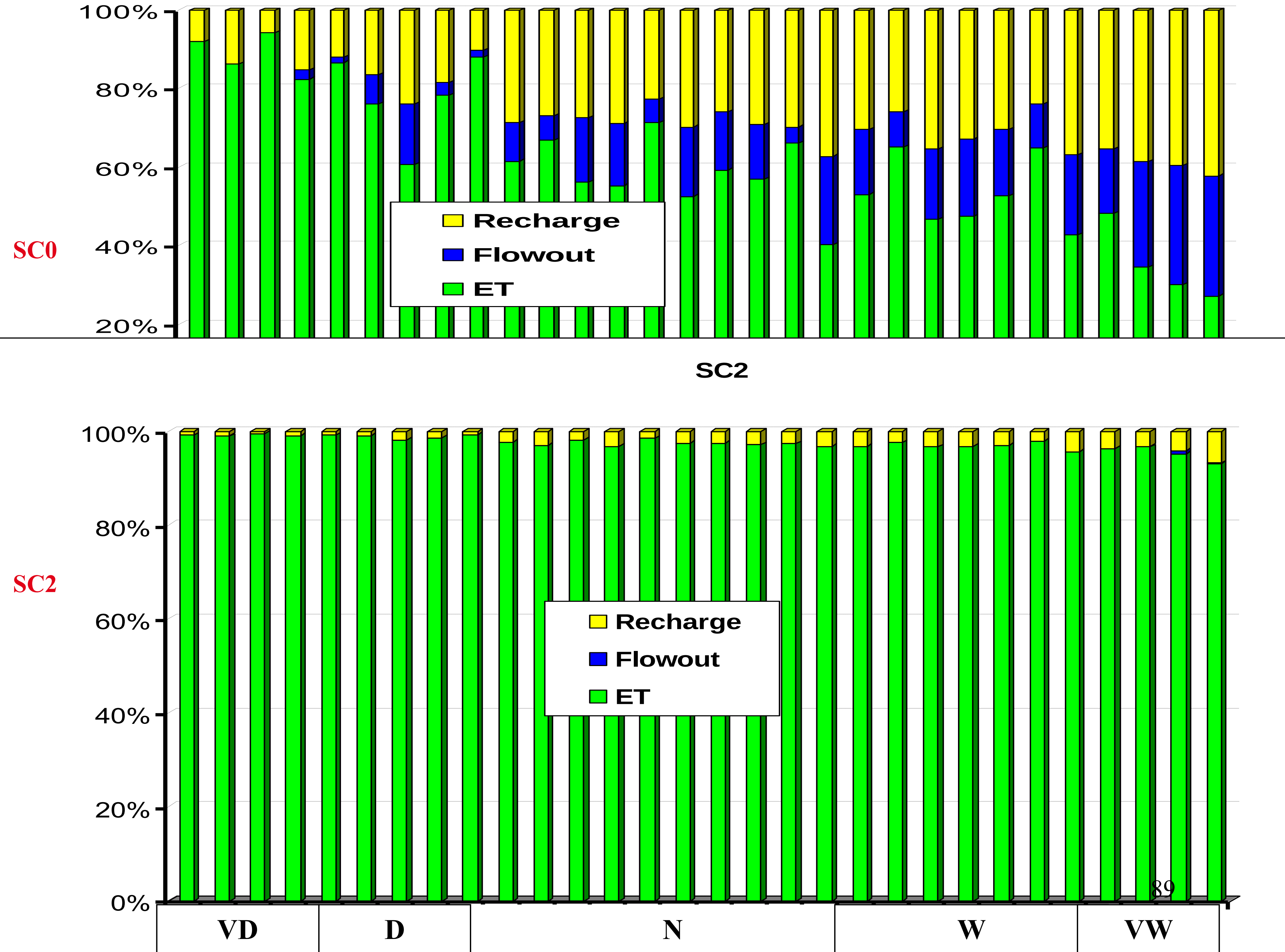
- **SC0:** **It is a hypothetical scenario: natural watershed, no water harvesting works nor crops.**

- **SC1:** **water harvesting systems: *jessour* on the mountain area and *tabias* on the foothills.**

- **SC2:** **new *tabias* in the plain zone; gabion check dams for aquifer recharge and flood spreading.**

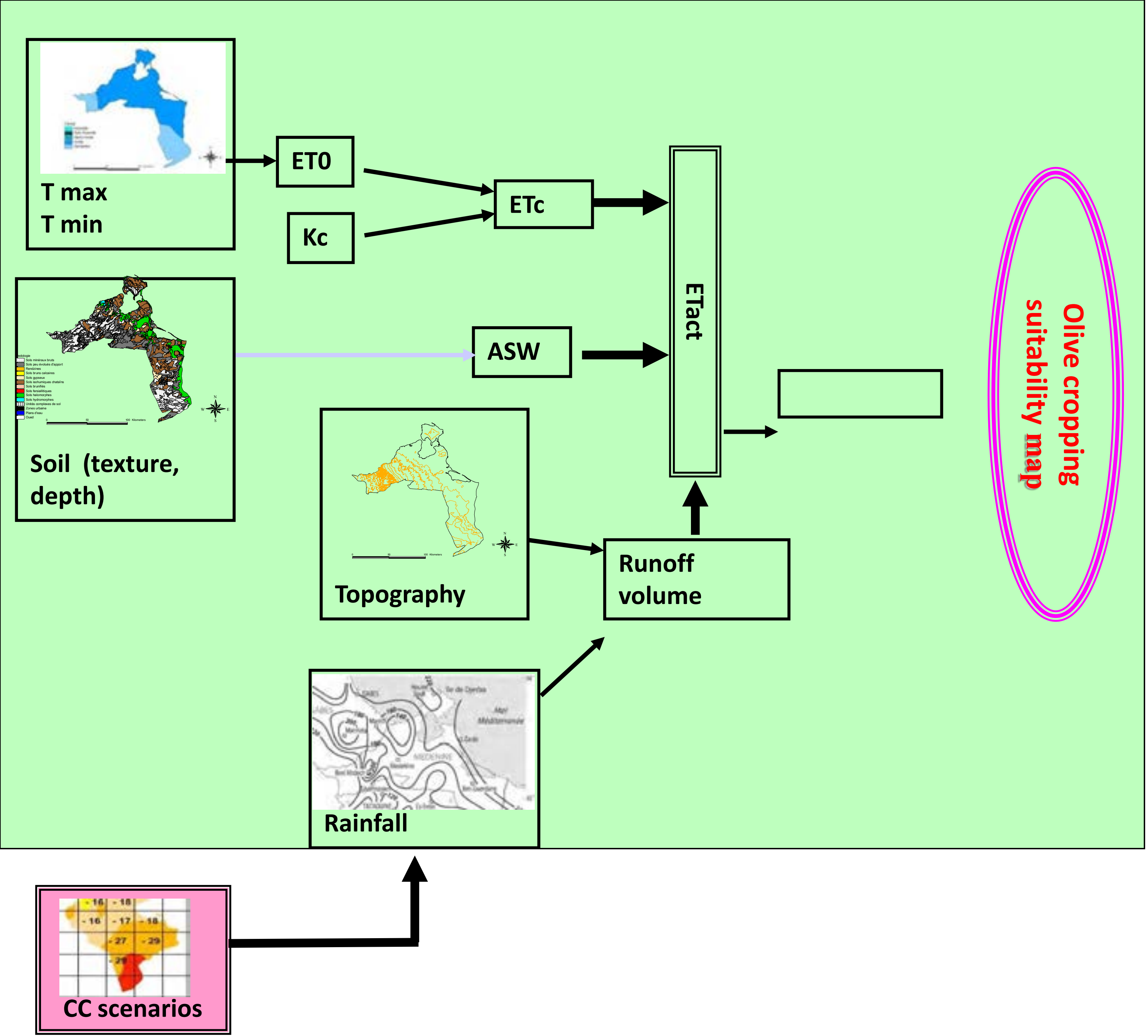
- **SC3:** **The land use is similar to SC2 with partial silting up of the gabion check dams.**

	SC0		SC1		SC2		SC3	
	mm	%	mm	%	mm	%	mm	%
Rainfall	183.9	-	183.9	-	183.9	-	183.9	-
ET	107.0 [a]	58.2	147.2 [b]	80.1	150.9 [b]	82.0	150.9 [b]	82.0
Outflow	34.3 [a]	18.7	4.0 [b]	2.2	0.1 [c]	0.0	0.1 [c]	0.0
Perco	14.5 [a]	7.9	24.3 [b]	13.2	28.2 [b]	15.4	28.3 [b]	15.4
TLOSS	28.0 [a]	15.2	8.2 [b]	4.4	3.1 [c]	1.7	3.2 [c]	1.7
Seepage	0 [a]	0.0	0 [a]	0.0	1.1 [b]	0.6	0.9 [b]	0.5


SC0
100%
80%
60%
40%
20%
Recharge
Flowout
ET
SC2
SC2
100%
80%
60%
40%
20%
0%
Recharge
Flowout
ET
VD
D
N
W
VW

Effects of CC on olive groves in the governorate of Médenine

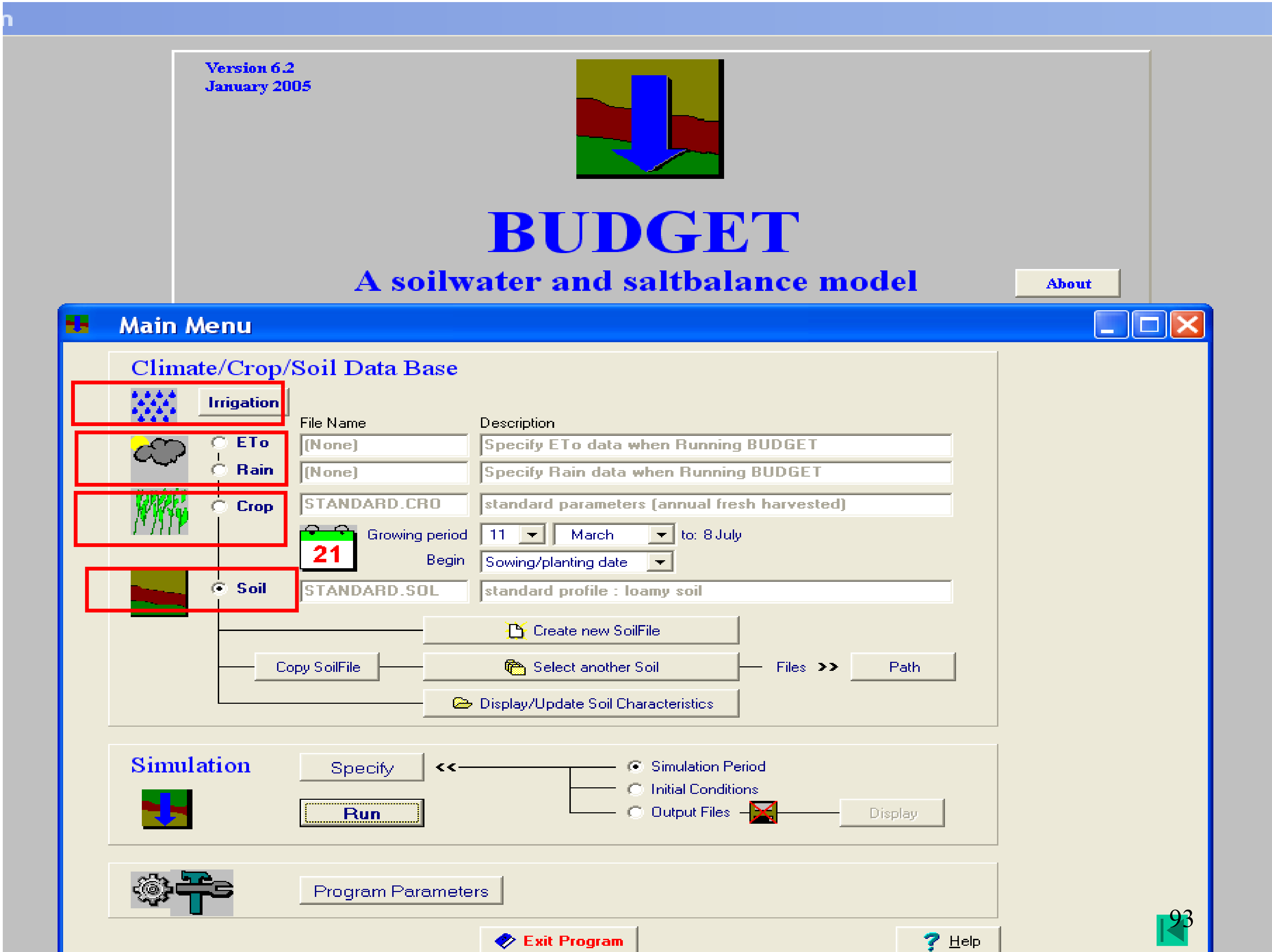
Sghaier et Ouessar, 2013


T max
T min
ET0
Kc
ETc
ETact
Soil (texture, depth)
ASW
Topography
Runoff volume
Rainfall
CC scenarios
Olive cropping suitability map

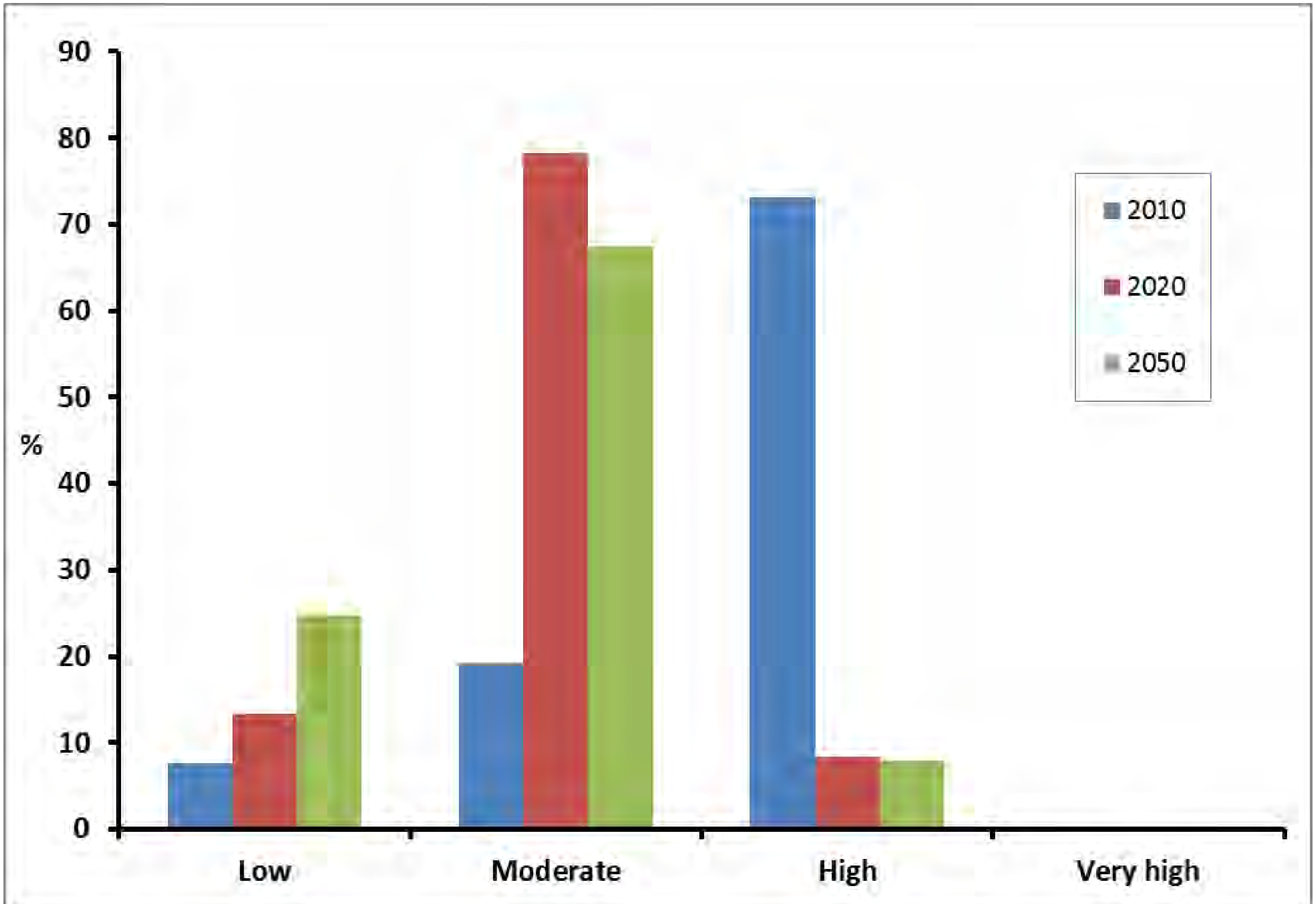
$$ET_{crop} = k_{crop} \times ET0$$

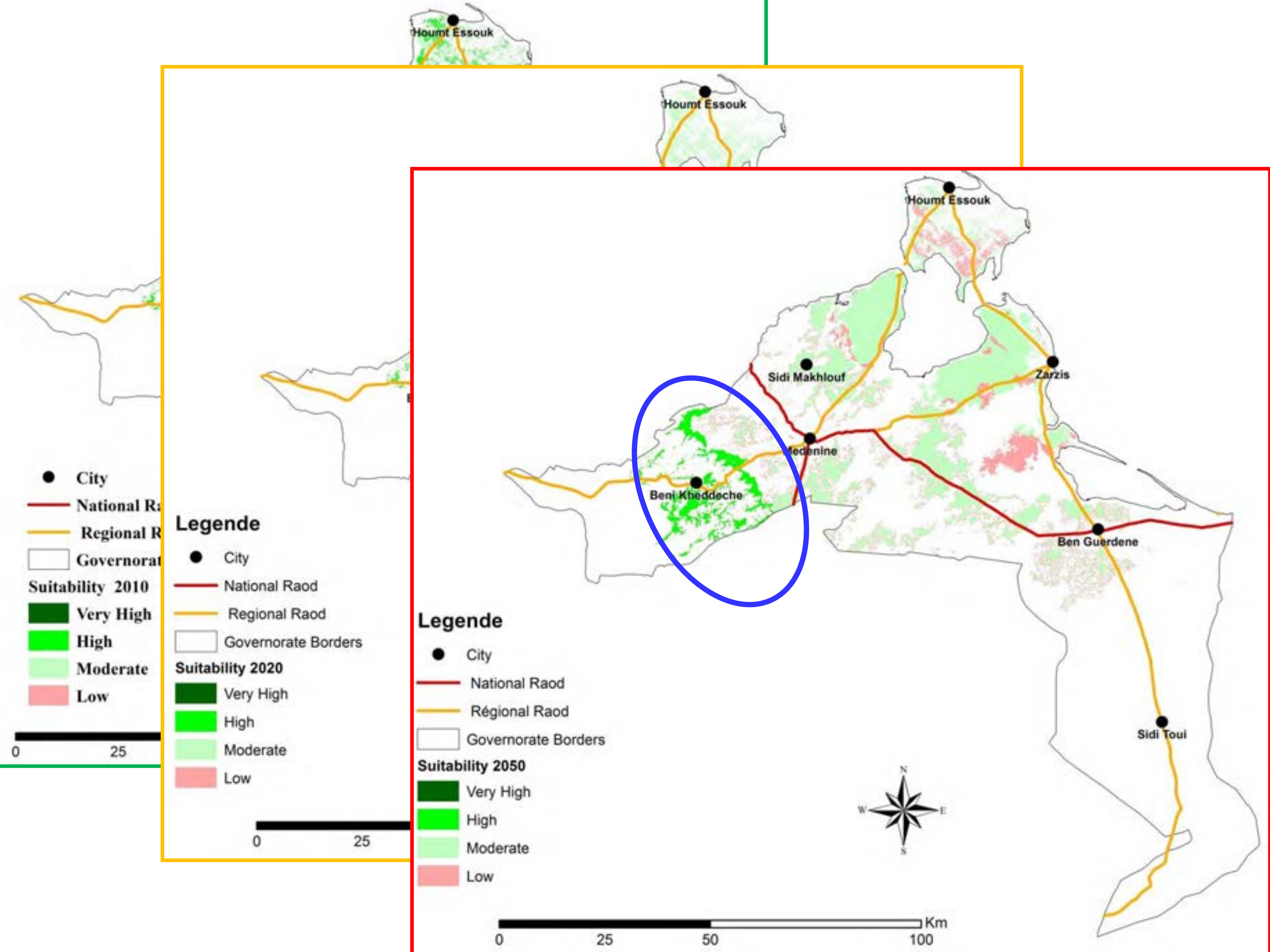
Month	Development stage	Vegetative growth	Fruit growth	Kc mountain [2]	Kc plain [3]
January	Dormant	Resting/dormant		0.40	0.30
February	Dormant	Resting/dormant		0.40	0.30
March	Initial	Resting/dormant	Bud differentiation	0.55	0.25
April	Development	Active		0.50	0.20
May	Development	Active	Flowering	0.45	0.20
June	Development	Active		0.40	0.20
July	Mid-season	Reduced	Yield formation	0.35	0.20
August	Mid-season	Reduced	Stone hardening	0.35	0.25
September	End	Active	Yield formation	0.45	0.25
October	End	Active	Yield formation	0.50	0.25
November	End	Resting/dormant		0.45	0.25
December	Dormant	Resting/dormant		0.40	0.30

Fleskens et al., 2005


Version 6.2
January 2005
BUDGET
A soilwater and saltbalance model
About
Main Menu
Climate/Crop/Soil Data Base
Irrigation
File Name
Description
ETo
[None]
Specify ETo data when Running BUDGET
Rain
[None]
Specify Rain data when Running BUDGET
Crop
STANDARD.CRO
standard parameters (annual fresh harvested)
21
Growing period
11
March
to: 8 July
Begin
Sowing/planting date
Soil
STANDARD.SOL
standard profile : loamy soil
Create new SoilFile
Copy SoilFile
Select another Soil
Files >>
Path
Display/Update Soil Characteristics
Simulation
Specify
Simulation Period
Initial Conditions
Run
Output Files
Display
Program Parameters
Exit Program
Help

Class	Eta/Etc (%)
Very High	> 75
High	62-75
Moderate	55-62
Low	<55




Houmt Essouk
City
National Ra
Regional R
Governorat
Suitability 2010
Very High
High
Moderate
Low
0
25
Houmt Essouk
Legende
City
National Raod
Regional Raod
Governorate Borders
Suitability 2020
Very High
High
Moderate
Low
0
25
Houmt Essouk
Sidi Makhlouf
Zarzis
Medenine
Beni Kheddeche
Ben Guerdene
Sidi Toui
Legende
City
National Raod
Régional Raod
Governorate Borders
Suitability 2050
Very High
High
Moderate
Low
N
W
E
S
Km
0
25
50
100

CONCLUSIONS

- Water harvesting techniques have been developed since antiquity to cope with climate variability in the dry areas,
- They played major role in the development of rainfed agriculture in addition of providing other ecosystem services,
- Silting up of the structures remains a major concern,
- However, accelerated exodus into cities would threaten the maintenance of those structures,
- Conflicts of interests (upstream/downstream users, main activity, etc.) need to be taken into account as an integrated management plan at watershed level,
- New tools (GIS, RS, modeling, etc.) offer major advantages/capabilities for the implementation and assessment of WH projects/works,
- With the prospect of CC, those systems/techniques would be more useful. Therefore, they need to be well considered in the national/regional strategies for adaptation with CC,

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Thank you

This is an olive tree growing in a dry environment
(rainfall: 160 mm/year) …….